

**AFPP – 11^e CONFÉRENCE INTERNATIONALE
SUR LES RAVAGEURS ET AUXILIAIRES EN AGRICULTURE
MONTPELLIER – 25 ET 26 OCTOBRE 2017**

**ARE PLASTIC REFLECTIVE MULCHES AND KAOLIN PARTICLE FILM USEFUL IN THE BIOLOGICAL
CONTROL OF APPLE PESTS? - PRELIMINARY RESULTS.**

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ABSTRACT

Larvae of the apple leaf-curling midge *Dasineura mali* (Kieffer) (Diptera: Cecidomyiidae) cause important damages to young apple trees when feeding on leaves. This pest is present all season long (May to September) in apple orchards and is mainly controlled by chemical insecticides. Alternatively, plastic reflective mulches and kaolin application are physical methods potentially efficient against midge and other pests present in orchards. We tested the efficiency of reflective mulches used alone or in synergy with kaolin application against the apple leaf-curling midge and other insects in apple orchards. Three generations of apple midges were observed. Rather than protect the apple tree, kaolin applications and, to a lesser extent reflective mulches, actually increased damage on trees compared to the control treatment. Their potential detrimental effects on predators are discussed.

Keywords: apple leaf-curling midge, integrated pest management, reflective mulch, kaolin, apple.

RÉSUMÉ

EFFICACITE DU PAILLIS REFLECHISSANT ET DU KAOLIN COMME METHODE DE LUTTE CONTRE LES RAVAGEURS DU POMMIER-RESULTATS PRELIMINAIRES.

Les larves de la cécidomyie du pommier, *Dasineura mali* (Kieffer) (Diptera: Cecidomyiidae), provoque des dommages importants aux jeunes pommiers lors de l'alimentation sur les feuilles. Ce ravageur est présent toute la saison (de mai à septembre) dans les vergers de pommes et est principalement contrôlé par des insecticides chimiques. Alternativement, les paillis plastiques réfléchissants et les applications de kaolin sont potentiellement efficaces contre les cécidomyies et autres ravageurs du pommier. Nous avons évalué l'efficacité des paillis réfléchissants utilisés en combinaison ou non avec le kaolin contre la cécidomyie du pommier et d'autres organismes dans un verger de pommiers. Trois générations de la cécidomyie du pommier ont été observées durant la saison 2016. La protection des pommiers en utilisant les méthodes testées n'ont pas démontré une grande efficacité, mais plutôt des dommages accrus sur les pommiers comparativement au traitement témoin. Leur effet potentiellement préjudiciable sur les prédateurs est aussi discuté.

Mots-clés : cécidomyie du pommier, lutte intégrée, paillis réfléchissant, kaolin, pomme.

INTRODUCTION

The apple leaf-curling midge *Dasineura mali* (Kieffer) (Diptera: Cecidomyiidae) is a major pest of young apple trees in Quebec orchards (Brousseau et al., 2013; Charpentier and Joannin, 2013; Legault and Turcotte-Côté, 2013). The midge larvae feed on apple leaves which negatively impacts photosynthesis and young tree growth (MacPhee and Finnamore, 1978). This pest is observed during all the production season (from May to September in Quebec, Canada) and three peaks were observed under Quebec orchards (Laroche and Provost, 2015). Hence, pest control strategies must be efficient for a broad period and especially during the second generation (about mid-July) that causes the higher level of damages (Cormier et al., 2017). Presently, pyrethroids are used to control apple midge in orchards. These chemical products are known to negatively affect natural enemies and are moderately recommended according to an integrated pest management program. Use of these chemicals are often limited according to the lack of life cycle information and the larvae location (inside leaves) (Shaw et al. 2003 ; Smith et al. 1998). Moreover, the impact of potential predators (e.g. predatory bugs and coccinellids) are not well known in orchards and may not be efficient enough to maintain midge populations under economic threshold (Shaw and Wallis, 2012).

