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Impact of exclusion netting row covers on arthropod presence and crop damage to 'Honeycrisp' apple trees in North America: A five-year study

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ABSTRACT

Exclusion nets have been used successfully in France against codling moth *Cydia pomonella* (L.) since the early 2000s. Such a system has been adapted for North American conditions and was tested in an experimental apple orchard ('Honeycrisp') in southern Quebec, Canada from 2012 to 2016. Evaluation of insect and disease damage, as well as physical and physiological damage, was made in complete exclusion plots—in which the soil is also excluded—and in unnetted control plots. The exclusion system proved to be an effective protection device for the vast majority of key pests of apple fruit in most years. Damage from key insect pests such as the apple maggot *Rhagoletis pomonella* (Walsh), the tarnished plant bug *Lygus lineolaris* (Palisot de Beauvois) and the codling moth was significantly lower in netted plots than in unnetted plots. However, obliquebanded leafroller *Choristoneura rosaceana* (Harris) damage increased over the years to the point of being significantly more important in netted plots in 2015. Minimal or non-significant effects were observed on smaller, foliar pests, while highly significant protection effects were recorded for abiotic damage from frost and hail events that occurred during the study. Nets showed a significant protective effect on diseases such as apple scab *Venturia inaequalis* (Cooke) G. Wint., *Gymnosporangium* spp. rusts, and sooty blotch and flyspeck (SBFS) complex, when these were present in our plots.

1. Introduction

Exclusion nets are commonly used in many agricultural commodities as a non-aggressive pest control tool, but they seldom have been considered economical to use in pome fruit production (Chouinard et al., 2016). The main mode of action of such nets is to act as a barrier to deny access to the crop, but other mechanisms, including behavioral, may be involved for some species, such as the codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) (Sauphanor et al., 2012).

In light of their sustainability and effectiveness against various pests (birds, insects, frugivorous bats, and other mammals), but also against hail, wind, frost, and sunburn (Alaphilippe et al., 2016; Granatstein et al., 2016; Iglesias and Alegre, 2006; Tasin et al., 2008), net exclosures for tree fruit are gaining interest, mostly in organic agriculture but also in integrated fruit production (Marliac et al., 2015). They are also currently being investigated as a potential solution to the devastating problems caused by the brown marmorated stink bug, *Halyomorpha halys* Stål (Hemiptera: Pentatomidae) in the United States (Marshall and Beers, 2016).

Various exclusion systems have been studied for pests of pome and stone fruits. These systems can be grouped into two categories: *complete* or *incomplete* exclusion (Chouinard et al., 2016). Complete exclusion refers to row-by-row systems in which the soil is also excluded from the zone, whereas incomplete exclusion refers to full block netting systems covering entire orchards (Rigden, 2008) or row-by-row systems in which the nets are left hanging down to the ground.

Despite a good environmental profile and an excellent effectiveness against *C. pomonella* (Romet et al., 2010), the Alt'Carpo (complete) exclusion system, developed in France, is considered a "technologically-intensive strategy" (Marliac et al., 2015). Moreover, it is designed to control a single pest species, although other pests might also be controlled, depending on the mesh size used. In the following paper, we present the results of a study that focused on the plant protection properties of a simple, cost-effective netting

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system (Chouinard et al., 2016) designed to provide complete exclusion of key pests of apples grown in northeastern North America. Orchards growing in this part of the world are subjected to the attack of *C. pomonella* (in Quebec, 22% average damage at harvest when left unchecked) (Vincent and Bostanian, 1988), but also to a high number of other direct and indirect pest species (Chouinard et al., 2016) which leads, on average, to annual applications of over 14 pesticide sprays (Morin and Chouinard, 2001). We hypothesized that, in the absence of any insecticide, acaricide and fungicide, our netting system, deployed over a high-density plot of high-valued apple trees, would allow fruit and foliage to grow while suffering less damage than trees without netting. Between 2012 and 2016, we evaluated the impact of this netting system on fruit and foliar damage.

