Characterization of microclimate and turbulent fluxes at a Mediterranean kiwi orchard covered with hail-protection net

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***Abstract*— Screens and covers are increasingly used to protect crops from pests and extreme meteorological events. Their use affects plant microclimate and physiological responses as well, but this is only partly understood, particularly when considering the interaction among the cover and the training system. This study focuses on the microclimatic effects of the use of a hail protection net and an horizontal (pergola) kiwifruit canopy. The system splits the orchard environment in three distinct layers, determining a shaded understory, a space comprised between the canopy and the net, and the atmosphere above the net. To accent the effects, we considered a high-water demanding crop - kiwifruit, in an environment characterized by high evaporative demand (Bernalda, southern Italy).**

Three full eddy covariance and radiative balance equipment were used to assess fluxes (carbon dioxide, water vapor, and sensible heat) in the three layers and monitor meteorological variables (air temperature and relative humidity, wind, upward and downward short and long wave radiation, carbon dioxide and water vapor concentrations). Data from a typical clear-sky summer day are considered in this paper.

While the net strongly reduced wind speed , it had a modest impact on all other variables. Conversely, the tick canopy layer had a major impact on all variables, determining a highly shaded, cooler and more humid understory, with very light wind. Nevertheless, the combination of high relative humidity and presence of the net was able to reduce the net loss of longwave radiation from the canopy during night, mitigating its cooling under these conditions.

The reduction in wind speed and the increase in incoming longwave radiation around the crop, observed at night time, indicate potential valuable mechanisms that may be exploited to decrease water needs and prevent late frosts in the context of climate change, where extreme climatic events are more frequent and crop water requirements continue to increase.

Keywords—Energy fluxes, eddy covariance, kiwi orchard, protection net, radiation balance

I. INTRODUCTION

Multifunctional screens and covers were initially introduced to protect trees from extreme meteorological events (i.e. hailing and wind) and pests (e.g. *Drosophila suzuki*) [1]. At the same time, their use implies additional relevant beneficial or undesirable effects. On one hand, beneficial effects include the increase in air humidity, and the reduction in evapotranspiration and water use [2], [3], [1], [4], particularly interesting properties when considering the higher evaporative demand and droughts associated to climate warming [5], [6], [7]. Additional effects include a reduction in incident radiation and an increase in diffuse fraction, with cascade effects on photosynthesis, radiation use efficiency [8], and temperature [9]. On the other hand, the use of covers may increase the occurrence of fungal infections [10], due to the creation of a more humid canopy microclimate [4].

The impact on water use is related to the modification of the meteorological drivers of evapotranspiration below the cover. The artificial barrier physically splits the system in two layers (above and below the cover), exerting a friction on the wind flow, reducing vertical air movement and thus decreasing the coupling of air masses between the different levels [11]. Further, the reduced coupling is likely to increase the residence time of gases under the cover, possibly reducing exchanges and increasing the "recycling" of water vapor and carbon dioxide. These processes, together with a reduction of excessive solar radiation, could decrease evapotranspiration, a condition that may be beneficial especially in environments with high evaporative demand and scarce water availability, increasingly occurring conditions due to climate warming [5], [6], [7].

The use of cover nets on high value fruit orchards, such as kiwifruit (*Actinidia chinensis*), has the main objective of protecting plants and fruits from hailing. Kiwifruit is most commonly trained as pergola, an architecture characterized by a dense, continuous, horizontal foliage, splitting the plant environment in an upper layer, with highly sun exposed leaves, and lower, heavy shaded understory. Similarly to protection covers, this canopy structure affects microclimate and the coupling of air masses across the canopy. The concurrent use of protection nets and of the pergola training system creates a three-layered environment, where the presence of the net and canopy foliage is substantially impacting the below microclimate.

The current study aims at characterizing how the combination of an hail protection net and a pergola training system impact the meteorological drivers of evapotranspiration and the main gas exchanges (carbon dioxide and water vapor). As a case study we chose a kiwifruit orchard located in a Mediterranean environment, an interesting subject because of the characteristic high stomatal conductance and thus water requirements of this species under high evaporative demand environments.

