Pre-attack systemic applications of a neem-based insecticide for control of the mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera: Scolytidae)

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ABSTRACT

An insecticide from neem, *Azadirachta indica* A. Jussieu, seeds, applied to the xylem of lodgepole pine trees at 0.05 g of the active ingredient, azadirachtin per cm diameter at breast height, reduced larval numbers and almost totally prevented successful development to adulthood of the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, whether applied before or after trees were attacked. Smaller amounts of azadirachtin were less effective. Neem was effective up to the top of the beetle attack zone (4 m), indicating that the active ingredient was effectively translocated. The treatment window for applying neem systemically against this pest is longer in duration than previously thought, and pre-attack treatments can be used to create lethal trap trees.

Key words: neem, mountain pine beetle, pre-attack systemic application

INTRODUCTION

The mountain pine beetle, *Dendroctonus ponderosae* Hopkins (MPB), is the most economically important bark beetle in western North America. In British Columbia, it attacks lodgepole pine, *Pinus contorta* var. *latifolia* Engelmann, and ponderosa pine, *P. ponderosa* Douglas ex Lawson (Unger 1993). In the Cariboo Forest Region in 1984, 405,000 ha were infested (Anonymous 1993). Current control measures include sanitation harvesting of large, infested areas, and control of spot infestations by trapping into pheromone-baited trees for later destruction. Immediate and effective control of spot infestations is essential to prevent the spread of outbreaks and their ascension to outbreak status (Borden 1993; Brooks and Maclauchlin 1994). Beetle larvae in baited trees are usually removed by sanitation cutting, or killed by winter-time "fall and burn" treatments, or by the post-attack injection of monosodium methane arsenate (MSMA). MSMA is potentially toxic to applicators and other organisms, and its mode of action remains unclear (Maclauchlin *et al.* 1988a). Naumann *et al.* (1994) reported that an insecticide extract of the neem tree, *Azadirachta indica* A. Jussieu (Meliaceae), controlled MPB when applied systemically to recently attacked lodgepole pine trees.

Extracts of neem seeds have been successfully tested for the control of many phytophagous insects (Koul *et al.* 1991; Schmutterer 1990). These extracts contain many compounds, but most of the insecticidal activity can be attributed to the tetranortriterpenoid azadirachtin (Isman *et al.* 1990). Neem is proving to be safer than most conventional insecticides for non-phytophagous insect species, including entomophagous insects (Lowery and Isman 1994; Stark 1992).

The systemic activity of neem seed extracts has been demonstrated on several pests of conifers including the MPB (Naumann *et al.* 1994), spruce budworm, *Choristoneura fumiferana*

(Clem.) on black and white spruce, *Picea glauca* (Moench) Voss and *P. mariana* (Mill.) B.S.P., respectively (Wanner *et al.* 1997), and pine false webworm, *Acantholyda erythrocephala* (L.) on red pine, *Pinus resinosa* Ait. (Lyons *et al.* 1996). In lodgepole pine, neem applied to an axe frill at the base of the tree translocated at least 9 m up the bole in amounts sufficient to disrupt the development of the pine engraver, *Ips pini* (Say) (Duthie-Holt *et al.* 1999). However, Naumann *et al.* (1996) reported only minor effects on the white pine weevil, *Pissodes strobi* (Peck) in Sitka spruce, *Picea sitchensis* (Bong.) Carr., and no effects on the same weevil species in hybrids of white spruce and Engelmann spruce, *P. engelmannii* Parry. Naumann *et al.* (1994) tested only post-attack treatments. Moreover, evaluation of efficacy by Naumann *et al.* (1994) was made low on the bole of the tree. If the treatment window could be extended by applying neem before attack by the MPB, forest pest managers would have more time to apply treatments, and treatment costs could be lowered by applying pheromone lures and insecticidal treatments to create lethal trap trees on a single visit to an infestation.

Our objectives were to determine if systemic applications of a neem-based insecticide can control the MPB if injected into pheromone-baited trees prior to beetle attack, and to evaluate the efficacy of neem near the low and high extremities of attack on the bole of lodgepole pines.

MATERIALS AND METHODS

The neem seed extracts used in this study were formulated as emulsifiable concentrates (Phero Tech Inc., Delta, BC), and are described in terms of percent azadirachtin (Naumann *et al.* 1994). A formulation control consisted of proprietary emulsifiable concentrate without the neem extract.

