Efficacy of Spinetoram, Methoxyfenozide and Lambda-Cyhalothrin for Control of European Pine Shoot Moth (*Rhyacionia bouliana*)

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Abstract

Four trials were conducted in 2017 and 2018 in British Columbia, Canada, to test newer insecticides for control of European pine shoot moth in a conifer seed orchard. In each of the four trials, the insecticides spinetoram and lambda-cyhalothrin gave over 80-percent reduction in insect damage when compared to untreated. The insecticide methoxyfenozide was tested in one trial and also provided over 80-percent control. In two trials, excellent control of the pest was obtained with one application made in late April, targeting the larvae moving from overwintering sites to new developing shoots. In the other two trials, excellent control was obtained with two consecutive applications made in mid-June and early July, targeting adults and newly hatched larvae on new plant shoots. This work helped generate data for label extension of the products.

Background

Forest seed orchards are managed similarly to tree fruit orchards except cones are harvested, from which seeds are extracted for later sowing in nurseries (figure 1). In British Columbia, more than 250 million trees are produced annually specifically for reforestation efforts after logging of forests (BC Ministry of Forests 2017). Seed orchards grow mostly conifer trees, including a large component of lodgepole pine (*Pinus contorta* Douglas ex Loudon var. *latifolia* Engelm. Ex. S. Watson) (BC Ministry of Forests 2020).

European pine shoot moth (*Rhyacionia bouliana*, Lepidoptera: Tortricidae) is a pest of pine plantations in many areas of Canada. This pest was first reported in North America in 1914 and has since migrated across the continent (Pointing 1967). A night flying moth (figure 2), European pine shoot moth is also found on mugo pines (*Pinus mugo* Turra) in ornamental landscapes and production nurseries.

All of the damage from European pine shoot moth is done by the larva (figure 3), which attacks new shoots and reduces conelet production. The European pine shoot moth overwinters as a third instar larva in

Figure 1. Forest seed orchards are managed similarly to fruit tree orchards except cones are harvested, from which seeds are extracted for later sowing in nurseries. (Photo by Stefanie Harder 2019)

Figure 2. The European pine shoot moth adult has orange or bright ochre forewings with irregular, diagonal silvery lines and a wingspread of 15 to 20 mm. This insect flies mostly at dusk. (Photo by Cora Watts 2018)

Figure 3. The European pine shoot moth larva has a smooth, dark brown abdomen with a shiny black head and thoracic shield. This caterpillar may reach 16 mm in length. (Photo by Mario Lanthier 2017)

Figure 5. In early spring, presence of European pine shoot moth is noted by a dying terminal bud or a crust of dried pitch on the host tree. Most of the feeding is done in April and May when the elongating shoots are tunneled by the larvae. (Photo by Mario Lanthier 2017)

hibernacula (pitchy web) beside the terminal bud, or on smaller buds next to the terminal bud. In spring, the larvae becomes active and moves into the terminal bud (figure 4). During May and June, the larva feeds within the terminal bud, also damaging the stem (figure 5). Attacked shoots are visible as wilting terminals with pitch accumulation at the base of buds (figure 6). Terminal shoots may be killed (figure 7). The larvae pupate inside the shoot before exiting in late spring to early summer (figure 8). Adults live for about 1 month, with females laying eggs on twigs or on sheaths of new needles. Eggs hatch shortly after and young larvae bore into new needles (Martineau 1984). Over time, a high population of this insect may cause substantial reductions in shoot growth and losses to cone production sites (figure 9). Additionally, field observations indicate that feeding damage to the shoot may cause young conelets to abort.