The use of plastic reflective mulches is a potential alternative to the actual chemical strategies used to control the midge (Greer and Dole, 2003). Reflective mulches operate by reflecting UV rays, which confuse and repel reproductive adults. Use of reflective mulches showed effective results to control pests such as whiteflies (Summers et al., 2004), leafhoppers (Summers and Stapleton, 2002), thrips (Momol et al., 2001) and aphids (Kring and Schuster, 1992; Brown et al., 1993; Stapleton and Summers, 2002) in many crops. Summers and Stapleton (2002) observed that metallic reflective mulches were more efficient than insecticides against the corn leafhopper *Dalbulus maidis* (Delong) (Hemiptera: Cicadellidae). Moreover, reflective mulches increased sweet corn yields by a combined action of its repulsive effect on apple midge and associated disease (corn stunt disease), and an increase in light availability to the plants (Summers and Stapleton, 2002). Reflective mulches reflect more than 90 % of the light in the 400 to 700 nm spectrum, which is necessary for photosynthesis (Summers et al., 2004). However, the efficiency of reflective mulches is reduced in crops with abundant foliage (Kring and Schuster, 1992) and is inefficient against nocturnal species. In the specific case of young apple tree plantations, the foliage may not be abundant enough to cause a reduction of the reflective mulches efficiency against diurnal pests (e.g. apple leaf-curling midge).

Calcined kaolin particle film is another physical method potentially efficient that could be integrated in biological control of the apple midge (Unruh et al., 2000; Knight et al., 2001; Pasqualini et al., 2002; Lalancette et al., 2005). It creates a physical barrier that prevents the larvae of obliquebanded leafroller *Choristoneura rosaceana* (Harris) (Lepidoptera: Tortricidae) to feed on leaves (Sackett et al., 2005). A negative effect on several apple pest species (i.e. leafhopper, sawfly and aphids) is also observed (Bürgel and Wyss, 2005; Bostanian and Racette, 2008). Therefore, the kaolin spray could also be effective against the apple midge. However, kaolin spray can generate varying results depending on the targeted species (Smirle et al., 2007; Bostanian and Racette, 2008; Jaastad et al., 2009) and could only have a limited effect when used alone (Bürgel and Wyss, 2005). Among the undesirable effects, kaolin can considerably decrease the abundance and species richness of the community and alter the species composition (Marko et al., 2010). Hence, this physical method affects several untargeted organisms, notably predatory mites, spiders, predatory bugs and ladybird beetles (Jaastad et al., 2006; Marko et al., 2006; Sackett et al., 2007; Marko et al., 2008; Marko et al., 2010). Despite these mitigating effects, kaolin could be a useful complement to reflective mulches because of its potential repressive effect against nocturnal pests such as the obliquebanded leafroller and the spotted tentiform leafminer *Phyllonorycter blancardella* (Fabricius) (Lepidoptera: Gracillariidae).

The aim of this study was to test the efficiency of reflective mulches used alone or in synergy with kaolin spray (i.e. Surround) against the apple leaf-curling midge (diurnal pest) on young apple trees. We predict that the use of reflective mulches will decrease the level of damage by apple midges and increase light availability, two consequences that favor young apple tree growth. The use of kaolin application could decrease the population of both apple midges and leafminers and thus promote tree growth. Simultaneous use of reflective mulches and kaolin application would have a better effect than when these methods are used alone.

METHODS

Study site

The experiment was performed during the 2016 growing season in a commercial apple orchard (Verger Trottier) in Oka, Quebec, Canada (45.502533; -74.005740). Trials were conducted on apple trees planted in 2013. Apple trees were semi-dwarf Fortune variety grafted on M-106 rootstock. Apple midge damage history from 2014-2015 was also observed.