1994 Season. On 5 July, prior to adult beetle flight at Lyne Lake, near Williams Lake, BC, baits containing MPB aggregation pheromones (Phero Tech Inc., Delta, BC, Canada) were hung 2.5 m high on the north sides of 35 lodgepole pines distributed in a grid, with baited trees ≈ 50 m apart. Mean tree diameters were 34.1 ± 2.1 cm at breast height (1.3 m). Baited trees were randomly assigned to five treatment groups. Two treatments were applied to 6 trees each, prior to beetle attack: 3% neem applied into a continuous axe frill at the base of the bole (Lister *et al.* 1976), and a frill-only control. On 5 August, after beetle attack, three treatments were applied into axe frills in five trees each: 3% neem, MSMA (Glowon Liquid Tree Killer^R, Later Chemicals Ltd., Richmond, BC), and a formulation control. Neem and formulation control treatments were applied at 50 ml per tree, corresponding to 1.5 g azadirachtin per tree, or 0.048 g/cm dbh = 15 mg/cm circumference), for the neem treatment. MSMA was applied at the recommended rate of ≈ 1 ml/2.5 cm tree circumference. Not all baited trees were successfully attacked. Therefore, the post attack groups included some nearby attacked, but unbaited trees which were randomly assigned to each of the post-attack treatments.

During 8 – 14 November, 175 cm^2 discs of bark were removed 10 m high from each of the test trees. The discs were cut with a gas-powered hole cutting saw, into the first layers of xylem, and pried loose using chisels so that the bark remained attached to the wood. Bark discs were stored in the dark at ca. 10° C and 80% R.H. until dissected to determine the numbers of surviving and dead larvae/25 cm of adult gallery, and total lengths of adult galleries.

On 17 November, sections of the bole were cut 1 m above the frill line of each control and neem-treated tree. The 1m-long log sections were maintained in individual cages, at ca. 22° C and 12:12 L:D, and adults were collected from each cage every 2 - 3 days, until adult emergence was complete.

1995 Season. A second experiment was conducted at a MPB-infested site near Redeau Lake, east of 150 Mile House, BC. Pheromone baits were applied to 63 trees on 17 July, as in 1994, except that the baited trees (dbh = 29.4 ± 0.7 cm) were ca. 20 m apart. Trees were randomly assigned to five treatments but, as in 1994, not all baited trees were successfully attacked, and therefore, some nearby attacked, but unbaited trees were randomly assigned to post-attack treatments. Two treatments were applied on 17 July, 2 - 5 days before MPB attack: 50 ml of 2% neem (equivalent to 1 g azadirachtin/tree = 0.034 g azadirachtin/cm dbh = 11 mg/cm circumference; n = 10), and 50 ml of a formulation control with no neem (n = 10). Three post-attack treatments applied on 22 August were: 50 ml of 2% neem (n = 8), 50 ml of 0.7% neem (equivalent to 0.35 g azadirachtin/tree = 0.012 g azadirachtin/cm dbh; n = 8), and MSMA (2 ml/cm tree circumference; n = 7).

All beetle-attacked test trees were felled on 31 October. On 4 November, two 0.5 m log sections were cut from each felled tree, one 1 - 2 m high, the other 1-2 m below the highest point of attack ($\bar{x}$ = 5.5 ± 0.5 m). The highest attacks were frequently unsuccessful. The log sections were caged, as in 1994, and the numbers of emergent adults recorded.

Statistical Analysis. Data, log transformed where necessary, were subjected to t-tests or ANOVA followed by Tukey's multiple comparison test using the Statistix software program (Anonymous 1991). In all cases $\alpha = 0.05$.

RESULTS

1994 Season. Pre-attack 3% neem treatments had no effect on the density of surviving larvae 3 months after application (Fig. 1), but almost completely eliminated later adult emergence (Fig. 2). Two months after application, post-attack neem and MSMA treatments reduced larval densities near the frills but had no effect 10 m up the tree (Fig. 1). Post-attack treatments of neem almost completely stopped adult emergence (Fig. 2).

1995 Season. Pre- and post-attack treatments of 2% neem both reduced numbers of emerging adults, although the reduction was not as overwhelming as seen with a 3% formulation in 1994 (Fig. 3). Post-attack treatments with 0.7% neem had no significant effect. The relative levels of reduced emergence induced by the different treatments were similar at the bottoms and tops of the attack zones.