Figure 6. During May and June, the European pine shoot moth larvae feed within the terminal bud and terminal stem. Attacked shoots are visible as wilting terminals with pitch accumulation at the base of buds. (Photo by Mario Lanthier 2018)

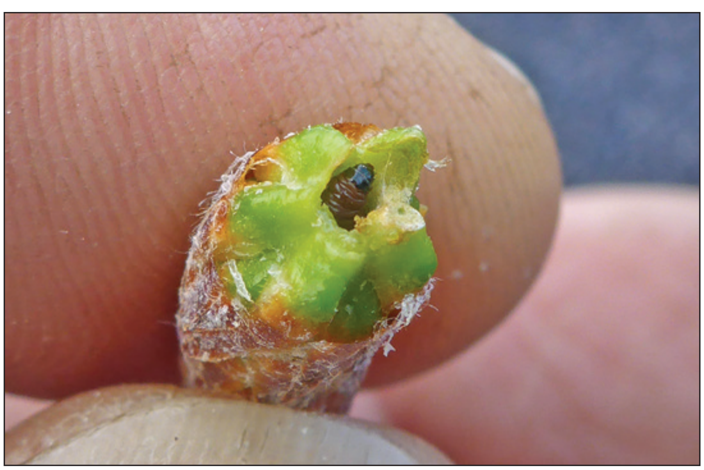

Figure 4. The European pine shoot moth overwinters as a third instar larva resting on, or inside, the terminal bud. (Photo by Mario Lanthier 2017)

Figure 7. Terminal shoots are killed following feeding by European pine shoot moth. (Photo by Mario Lanthier 2018)

Figure 8. The larvae of European pine shoot moth will pupate inside the shoot before exiting in late spring to early summer. (Photo by Mario Lanthier 2018)

In conifer seed orchards, European pine shoot moth was previously considered a minor pest but the population has increased in recent years. Control treatments are now applied at many facilities. At one location in south-central British Columbia, infestation by larvae on lodgepole pine increased from 25 percent of trees affected 1 year to 80 percent of trees affected the following year (Heeley 2003).

The insect population can be managed by manual removal of infected shoots before the larvae pupate into adults. This method is useful in landscapes but is slow and labor-intensive on tall trees typical of conifer seed orchards. Recently grafted young trees may require a pesticide treatment to protect newly elongating shoots.

Figure 9. In conifer seed orchards, damage by European pine shoot moth negatively impacts subsequent cone production. The photo shows an unaffected shoot (left) and an affected shoot (right). (Photo by Mario Lanthier 2018)

In Canada, no pesticide product is registered for European pine shoot moth in conifer seed orchards. Formulations of dimethoate (trade names Cygon® 480EC and Lagon® 480E) are registered for this pest on pine trees grown as ornamentals or Christmas trees (PMRA 2019). The label rate is 2 L in 1000 L of water, or 0.2 percent concentration. Some conifer growers report better efficacy for this pest at 0.5 percent concentration. The label rate of dimethoate for other seed cone pests is 1 to 2 percent.

Dimethoate is an organophosphate compound of moderate to high toxicity to mammals, based on laboratory studies on rats and rabbits (Health Canada 2011). Since 2016, the active ingredient is subject to long restricted re-entry after application: 18 days for thinning of pine trees in Christmas tree plantations and 49 days for seed cone harvest of spruces (*Picea* spp.) in seed orchards (Health Canada 2015). The objective of our study was to evaluate newer insecticides of lower acute toxicity for their efficacy against European pine shoot moth in pine seed orchards.

Methodology

Various insecticides were tested over four distinct trials (table 1). The products were applied on lodgepole pine trees at Vernon Seed Orchard Co. Ltd., British Columbia (50˚13' north, 119˚19' west, elevation 500 metres). The trees were field-grown, grafted, and planted in 1995 at a spacing of 3.5 m within the tree row and 6.0 m across the tractor alley. Each trial was set up in a randomized, complete block design.

Trials 1 and 2 were conducted in spring 2017 and 2018, respectively, and targeted larvae moving from overwintering sites to new developing shoots. Six treatments were applied over eight replicates in trial 1 and nine replicates in trial 2 (tables 2 and 3). Each replicate was an individual tree surrounded by untreated buffer trees. One application was made in each trial, on April 21, 2017 (trial 1) and April 23, 2018 (trial 2). The spray solution was prepared with municipal water. Each treatment was applied at a rate of 2 L per tree using hand-held backpack sprayers (Solo 475, Solo Inc., Newport News, VA, hollow cone nozzles 1.8 mm orifice) (figure 10).

Trials 3 and 4 were both conducted during summer 2017, and targeted adults and newly hatched larvae on new plant shoots. Three treatments were applied over five replicates in trial 3 and four replicates in

Table 1. Products selected for trials to control European pine shoot moth.

Active ingredient (a.i.)	Trade name	Concentration of a.i.	Label rate
Dimethoate	Lagon® 480E	480 g/L	0.2 L / 100 L (0.2%)
Lambda-cyhalothrin	Matador® 120EC	120 g/L	104 ml / 1000 L / ha
Methoxyfenozide	Intrepid™ 240F	240 g/L	1.0 L / 1000 L / ha
Spinetoram	Delegate™ WG	25%	420 g / 1000 L / ha
Thiamethoxam	Flagship® WG	25%	35 g / 100 L

Table 2. Trial 1 (spring application, 2017) treatments and results. Treatments were applied April 21 except dimethoate 0.5% on April 28 and thiamethoxam was repeated May 2.

Treatment	Trial rate	Mean flagging shoots per tree (sd)
Untreated	n/a	36.6 (7.9)
Dimethoate 480 g/L	2 ml / L	14.8 (10.6) *
Dimethoate 480 g/L	5 ml / L	5.4 (3.8) *
Lambda-cyhalothrin 120 g/L	0.10 ml / L	2.9 (3.9) *
Spinetoram 25%	0.42 g / L	2.3 (2.6) *
Thiamethoxam 25%	0.32 g / L	27.0 (17.6)
Treatment probability (F 5,42)		0.0001

Means followed by * are statistically different from the untreated treatment at p=0.05 Tukey's HSD.
sd = standard deviation.

Table 3. Trial 2 (spring application, 2018) treatments and results. Treatments were applied April 23 except dimethoate 0.5% was applied on April 27.

Treatment	Trial rate	Phytotoxicity Mean (sd)	Mean # flagging shoots per tree (sd)
Untreated	n/a	2.0 (1.12)	27.9 (13.1)
Dimethoate 480 g/L	2 ml / L	1.9 (0.93)	12.4 (5.8) *
Dimethoate 480 g/L	5 ml / L	1.7 (0.71)	9.1 (8.1) *
Lambda-cyhalothrin 120 g/L	0.10 ml / L	1.8 (0.97)	3.0 (2.3) *
Methoxyfenozide 240 g/L	1 ml / L	1.4 (0.73)	0.2 (0.7) *
Spinetoram 25%	0.42 g / L	2.0 (0.50)	1.1 (1.8) *
Treatment probability (F 5,48)		0.7154	0.0001

Means followed by * are statistically different from the untreated treatment at p=0.05 Tukey's HSD.
sd = standard deviation.

Figure 10. For trials 1 and 2, insecticide treatments were applied with a backpack sprayer at a rate of approximately 2 L of spray solution per tree. (Photo by Stefanie Harder 2018)

trial 4 (tables 4 and 5). Each replicate consisted of two rows totalling 100 trees (trial 3) or 120 trees (trial 4), separated from the next replicate by three unsprayed rows. Treatments were applied on June 19 and again on July 5 with an air-blast sprayer (Slimline Manufacturing, Penticton BC) (figure 11). This is the standard spray equipment for commercial applications at these facilities. The sprayer was calibrated on June 15 to determine delivery rate per hectare. Treatments were applied with the sprayer in low range third gear, middle 8 nozzles, giving a delivery of 840 L/ha. Calibration was done using the standard formula:

$$\text{Delivery rate (L / ha)} = \frac{\text{Output (L/min)} \times 600 \text{ (conversion factor)}}{\text{Speed (km/h)} \times \text{Row spacing (metres)}}$$

Application timing mimicked standard grower practices for the target pest. Dimethoate was applied as a grower control. Trial plants were managed following normal practices. No other pesticide applications were made in the trial areas and weather was seasonal for the duration of the project.