Experimental design

Four treatments were implemented following a randomized complete block design: 1) control treatment with black plastic mulches and no kaolin spray; 2) plastic reflective mulches (no kaolin spray); 3) kaolin spray (with black plastic mulches); and 4) reflective mulches and kaolin spray. Plastic reflective mulches were installed at the end of April 2016. Each plot was composed of five consecutive apple trees. All treatments were repeated five times. Kaolin (Surround) was applied at nine different moments during the 2016 growing season (May 3rd, 19th, 24th, 31st, June 7th, 14th, 21st, 30th and August 15th) with a dosage of 50 g/L.

Measured parameters

Apple tree growth. The basal trunk diameter (30 cm from the ground) of each tree was measured with a calliper. A white line was painted on the trunk to mark the exact location of the first measurement (the initial diameter was measured on April 18th, 2016). The final measurement was taken at the end of the growing season on October 19th, 2016.

Pest population survey. A 'Delta' trap was installed in the center of the experimental site to follow the local populations of the apple leaf-curling midge. These traps were replaced weekly from May 3rd to September 20th 2016. Captured insects were identified and counted.

Apple midge damages. Apple leaves damaged by apple midge were counted weekly on five randomly chosen shoots on each central tree (3) of the plots (for a total of 15 shoots observed per plot). Observations were done from June 9th to September 6th 2016.

Predator population survey. Coccinellids, lacewings, syrphid flies, predatory bugs and predatory midges were counted during the sampling of midge damages.

Statistical analysis

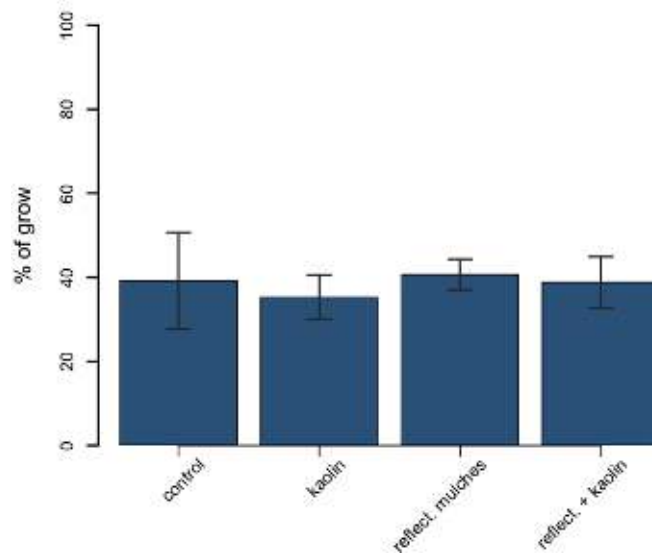
Linear mixed models (LMM) or generalized linear mixed model (GLMM) were used to test the effect of reflective mulches, kaolin application and the interaction between these factors on apple tree growth (LMM), the number of damaged leaves per tree (LMM) and number of damaged shoots per tree (GLMM for Poisson distribution). The plot was set as a random effect in the model because of repeated measures. All analyses were performed using R (R Core Team 2013) and lmer function of the lme4 library (Zuur et al., 2009; Bates et al., 2016).

RESULTS

Apple tree growth

The growth of young apple trees was not affected by the use of plastic reflective mulches (LRT = 2.29; df = 1; p = 0.13) nor by kaolin application (LRT = 1.68; df = 1; p = 0.19) (Figure 1). No interaction between these factors was observed (LRT = 0.32; df = 1; p = 0.57).

Figure 1: Apple tree growth according to the different treatments
(Croissance des pommiers selon les différents traitements)



Pest population survey

Apple leaf-curling midges were captured all season long. Three peaks in the population were observed during the 2016 season in the study site (Figure 2). The highest population density was recorded at the end of May (809 individuals by trap), whereas the other two peaks occurred in the middle of July (677 ind./trap) and at the beginning of September (465 ind./trap). Each generation (peak) lasted about three weeks.

Apple midge damages

The apple midge causes considerable damage to young shoots. The amount of damage observed increases during the season, but major increases occur at the end of June and early August following the peaks of the first two generations (Figure 3)

Higher levels of damage to leaves (number of leaves damaged by shoot) were observed in the kaolin application treatment compared to the control treatment (Figure 4). The statistically significant interaction between the use of plastic reflective mulches and kaolin application (LRT = 9.01; df = 1; p = 0,003) indicates that the negative effect of kaolin was reduced when combined with reflective mulches. When used alone the reflective mulches did not result in a decrease of damage (LRT = 0.0001; df = 1; p = 0.99).

The interaction between plastic reflective mulches and kaolin application had an effect on the percentage of shoots damaged by tree (LRT = 12.40; df = 1; p = 0.0001) (Figure 5). Kaolin application used with black plastic mulches generates the highest percentage of damaged shoots by tree. The

negative effect of kaolin decreased when used with reflective mulches, but the lower level of damage was observed in the control treatment.

Figure 2: Weekly capture of the apple curling-leaf midge (individuals by trap)
(Capture hebdomadaire de la cécidomyie du pommier durant la saison 2016)

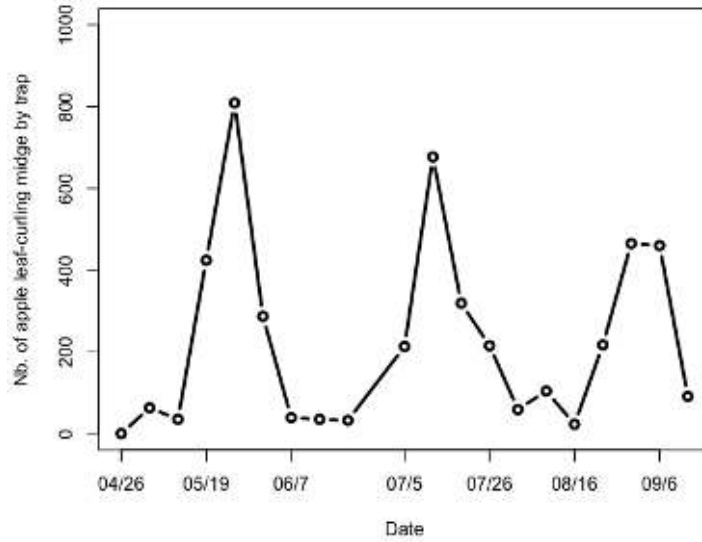


Figure 3: Number of leaves damaged by the apple leaf-curling midge during the 2016 growing season.

(Nombre de feuilles endommagées par la cécidomyie du pommier durant la saison 2016)

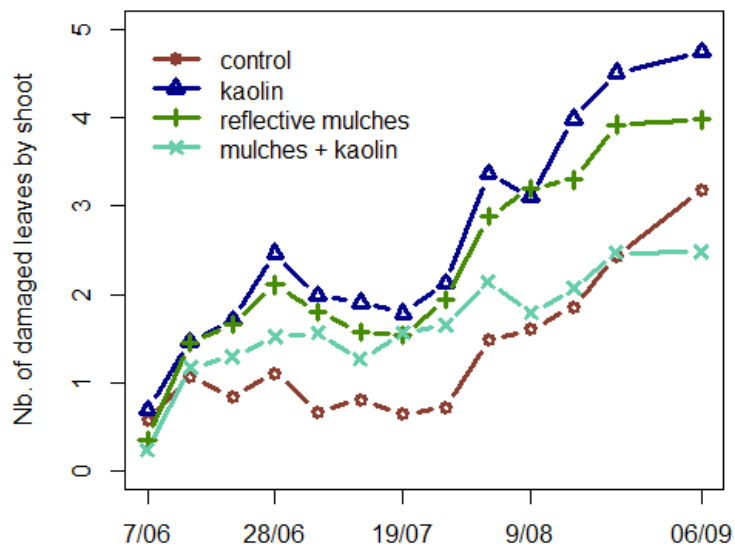


Figure 4: Number of leaves damaged by the apple leaf-curling midge as a function of the treatments. (Nombre de feuilles endommagées par la cécidomyie du pommier en fonction des traitements)