DISCUSSION

Our results corroborate those of Naumann *et al.* (1994), demonstrating a reduction in larval MPB densities 3 - 4 months after systemic neem application, followed by a much greater reduction in later adult emergence. Moreover, they demonstrate that the active ingredients in the neem seed extract were translocated, in effective amounts, to the top of the attack zone, supporting the results of Duthie-Holt *et al.* (1999) with trees felled 1 week after treatment and then infested by *I. pini*. The absolute numbers of adults emerging from neem-treated trees were always greater than those from trees treated with MSMA, although the differences were not significant. Our results, plus those of Naumann *et al.* (1994), Duthie-Holt *et al.* (1999), and Naumann (unpublished data), indicate that the delivery of at least 0.05 g of azadirachtin per cm tree diameter at breast height is required to give a level of control comparable to that of MSMA.

Lastly, our results demonstrate that pre-attack treatments of neem with 3% azadirachtin are as effective as post-attack applications, suggesting that the window of application can be extended to several days before peak adult flight. In this respect, neem is superior to MSMA, which must be applied post-attack because it repels adult MPB (Maclauchlin *et al.* 1988b) and would therefore disperse them to untreated trees. The neem treatments did not appear to repel adults, supporting Duthie-Holt and Borden's (1999) finding that trees sprayed with a 0.2% neem formulation were attacked by the MPB within 24 h of application.