Table 4. Trial 3 (summer application, 2017) treatments and results. Treatments were applied June 19 and July 5, 2017. Damage (flagging shoots) was assessed on June 27, 2018.

Treatment	Trial rate	Phytotoxicity 8 days after second treatment (sd)	Mean # flagging shoots per tree (sd) 1 year after treatment
Untreated	n/a	1.30 (0.64)	14.5 (7.19)
Lambda-cyhalothrin 120 g/L	104 ml / ha	1.45 (0.74)	1.22 (1.66) *
Spinetoram 25%	420 g / ha	1.48 (0.75)	0.72 (1.05) *
Treatment probability F (2,146)		not significant	< 0.0001

Means followed by * are statistically different from the untreated treatment at p=0.05 Tukey's HSD.
sd = standard deviation.

Table 5. Trial 4 (summer application, 2017) treatments and results. Treatments were applied June 19 and July 5, 2017. Damage (flagging shoots) was assessed on June 15, 2018.

Treatment	Trial rate	Phytotoxicity 22 days after second treatment (sd)	Mean # flagging shoots per tree (sd) 1 year after treatment
Untreated	n/a	1.93 (0.97)	7.5 (5.16)
Lambda-cyhalothrin 120 g/L	104 ml / ha	2.13 (1.22)	0.78 (1.49) *
Spinetoram 25%	420 g / ha	1.98 (1.07)	0.73 (1.85) *
Treatment probability F (2,117)		not significant	< 0.0167

Number followed by * is statistically different from untreated at p=0.05 Tukey's HSD.
sd = standard deviation.

Figure 11. For trials 3 and 4, insecticide treatments were applied with a commercial air blast sprayer. This is the standard application equipment in commercial forest seed orchards. (Photo by Mario Lanthier 2017)

Figure 12. Assessment of European pine shoot moth damage was made by visually counting flagging shoots in mid-June. (Photo by Mario Lanthier 2018)

Measurements

Phytotoxicity was evaluated prior to and after pesticide applications. Plants were visually examined for symptoms typical of pesticide injury (leaf spots, speckles, tips brown, margins brown, needles brown, tips chlorotic, needles chlorotic) (Costello 2003). Plant injury was rated from 0 (no damage) to 10 (100 percent of the plant is affected), by increments of 10 percent. All plants were examined in trials 1 and 2, whereas 20 or 10 randomly selected plants were examined in trials 3 and 4, respectively.

Insect damage was evaluated in mid-June for all trials (51 to 55 days after the spring application in trials 1 and 2 and approximately 1 year after application in trials 3 and 4). The number of flagged shoots per tree was recorded as an indirect measure of insect activity (figure 12). Each trial tree was examined by two persons simultaneously doing a visual count. The count was repeated and the results compared to ensure consistency. All trees were examined in trials 1 and 2 and 10 trees per replicate were randomly selected for examination in trials 3 and 4. Pest identity was confirmed by visual examination of larvae by a specialist on European pine shoot moth.

Data analyses

All data were subjected to analysis of variance (ANOVA) with F-test set at $p=0.05$. Where results indicated statistical significance, pairwise comparison was done with Tukey's HSD to determine significant differences between sample means. The analysis was done with ARM software (https://www.gdmdata.com/Products/ARM).

Results

This project relied on natural infestation of the target pest, as the site had extensive damage in 2016. Untreated trees showed extensive damage (figure 13). In all four trials, most treatments significantly reduced the number of flagged shoots per tree when compared to the untreated trees (tables 2, 3, 4 and 5). Some treatments differed significantly from the grower control.