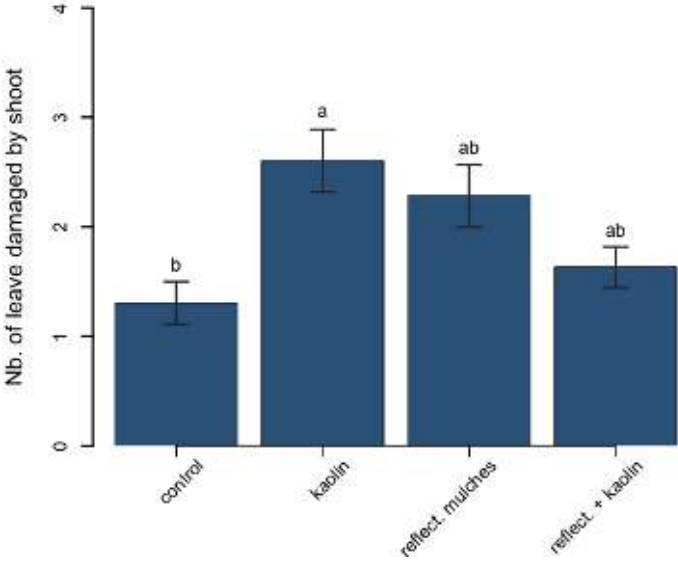
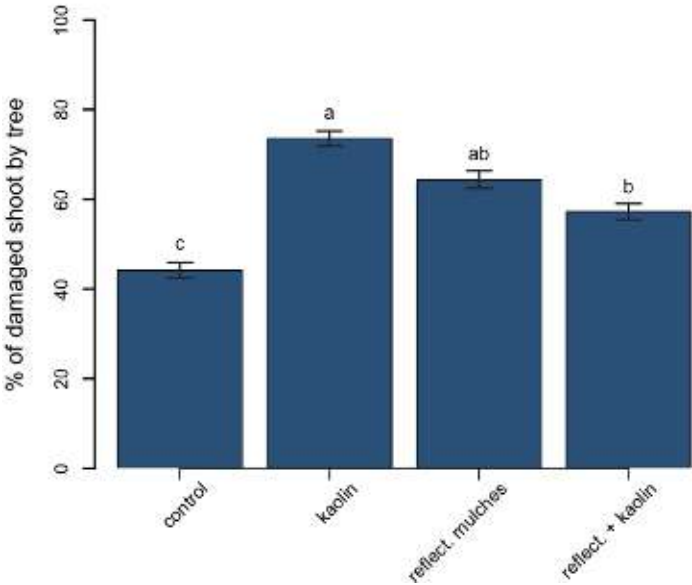


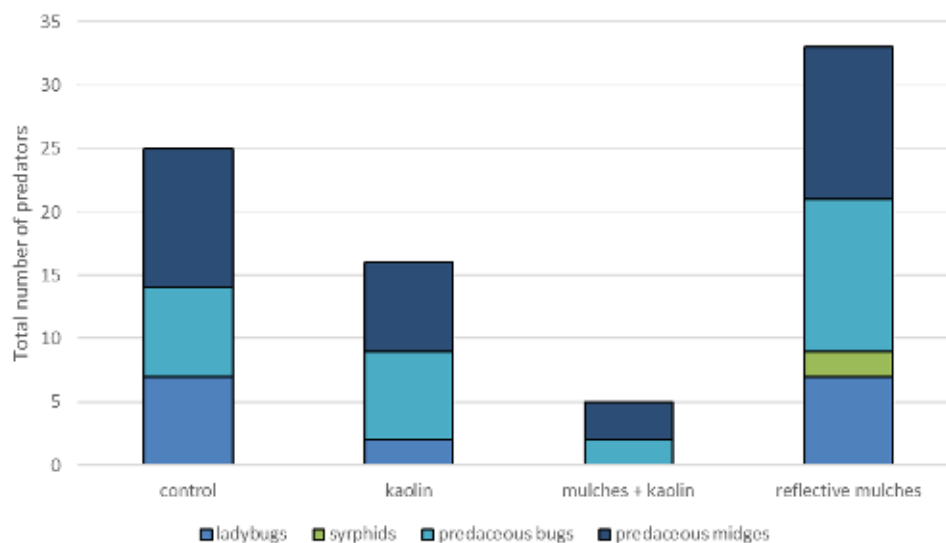
Figure 5: Percentage of damaged shoots by tree caused by the apple leaf-curling midge. (Taux des pousses endommagées par la cécidomyie du pommier par arbre)