2. Methods

2.1. Experimental setup

Operations were conducted from 2012 to 2016 in the experimental orchard of the Research and Development Institute for the Agri-Environment (IRDA), located in Saint-Bruno-de-Montarville, QC, Canada (45.533289°, −73.349876°). Eight adjacent rows of dwarf apple trees (l: 22 m; h: 2–2.5 m) of the cultivar Honeycrisp were selected from a 6-year old high-density plot, with trees from four rows on B-9 rootstock and the others on M-26. Bordering rows were used as buffer zones so that the inner six rows would not receive any pesticide sprays or drift from adjacent plots. In each of these six rows, there were two experimental units (l: 10 and 12 m, containing 8–12 trees each), separated by the middle stakes of the existing apple tree training and support system, for a total of 12 experimental units in which samples were taken as described below. All trees comprised within an experimental unit were subjected to sampling, except if otherwise stated in the "sampling" section. "Hobo" temperature and humidity sensors (Onset Co., Bourne, USA 02532) were present in each experimental unit (Chouinard et al., 2016).

Two treatments were compared: exclusion (nets) and control (no nets). In 2012, six pairs of the two treatments were distributed randomly within the 12 experimental units. No insecticides, fungicides or acaricides, were sprayed in any of the experimental units, except for two fungicide sprays (captan and mancozeb) applied prior to net installation in 2012. Ground fertilizers were applied uniformly in all treatments according to grower practices.

2.2. Exclusion system

Vertical stakes from the existing apple tree training and support system were used to support the netting system (Fig. 1). Two wooden studs (l: 185 cm) were fixed horizontally to the stakes at each extremity of the netted units: one at 95 cm from the ground and the other at 189 cm. Four polyester wires (Esterwire®, Impact Synergie, Repentigny, QC, Canada) were attached to the tips of the two crosses from one end and extended to the other end of the unit, where they were attached to the corresponding tips. Two more wires were installed this way, from one stake to the other, at 30 cm (bottom wire) and 257 cm (top wire) from the ground.

Once the wires were tightened, clear high-density polyethylene nets (19 × 8 m; mesh size: 1.90 mm × 0.95 mm; 60 g/m^2; 87% light transmission) (ProtekNet®, Dubois Agrinovation, Saint-Rémi, QC, Canada) were placed over the top wire, then around the side ones. Both sides of the nets were rolled together and fixed to the bottom wire by clips (EasyKlip®, Dubois Agrinovation, Saint-Rémi, QC, Canada) placed on each side of trunks and stakes to allow tight closing and avoid undesired entry. This mesh size was selected

Fig. 1. An experimental unit of the complete exclusion system used, showing the net, wires and clips installed over the existing apple tree training system.

because we thought it would allow physical exclusion, based on the adult size of insect pests known to affect apple orchards in this part of the continent (Agnello et al., 2006). About one clip every 2.5 m was also used to attach the net to the top wire to assure more stability. The two ends of the nets were also closed using clips.

The nets were installed before the trees blossomed, between April 22 (bud break) and May 13 (pink stage) depending on the year. They were removed just before harvest, (mid-September), and stored until the following spring, when they were installed again in the same plots. Nets were opened each year during bloom, between two (2014, 2015, 2016) and four (2012, 2013) occasions, i.e. on sunny days with fair weather, to allow between 20 (2013–2016) and 40 (2012) hours of effective pollination, mainly by honey bees from several hives deployed in the orchard. This number of pollination hours has been found each year to be sufficient to obtain good fruit set, *i.e.* at least one fruit set per 8 flowers, based on visual counts made prior and after bloom each year (unpublished data). On each of these "pollination days", the bottom clips were detached in the morning, the nets were rolled up and attached to the 189 cm wire on each side of the row, and then closed again at dusk to reduce the risk of entry by nocturnal pests. Nets were also opened for periods of 30 min to collect data on several occasions (10–15 per year) during the summer. However, for these observations, nets were not attached to the 189 cm wire, but were rather left hanging down to the ground.

Sampling. Because multiple variables had to be followed, the sampling scheme was carefully planned to make sure assessments could be performed simultaneously in all experimental units and avoid any possible bias that could arise due to lack of time or climatic events. Samplings were thus performed whenever possible at predicted peak activity, based on historical data (foliar pests and beneficials) or at the end of the season (fruit damaging agents) to accurately reflect the real situation in the shortest possible time.

In mid-August of 2012, 2013 and 2016, the population density of green apple aphids, *Aphis pomi* De Geer (Hemiptera: Aphididae) was assessed on 120 randomly selected shoots from each experimental unit, excluding the two outermost trees. A value was given to different densities: 0 for no aphid colonies, 1 for small colonies, 2 for medium-sized colonies, and 4 for large colonies. A "score" was given to each unit by adding the values of each of the 120 shoots. Incidental observations of aphid predators—such as gall midges (Diptera: Cecidomyiidae) and lady beetles (Coleoptera: Coccinellidae)—and allies—such as ants (Hymenoptera: