Potential of Propane Flamers for Reduction of Apple Scab Primary Inoculum on Orchard Ground

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Abstract. The potential impact of propane flamers on the development and release of ascosporic inoculum of *Venturia inaequalis* (Cke.) Wint. from infected dead apple (*Malus domestica* Borkh.) leaves that overwintered on the soil of an experimental orchard was assessed. Thermal reduction of scab primary inoculum was first conducted under controlled conditions using an indoor testing facility. At the time of ascospore maturation, heavily infected leaves were submitted to temperature rises ranging from 150 to 200 °C with open-flame burners, thus reducing the number of ascospores subsequently released by 76% and 87%, respectively. During Spring 1995, thermal treatments of overwintered dead leaves were performed directly on the ground of an apple orchard with an experimental propane flamer design to generate uniform heat at ground level. Four thermal treatment strategies, involving two dates of flaming and two heat intensities, were tested. Flaming orchard ground, when performed in early May, before significant development of ground cover, reduced the number of ascospores released from infected dead leaves by half. A significant residual effect of the treatments on ascospore ejection was still observed 2 and 4 weeks after the treatments, thus indicating that ascospore maturation inside the leaves may be reduced by heat treatment. These results indicate potential for propane flamers to reduce apple scab primary inoculum in orchards.

Apple scab, caused by the fungus *Venturia inaequalis*, is the most important disease in apple orchards in northeastern North America. The infection may be particularly severe under cool and moist conditions prevailing during spring. Apple scab has been traditionally controlled by intensive chemical treatments, currently a minimum of 12 fungicide applications per season, which represents an important part of the production costs for this crop (Gadoury et al., 1989; Merwin et al., 1994). During the last decades, to optimize and reduce fungicide applications, several countries have successfully implemented disease forecasting programs based on Mills' system (Mills, 1944). However, complementary approaches remain to be developed to reach current requirements of consumers and governments for pesticide reduction.

In temperate climates, *V. inaequalis* overwinters mainly as pseudothecia that form inside fallen apple leaves (Keitt and Jones, 1926; Wilson, 1928). In spring, following their maturation in pseudothecia, ascospores are discharged, thus initiating infection under conducive environmental factors. From year to year, the level of disease observed during the growing season appears to be greatly conditioned by the intensity of the primary infection on

buds, fruits, and new foliage. Several authors have, therefore, suggested that reduction of primary inoculum would represent a key factor in controlling apple scab (Burchill and Hutton, 1965; Kumar and Gupta, 1990; Palminter, 1946).

Various experimental approaches have been investigated to reach this objective. Some are based on chemical control of fungal development by fall applications of systemic fungicides before leaf abscission (Biggs and Warner, 1990; Coulombe and Jacob, 1980; Gupta, 1979). Other alternative methods that showed promising results under experimental conditions included biological control of the primary inoculum with antagonistic agents (Andrews and Berbee, 1981; Cullen et al., 1984; Heye and Andrews, 1983), control of leaf litter density (Kumar and Gupta, 1990), and enhancement of leaf degradation with urea (Miller, 1970) or earthworms (Niklas and Kennel, 1981). However, none of these practices are currently used on a commercial scale in orchards, as they are perceived by growers to be unproven or uneconomical (Merwin et al., 1994).

The use of propane flamers in agriculture could provide a useful alternative to agrochemicals. Flaming orchard ground was introduced initially to repress weeds in several crops (Withney, 1968). Even though the emergence of a new generation of herbicides marked a decline in popularity of this technology, it has been reintroduced recently and evaluated in several crops (Morelle, 1993). Recent experiments conducted in apple orchards have confirmed that thermal treatment with pro-

pane flamers is a promising approach to controlling broadleaf weeds under laboratory and field conditions (Rochefort, 1994). So far, a few studies also have been devoted to repression of fungal pathogens with propane flamers during intercrops. *Verticillium* spp. were efficiently controlled in infested soils, potato (*Solanum tuberosum* L.) vines, and peppermint (*Mentha x piperita* L.) stubbles (Dooley, 1965; Easton et al., 1969).

The objective of the present study was to assess the potential of thermal treatments with propane flamers in reducing development and release of *V. inaequalis* ascospores. In a first step, heavily infected dead leaves that overwintered on the soil of an apple orchard were subjected to thermal treatments under controlled conditions using an indoor testing facility. To validate laboratory results, a second experiment was conducted under field conditions. Propane flamers were used during the spring to treat the ground cover of a standard apple orchard otherwise subjected to minimum chemical spray strategy.

Materials and Methods

Laboratory experiment. In Oct. 1993, scab-infected apple leaves were collected on the ground of a mature apple orchard that was out of production and had not received any chemical treatments for many years. Leaves were placed in 12 wire mesh cages (100 × 50 × 5 cm) and were carried to an orchard planted with standard trees of mixed cultivars, at the Joseph-Rhéaume Experimental Farm (Ste-Croix de Lotbinière, Québec, Canada). Cages containing infected leaves were randomly distributed on the ground of the orchard to overwinter (St-Arnaud et al., 1985).

In Apr. and May 1994, maturation of ascospores in experimental leaves was monitored weekly. Dead leaves collected in cages were fixed in hot water and pseudothecia were sampled from leaf tissues to assess spore maturity on squash mounts (Gadoury and MacHardy, 1982). Infected leaves were subjected to thermal treatments in early May, at the beginning of spore maturation and before the onset of ejection. Cages were then brought back to a laboratory equipped with a specially dedicated indoor testing apparatus (Gill et al., 1994). This experimental facility consists of a mobile carriage on which specimens are placed, and a burner-supporting frame on which various burner settings can be performed. Multiple thermal treatment intensities can be generated at the target level by combinations of propane feeding pressure and operating speed of the carriage (Gill et al., 1995). In our experiment, heat from three flat burners placed at a height of 30 cm over the carriage was directed vertically downward toward the specimen apple leaves distributed in a uniform layer 1 cm deep.

The effect of two thermal treatments intensities generated by an operating speed of 4 km·h⁻¹ (usual tractor speed in orchard) combined with propane feeding pressures of 207 and 345 kPa was evaluated. These thermal treatments generated, respectively, tempera-

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ture rises of 150 and 200 °C at the target level. Each of the two burning intensities was randomly applied to leaves from eight distinct cages. Control leaves were not subjected to heat.

Following the treatment application, 10 leaves were randomly selected in each experimental unit and the ascospores released from leaf samples were quantitatively evaluated (Lagarde, 1988). The method consisted of provoking ascospore ejection by submersing leaves (2.5 to 3 g of dried material) in 100 mL of water and agitating them on a rotary shaker (75 rpm) at room temperature for 6 h. The number of mature spores (dark brown colored) released after this period was then counted from two subsamples of the spore suspension under a microscope using a hemocytometer.

Field experiment. The field experiment was performed in an orchard at the Joseph-Rhéaume Experimental Farm. The occurrence of infection on naturally fallen apple leaves was confirmed by squash mounts in May 1995. Experimental plots (4 × 12 m) were established between the rows of apple trees (four randomized complete blocks) to be subjected to five thermal treatment strategies. The first thermal intervention was performed on 3 May, at the beginning of ascospore maturation. Burners were operated with propane feeding pressure of 345 kPa combined with a speed of 4 km·h⁻¹ (T1), conditions proven to be effective in reducing spore ejection under laboratory conditions. For the second intervention (19 May), two burning intensities, 345 kPa (T2) and 480 kPa (T3), were applied under the same operating speed as before. The fourth strategy (T4) consisted of repeated flaming applications (345 kPa) at both dates. Control plots (T5) were not burned. The equipment used for thermal treatments in the orchard consisted of a 3.6-m experimental flamer pulled by a tractor and equipped with 16 open-flame burners designed to generate uniform heat application at the target level.