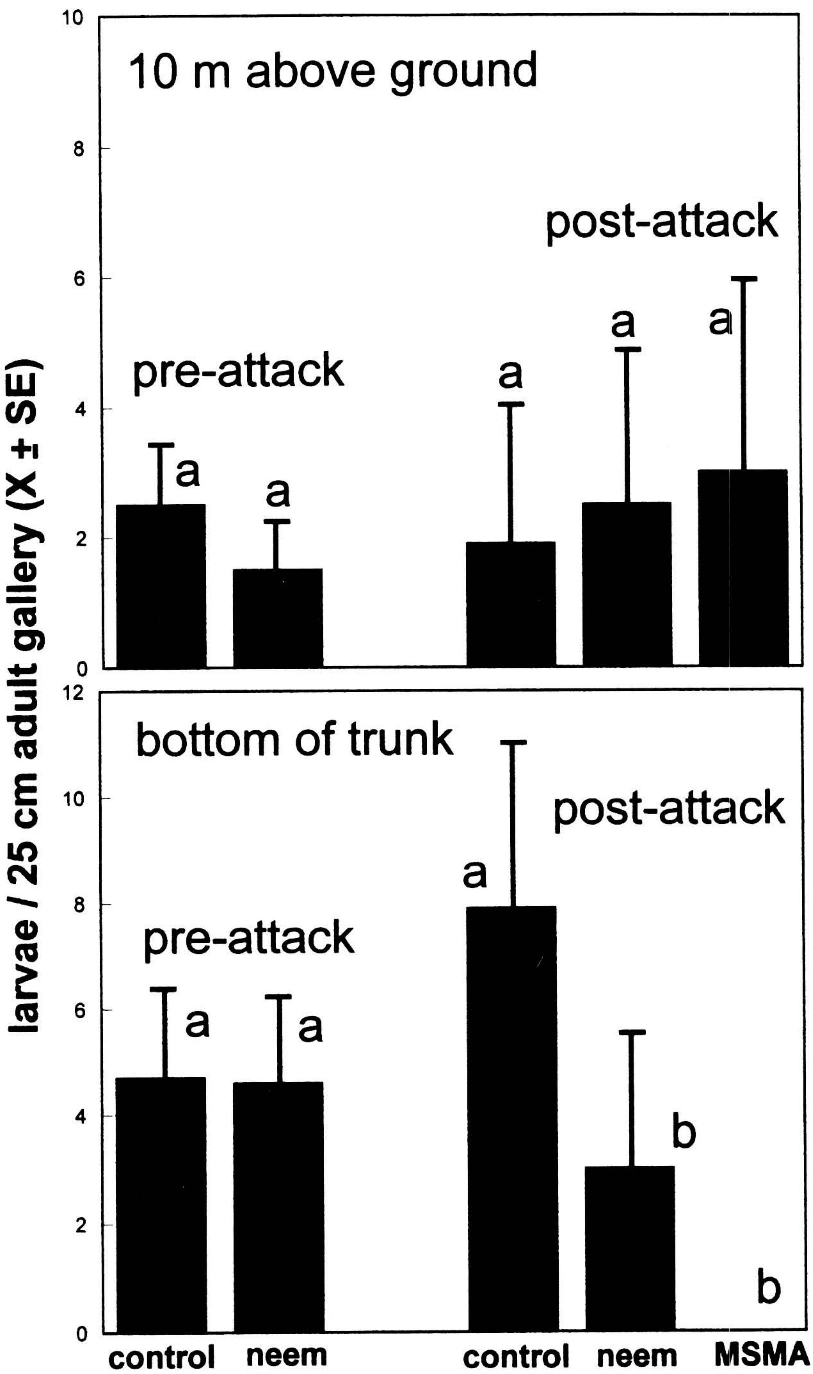

Figure 1. 1994 Season. Number of surviving mountain pine beetle larvae per 25 cm of adult gallery length in lodgepole pine trees 3 months after systemic application of 50 ml of neem (3% azadirachtin), MSMA, or a control solution. Bars within pre- or post-attack treatments with the same letter are not significantly different (Tukey's test, $P > 0.05$).

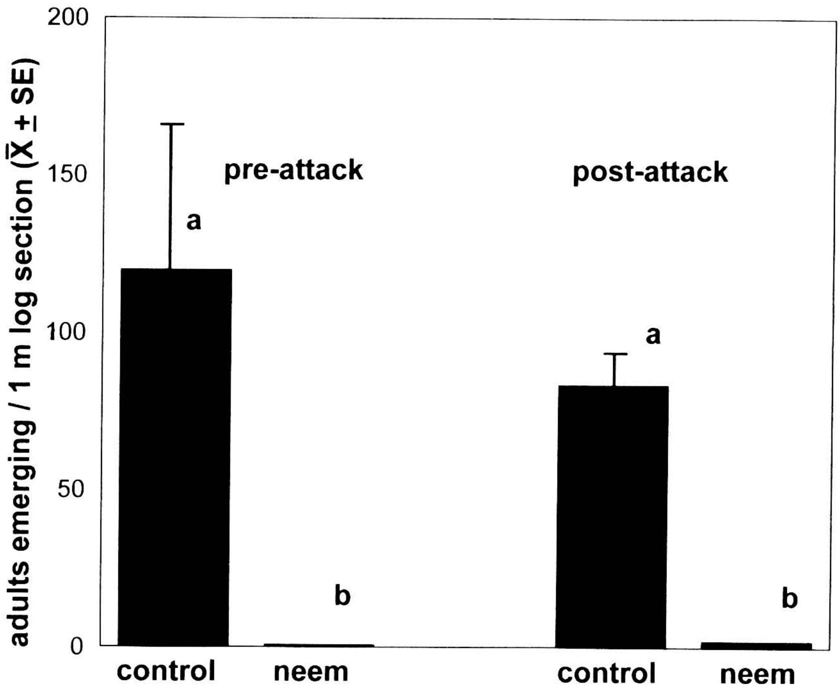

Figure 2. 1994 Season. Number of adult mountain pine beetles emerged from 1 m log sections following systemic applications of neem (3% azadirachtin) or a formulation control. For each treatment time, bars with the same letters are not significantly different (t = 2.37, df = 10, P = 0.04 for pre-attack treatment, and t = 6.44, df = 9, P = 0.0001 for post-attack treatment).

We did not assess the age at which mortality occurred, nor the direct cause. It is probable that high doses of azadirachtin ingested by larvae near the axe frills had an acutely toxic effect. Azadirachtin is well known to produce morphological deformities in many insect taxa (Mordue and Blackwell, 1994). Similarly, the survival of larval MPBs (Fig. 1) (Naumann *et al.* 1994) and pine engravers (Duthie-Holt *et al.* 1999) followed by failure of adult emergence suggests that the efficacy of neem against bark beetles lies in a late larval or pupal developmental effect. These results, plus the finding that systemic neem applications had no effect on *D. ponderosae* larval weights (Naumann *et al.* 1994) and that attack occurred on freshly sprayed bark (Duthie-Holt and Borden 1997) indicate that feeding inhibition is not an important cause of mortality in bark beetles.