Figure 13. The site had severe damage by European pine shoot moth in 2016. Trees left untreated for the trials showed extensive damage in 2017 and 2018. (Photo by Mario Lanthier, 2018)

Figure 14. Treated trees showed little damage by European pine shoot moth. In all four trials, the test products lambda-cyhalothrin and spinetoram provided over 90-percent control compared with untreated treatments. (Photo by Mario Lanthier 2018)

In all trials, the test products lambda-cyhalothrin and spinetoram provided 90-percent control or better when compared with untreated treatments (figure 14). Methoxyfenozide was applied in trial 2 and also provided more than 90-percent control. Thiamethoxam was applied in trial 1 and provided poor control of the target pest. No treatment-related phytotoxicity was associated with any of the products in any of the trials.

Discussion

Based on the conditions of these trials, the insecticides lambda-cyhalothrin and spinetoram provided effective control of European pine shoot moth, defined as more than 80-percent reduction in insect damage compared with untreated trees. Results were consistent when products were applied either once in the spring at the start of larvae moving from overwintering sites to newly developing shoots, or twice in early summer when newly hatched larvae are present on new plant shoots. The insecticide methoxyfenozide also provided effective control in one trial and is a candidate for further studies.

The main objective of this project was to confirm efficacy of newer insecticides for the target pest, for the purpose of label registration. Registration of pesticides in Canada is subject to a number of conditions (PMRA 2003). For insecticides, an adequate number of trials, usually three studies over 2 years, must demonstrate consistent performance with the proposed rates at the expected pest pressures. A statement of "control" indicates the product consistently reduces the pest damage to a commercially acceptable level and the performance provided should match or exceed that of a commercially acceptable standard treatment.

Dimethoate is a broad-spectrum organophosphate insecticide belonging to Resistance Management Mode of Action Group 1B, which inhibits the enzyme acetylcholinesterase, interrupting the transmission of nerve impulses in insects (IRAC 2019). It works by systemic and contact action. It is considered of high oral acute toxicity to mammals, with identified occupational risks when applied in seed cone orchards (Health Canada 2011).

Spinetoram has contact and translaminar activity: the compound crosses the leaf cuticle to provide control of insects feeding inside the tissue, such as leafminers (Bacci 2016). This mode of action is also called "locally systemic" and likely explains the excellent results in trials 1 and 2 when applied in early spring while the larvae are feeding inside terminal shoots (figure 15). The active ingredient is currently registered in Canada for fir coneworm (*Dioryctria abietivorella*), another important pest in conifer seed orchards (PMRA 2019). Spinetoram is a semi-synthetic spinosyn, a derivative of biological active substances produced by the soil actinomycete *Saccharopolyspora spinosa* (Sato 2012). It belongs to the Group 5 insecticides, acetylcholine receptor modulators that cause persistent activation of nicotinic acetylcholine receptors, thus disrupting normal synaptic signal transmission

Figure 15. Spinetoram has translaminar activity, providing control of insects feeding inside plant tissue. In this project, some terminal shoots were opened and revealed a dead caterpillar of European pine shoot moth. (Photo by Mario Lanthier 2018)

in the insect central nervous system. This particular mode of action is unique to spinetoram and spinosad, the only two active ingredients in Group 5 (Health Canada 2008).

Methoxyfenozide is a molting accelerating compound, also called insect growth regulator. It has low acute toxicity to mammals and is not a concern for chronic exposure (Health Canada 2004). It is not significantly leaf-systemic (Carlson 2001). Feeding on a treated plant surface induces a precocious moult in lepidopteran larvae, leading to cessation of feeding and premature head capsule slippage and death (Nauen 2002). This mode of action likely explains the excellent results in trial 4.

Lambda-cyhalothrin is currently registered in Canada for western conifer-seed bug (*Leptoglossus occidentalis*), a pest in conifer seed orchards (PMRA 2019). It is a non-systemic, contact or stomach poison with some repellent properties, with rapid knockdown and long residual activity (Health Canada 2003). It is the long residual activity that provided the excellent results noted in this project. Lambda-cyhalothrin is a synthetic pyrethroid insecticide of Group 3A (IRAC 2019). It acts as an axonic poison on both the peripheral and central nervous systems of the insect. A recent review determined there are potential risks of concern from dietary exposures. Cancellation was proposed for all applications on food crops but uses would remain for ornamentals and trees (Health Canada 2017).