On both dates of flaming, dead apple leaves were collected 1 h after treatments (10 leaves randomly collected in each plot). To evaluate inoculum development, plots were sampled again 10 d following the last flaming treatment. Chemical sprays in the experimental orchard were delayed until the last sampling date. The spraying program of 1995 included only two fungicide applications; spraying of Mancozeb ([1,2-ethanedithiolbis [carbamidithioato]] (2-)) manganese mixture with [[1,2-ethanedithiolbis [carbamidithioato]](2-)]zinc and Myclobutanil (α -butyl- α -(4-chlorophenyl)-1H-1,2,4-triazole-1-propanenitrile) on 20 May, and of Metiram (tris[amine-[ethylen bis (dithiocarbamato)] zinc(II)] (tetrahydro-1,2,4,7-dithiadiazocine-3,8-dithione)) and Myclobutanil on 16 June.

Leaf samples were stored at 4 °C until analysis. The number of spores was determined over the following days, using the methodology previously described. Given that spore concentrations from leaf samples collected on the experimental orchard were low, samples were concentrated four times by centrifugation before cell counts. To this end, aliquots of

the spore suspension were centrifuged 15 min (856 g_n) and adjusted to the volume needed.

Statistical analysis. Data from the laboratory experiment were analyzed by analysis of variance (ANOVA), and differences among treatments were tested by the LSD means procedure (Sokal and Rohlf, 1981; SAS Inst., Cary, N.C., 1988). The effects of flaming treatments on spore ejection in the field were examined by date using a one-way ANOVA (Sokal and Rohlf, 1981; SuperANOVA 1.11, Abacus Concepts, Berkeley, Calif.). Differences among treatments or groups of treatments were compared with single df contrasts. Field data were transformed by log (X + 1) transformation to meet the assumption of normality before analysis.

Results

Laboratory experiment. Flaming performed on uniform layers of overwintered infected apple leaves significantly reduced the number of ascospores that were subsequently ejected from the leaves (Fig. 1). Heat intensities generated by the combination of an operating speed of 4 km·h⁻¹ and propane feeding pressures of 207 and 345 kPa reduced the number of *V. inaequalis* spores ejected after a 6-h wetness period by 76% and 87%, respectively.

Field experiment. At the first date of intervention (3 May), the soil was covered by desiccated weeds from the previous growing

season and the annual development of new groundcover was just beginning. Flaming treatments that were conducted at this date (T1 and the first pass for T4) were efficient in reducing the ejection of *V. inaequalis* ascospores from dead leaves collected on treated plots immediately following the pass of the thermal ramp (Table 1 and Fig. 2). Furthermore, ascospore ejection was lower on leaf samples collected later in the season (29 May) from plots that received a thermal shock early in May (T1 and T4), thus indicating that flaming treatment performed in early May had a residual effect on apple scab primary inoculum 4 weeks following its application (Fig. 2).

The second intervention, planned for mid-May, was delayed because of rain. At the second flaming (19 May), grass weeds were about 25 cm tall and presumably maintained relatively high humidity at the ground level compared to the earlier treatments. The number of spores ejected from leaves collected on treated plots at this date was similar to the control and no differences were discernible among the thermal strategies (Table 1).

Based on the evaluation of samples collected on 29 May, heat treatments of orchard ground with propane flammers reduced the ejection of ascospores 10 and 26 days following its application. However, under our experimental conditions, the best results were obtained on plots that were treated in early May (Table 1). The treatment strategy involving two flaming applications (T4) were not more efficient than

Fig. 1. Number of mature *Venturia inaequalis* ascospores (X 10⁴) released per gram of dry mass of overwintered apple leaves subjected to heat treatments with flame burners at two gas pressures under laboratory conditions. Mean separation by LSD, *P* < 0.05, *n* = 8. Bars indicate standard error of the mean.

Fig. 2. Number of *Venturia inaequalis* mature ascospores ($\times 10^4$) released per gram of dry mass of overwintered apple leaves following heat treatments in an experimental apple orchard in May 1995. Arrows indicate treatments that were applied at the corresponding date. (T1) 345 kPa on 3 May. (T2) 345 kPa on 19 May. (T3) 480 kPa on 19 May. (T4) 345 kPa on 3 May + 345 kPa on 19 May. Operating speed was 4 km·h⁻¹. Control plots were not burned.

the early-May treatment (T1) alone (Table 1). Operating the flammers with propane feeding pressure of 345 and 480 kPa at the speed of 4 km·h⁻¹ gave similar results (Table 1).

Discussion

The detrimental effects of high temperature on fungal cells or spores are well documented and form the basis of sterilization practices of soil and substrates by heat and steam. However, the effect of a thermal burst at very high temperatures on the survival of fungi has been sparsely investigated (Dooley, 1965; Easton et al., 1969). In this report, we showed that, under controlled conditions, temperature rises of 150 and 200 °C interfered with ascospore development and release of the pathogenic fungus *V. inaequalis* into its natural overwintering substrate, apple leaf tissue. Flaming of infected leaves reduced the number of spores that were ejected after wetting.

Experiments conducted in a standard apple orchard further confirmed that a single pass of appropriate flammers over the ground may be a feasible and efficient method for reducing primary inoculum of apple scab. Heat treatments with propane flammers operating at 4 km·h⁻¹ combined with propane feeding pressure of 345 kPa, when performed early in the season, significantly reduced the number of spores ejected. Furthermore, flaming had a residual effect on the number of spores ejected later in the season.

Weather conditions and vegetative ground cover influence the efficiency of the flaming treatments. For mid-May treatments, high

moisture at the soil level and the presence of tall and dense grasses may have contributed to reduce intensity of the heat shock applied to the pathogen inside of leaf tissues. To optimize the efficiency of heat treatments with propane flammers, factors such as date of application, soil moisture content, and ground cover development will have to be considered for future application of this technology.

As stated by Gadoury et al. (1986), a reduction of the potential ascospore dose (PAD) mainly contributes to delayed onset of epidemics. Given the low levels of inoculum commonly encountered in commercial orchards, practices that greatly reduce PAD may be valuable in delaying the need for first fungicide sprays that are usually applied for apple scab control. Based on our results, thermal treatment of orchard ground in early spring tends to reduce the primary inoculum of apple scab. In addition, this practice gave effective weed control when compared to herbicides (Rocheffort, 1994). Thus, thermal ground treatments using propane flammers would represent a useful component in an integrated management program of these two major pests in commercial orchards.

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Table 1. The effects of heat treatments with flame burners on the ejection of *Venturia inaequalis* ascospores from overwintered apple leaves subjected to various thermal regimes in May 1995.² Following log (X + 1) transformation, data were analyzed by analysis of variance and selected treatments were compared by single df contrast.

Date of treatment	Contrasts	df	MS	P value
3 May	Treatments	4	0.128	0.0980
	Untreated vs. treated (T2 + T3 + T5 vs. T1 + T4)	1	0.399	0.0170
	Error	10	0.049	
19 May	Treatments	4	0.206	0.1698
	Control vs. treated (T5 vs. T1 + T2 + T3 + T4)	1	0.091	0.3690
	1 pass vs. 2 passes (T1 vs. T4)	1	0.065	0.4457
	345 kPa vs. 480 kPa (T2 vs. T3)	1	0.010	0.7629
	Error	10	0.103	
29 May	Treatments	4	0.528	0.0060
	Control vs. treated (T5 vs. T1 + T2 + T3 + T4)	1	0.690	0.0137
	Early May vs. mid-May (T1 vs. T2)	1	0.605	0.0192
	1 pass vs. 2 passes (T1 vs. T4)	1	0.001	0.9365
	345 kPa vs. 480 kPa (T2 vs. T3)	1	0.003	0.8480
	Error	11	0.800	

²See text for details of the flaming treatments.

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