# Protecting Flowers of Fruit Trees from Frost with Dynamic Agrivoltaic systems

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## 1. Introduction

Freezing temperatures during spring can damage the flowers on the tree and any potential fruit production from those flowers could be lost. Consequently, spring frost is a risk for fruit tree production in temperate regions [1]. Several methods exist to protect fruit trees from spring frost including water spraying, heating devices, air ventilation, use of chemicals and anti-frost nets. Agri-photovoltaic (APV) systems may be another solution because plants grown under solar panels maintain higher temperatures during the night than plants grown in the open field [2]. The objective of this study was to determine if this increase in air temperature during frost events is sufficient to reduce the damage to flowers of fruit trees grown under APV.

## 2. Material and methods

The study was done in apple and nectarine dynamic APV systems constructed by Sun'Agri in the south-east of France. The apple APV was constructed in 2019 in Mallemort in a mature 'Golden Delicious' apple (735 $m^2$ for the APV and 1482 $m^2$ for the control without solar panels). The nectarine APV was constructed in Étoile-sur-Rhône in a mature 'Kinolea' orchard (1725 $m^2$ for the APV divided in two replicates (A and B) and 1500 $m^2$ for the control). To protect trees from frost, solar panels were placed in horizontal position at night when temperatures were below 5 °C. In nectarine, anti-frost candles were additionally used for the control and APV systems when very low temperatures were predicted. Air temperature around trees was measured with thermo-hygrometers every 30 seconds (one tree per treatment and two sensors per tree). Additional frost sensors designed to replicate organ temperature were installed in nectarine. To determine the percentage of flowers injured by frost, one week after a frost event, 50 apple corymbs were selected in each treatment (25 corymbs in the beginning of petal fall phase (G) and 25 in the stage 'pink'). In nectarine, all the flowers for 16 shoots per treatment were monitored.

## 3. Results

In apple, full bloom occurred on the 7$^{th}$ and 8$^{th}$ of April in 2021 and 2022, respectively. In nectarine, in 2022, bloom extended from March 10 through April 1. A frost event during full bloom was observed in the apple orchard in 2021. In nectarine, there was two main frost events: from March 6 through 9 and 23 through 24. During the apple frost, trees under the panels maintained the temperature around the canopy higher than trees without solar panels [4]. In nectarine, the air temperature under panels was also higher than in control during the frosts (Fig. 1). The 9$^{th}$ of March, it was observed that the temperature of the air got up during the night due to anti-frosts candles. The candles raised air temperature by 2 °C. APV warming was about 0.3 °C compared to the control. The frost sensor provided similar trends than air temperature, but the values were lower (about 2 °C), indicating that the organs were subjected to critical values of temperature several times during bloom, including the APV modalities with the anti-frost candles. In the apple APV system, no mortal damage was observed for corymbs in stage G. For control trees, 32% of the flowers in stage G were necrotic. Because of a low bloom density (leading to no fruit thinning) accentuated by frost effects, APV trees produced 20 t/ha and control trees 10 t/ha, whereas the expected yield was 40 t/ha [4]. In nectarine, the percentage of frozen flowers and flowers without pistil after the first frost event was higher in the control trees than in the APV (Fig. 2). Despite the frost, crop load for both control and APV system was high enough for commercial purpose and a thinning was still required.

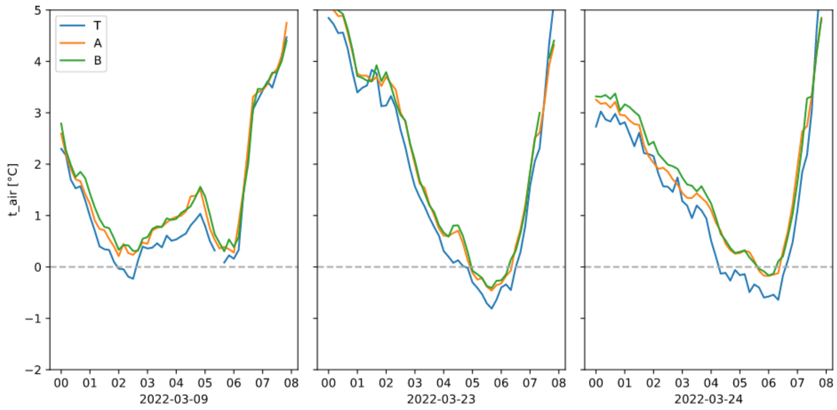


Fig. 1: Hourly patterns of night air temperature (t_air) around nectarine canopies for three nights of frost for control (T) and two replicates of dynamic agrivoltaic systems (A and B) in 2022. Each line is the mean value of two thermo-hygrometers.

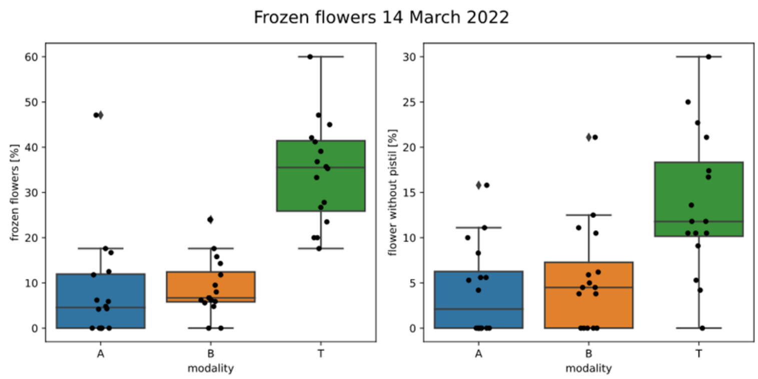


Fig. 2: Boxplot with the percentage of frozen flowers and flowers without pistil after a frost event for control (T) and two replicates of dynamic agrivoltaic systems (A and B) in nectarine.

## 4. Conclusions

Two frost events occurred during bloom for apple (2021) and nectarine (2022). The solar panels of dynamic APV were positioned in horizontal position during the night. APV maintained the night air temperature around the trees higher in comparison with the control. Less flowers were injured under the photovoltaic panels. APV can be used to protect flowers from injury during frost. If the number of flowers after the frost event is higher than the thinning requirements, no consequences in yield due to frost could be observed. However, when the number of flowers is below the thinning requirements, the APV system can preserve yield.

## Acknowledgement

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