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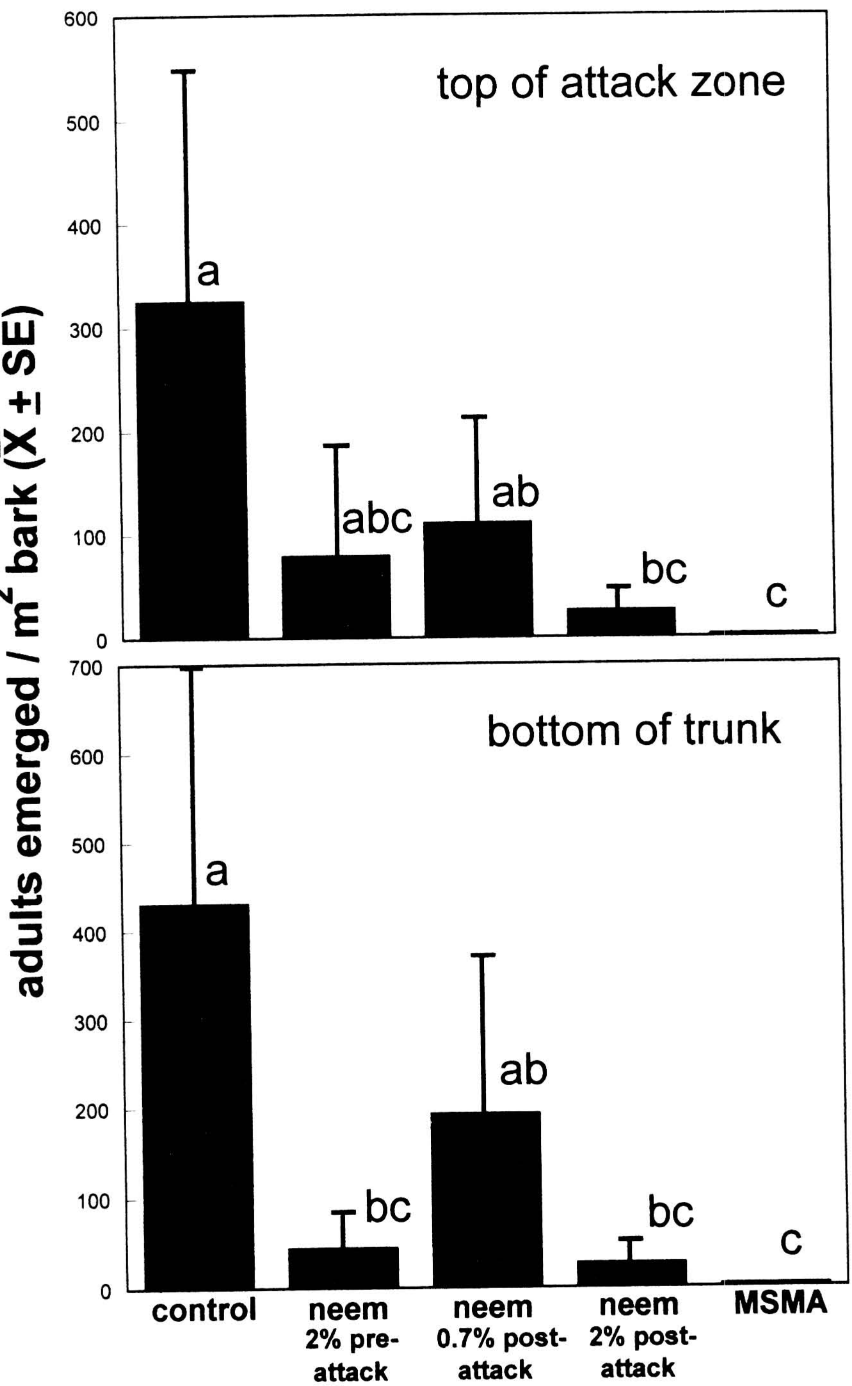

Figure 3. 1995 Season. Numbers of adult mountain pine beetles emerged per m^2 of bark from trees given pre- or post-attack 50 ml systemic applications of neem (2% azadirachtin applied before beetle attack, or 0.7% or 2% azadirachtin applied post-attack), MSMA, or a formulation control. Bars, within an attack zone, with the same letters are not significantly different (Tukey's test, $P > 0.05$).

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