Effective control of European pine shoot moth in seed cone orchards looks promising with newer insecticides such as spinetoram and methoxyfenozide. The compounds are fairly safe to humans and the environment and gave excellent control of the target pest in a series of trials conducted in a commercial facility in 2017 and 2018. Another effective product is lambda-cyhalothrin, especially because of its long residual on plant surfaces. Future registration for use in seed orchards, however, is uncertain.

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REFERENCES

Bacci, L.; Lupi, D.; Savoldelli, S.; Rossaro, B. 2016. A review of Spinosyns, a derivative of biological acting substances as a class of insecticides with a broad range of action against many insect pests. Journal of Entomological and Acarological Research. 48(1): 40–52.

BC Ministry of Forests. 2017. Factsheet: Reforestation in B.C. https://news.gov.bc.ca/factsheets/factsheet-reforestation-in-bc. (May 2020).

BC Ministry of Forests. 2020. Cone and Seed Pests Research Program. https://www.for.gov.bc.ca/HTI/projects/ConeSeedPest.htm. (May 2020).

Carlson, G.R.; Dhadialla, T.S.; Hunter, R.; Jansson, R.K.; Jany, C.S.; Lidert, Z.; Slawecki, R.A. 2001. The chemical and biological properties of methoxyfenozide, a new insecticidal ecdysteroid agonist. Pest Management Science. 57(2): 115–119.

Costello, L.R. 2003. Abiotic disorders of landscape plants – a diagnostic guide. Publication 3420. Oakland, CA: University of California, Agriculture and Natural Resources. 437 p.

Health Canada. 2003. Lambda-Cyhalothrin demand CS insecticide. Proposed Regulatory Decision Document PRDD2003-03. Ottawa, ON. 39 p.

Health Canada. 2004. Methoxyfenozide. Regulatory Note REG2004-08. Ottawa, ON. 92 p.

Health Canada 2008. Spinetoram (XDE-175). Evaluation Report ERC2008-01. Ottawa, ON. 112 p.

Health Canada. 2011. Dimethoate. Proposed Re-evaluation Decision PRVD2011-12. Ottawa, ON. 187 p.

Health Canada. 2015. Dimethoate. Re-evaluation Decision. RVD2015-04. Ottawa, ON. 99 p.

Health Canada. 2017. Lambda-cyhalothrin. Proposed Re-evaluation Decision PRVD2017-03. Ottawa, ON. 226 p.

Heeley, T.; Alfaro, R.; Humble, L. 2003. Distribution and life cycle of *Rhyacionia buoliana* (Lepidoptera: Tortricidae) in the interior of British Columbia. Journal of the Entomological Society of British Columbia. 100: 19–25.

IRAC (Insecticide Resistance Action Committee) 2019. The IRAC Mode of Action Classification. https://www.irac-online.org/modes-of-action/. (May 2020).

Martineau R. 1984. Insects harmful to forest trees. Forest Technology Report 32. Ottawa, ON: Canadian Forest Service. 261 p.

Nauen, R.; Bretschneider, T. 2002. New modes of action of insecticides. Pesticide Outlook. 13: 241–245.

PMRA (Pest Management Regulatory Agency). 2003. Efficacy guidelines for plant protection products. Regulatory Directive DIR2003-04. Ottawa, ON. 49 p.

PMRA (Pest Management Regulatory Agency). 2019. Pesticide Label Search. https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php. (May 2020).

Pointing, P.J.; Muller, W.E. 1967. European pine shoot moth *Rhyacionia buoliana* (Schiff.). In: Davidson, A.G.; Prentice, R.M., eds. Important forest insects and diseases of mutual concern to Canada, the United States and Mexico. Working Group on Forest Insects and Diseases. Food and Agriculture Organization of the United Nations.

Sato, N.; Yamaguchi, T. 2012. Development of the novel insecticide Spinetoram. Sumitomo Kagaku. 14 p.