Predator populations survey

Predaceous insects were observed on apples during the growing season. Overall, we observed more predators in all treatments compared to mulches + kaolin (Figure 6). Higher abundance of predators was observed in the reflective mulches treatment followed by the control treatment. Predaceous midges and bugs were frequently observed.

Figure 6: Number of predatory arthropods with respect to treatments (Nombre d'arthropodes prédateurs pour les divers traitements)



DISCUSSION

The weekly capture of apple leaf-curling midges confirmed that this pest is present all season long in apple orchards and has three generations. Both plastic reflective mulches (Greer and Dole, 2003) and kaolin application are physical methods expected to protect young apple trees against insect pests. Populations of whiteflies (Summers et al., 2004), leafhoppers (Summers and Stapleton, 2002), thrips (Momol et al., 2001) and aphids (Kring and Schuster, 1992; Brown et al., 1993; Stapleton and Summers, 2002) were all reduced by the use of reflective mulches in several crops. Similarly, kaolin applications negatively affected populations of leafhopper, sawfly and aphids (Bürgel and Wyss, 2005; Bostanian and Racette, 2008). However, these results do not concur with predicted results for the apple leaf-curling midge. Other impacts could occur and interfere with the repulsive effect or with natural enemies. It has been shown that these methods can also interfere with the beneficial role of predators and other beneficial biological agents. In the plot using reflective mulches, apple damages were higher than the control but we noted higher populations of natural enemies in these plots. Then, despite presence of predators, other effects reduce efficacy of predation in presence of reflective mulches. Our results suggest that the drawbacks of reflective mulches were much more important than the beneficial effects. Moreover, in our experiment, the use of kaolin application leads to increases in the level of damages to leaves, whereas the lower level of damages were observed in control treatment. Kaolin had also an impact on the predators populations and few individuals were observed in these plots.

The use of plastic reflective mulches had a positive effect on the growth of some crops (Summers and Stapleton, 2002; Greer and Dole, 2003; Summers et al., 2004). For instance, Summers and Stapleton (2002) observed an increase in sweet corn yields resulting from light availability. However, no such effect was observed in our experiment or was indistinct as a result of increased damage. The growth of young apple trees was not affected by either kaolin or reflective mulch treatments. Hence, the potential increase in solar radiation that could benefit young trees was not significant enough to make a difference.

CONCLUSION

Our preliminary conclusion must emphasize the potential detrimental effects of the use of kaolin application and reflective mulches on young apple trees. These methods affect a large spectrum of organisms, beneficials and pests, rather than only target pest species. These results suggest that predators (and/or parasitoids) potentially play an underappreciated beneficial role in apple orchards against important pests like the apple leaf-curling midge. While these predators may not be efficient enough to maintain pest populations under economic threshold for all season long, methods to enhance their benefits and protect them should be considered.

ACKNOWLEDGMENTS

The authors would like to thank Alexander Campbell for reviewing this document and CRAM technicians for their field assistance. This project was funded by the Innov'Action Agri-Food Program, a program under the Growing Forward 2 agreement between the Minister of Agriculture, Fisheries and Food and Agriculture and Agri-Food Canada .

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