II. MATERIALS AND METHODS

A. Study area

The study was conducted in a kiwifruit (cv Hayward) orchard, located in the Southern Italian municipality of Bernalda (Basilicata region), with a mean annual potential evapotranspiration of 1250 mm (estimated according to the Hargreaves method) and rainfall of 575 mm, provided by the nearby meteorological station of the regional agency for development and innovation in agriculture (ALSIA, Pantanello).

An horizontal, continuous hail protection net is installed at about 4.15 m height, covering the whole plot (Fig.1). The net has a mesh density of three and five wires/cm in two orthogonal directions. The field is about 1.3 ha, plants are trained as pergola, with an average height of 2.2 m, an inter-plant distance of 2.0 m and an inter-row distance of 4.5 m. Considering both the canopies and the net, the above ground environment is divided in three horizontal layers: below the canopy, between the canopy and the net, and above the net (Fig. 2). During summer, plants are irrigated once or twice a day, by both a drip and a sprinkler irrigation systems, for a total of about 6-8 mm/day during July 2021, and organic soil amendment was seasonally applied to the soil.

Fig. 1. The kiwifruit orchard, trained as pergola and covered by a homogeneous hail protection net.

B. Meteorological and turbulent fluxes data collection

The measurement campaign was conducted in late July 2021, a period characterized by particularly high vapor pressure deficit (VPD) values for the area. With the aim of measuring momentum, sensible and latent heat, and CO_2 fluxes, a full eddy covariance (EC) system, composed of 3D sonic anemometer (CSAT3, Campbell Scientific, Inc., Logan, UT, USA) and open-path infrared gas analyzer, IRGA, (LI-7500, Li-Cor Biosciences, Lincoln, NE, USA), was installed at three different levels on a 6-meter tower: below the canopy (L1, at 1.1 m height), between the canopy and the net (L2 at 3.0 m height) and above the net (L3 at 5.2 m height). Additionally, up- and down-welling short- and long-wave radiation (CNR1/4, Kipp & Zonen, The Netherlands), air temperature and relative humidity were monitored at the same height of each EC system. Instruments were installed on a 6 m vertical tower, positioned in the middle of the field, and sonic anemometers were oriented to face the prevailing wind directions. Data by sonic anemometers and gas analyzers were recorded synchronously on a single datalogger, at high frequency (10 Hz) and turbulent fluxes computed over 30-min periods, while "slow" meteorological variables were sampled at 1 or 5 sec intervals on another datalogger.

Fig. 2. (Top) Vertical mast hosting three aligned eddy covariance systems: above the net, between net and the canopy, and below the canopy. (Bottom) Detail of the below-canopy system (sonic anemometer, infrared gas analyzed, net radiometer, thermo-hygrometer).

In this manuscript, a representative day of the field campaign (July, 27th) was selected to analyze the patterns of energy fluxes (short- and long-wave radiation, sensible and latent heat) measured at the 3 levels, along with standard meteorological variables (wind speed, air temperature and humidity) in order to characterize the microclimatic conditions at each layer.

III. RESULTS

A. Radiation fluxes

The amount of incoming shortwave radiation (*Rs_in*, Fig. 3a) at canopy top (L2) was slightly reduced by the presence of the net compared to the one measured above it (L3). In contrast, the canopy foliage layer absorbed most solar radiation and only a small part was able to reach the ground (L1). As expected, a similar pattern was found for the reflected solar radiation (*Rs_out*).

The incoming longwave radiation (*Rl_in*) was substantially smaller at L3 and L2 compared to L1, while the difference of the outgoing flux (*Rl_out*) between the three levels was more limited, with smaller values at L1 only during daytime (Fig. 3b). In particular, *Rl_in* and *Rl_out* were similar at L1, resulting in a net longwave radiation close to zero at this layer. On the contrary, above the canopy (L2 and L3) the incoming longwave radiation was always substantially smaller compared to the outgoing flux, resulting in a net loss of longwave radiation. At L2, a different pattern of *Rl_in* was found during the first and second night. Indeed, the incoming flux was in between the one measured at L1 and L3 during the first night, but almost equal to L3 during the second night. This resulted in a smaller loss of longwave radiation below the net (L2), compared to above it, and a net radiation close to zero (Fig. 3c) during the first night but not in the second. Due to the small amount of *Rs_in* reaching the ground and the balanced incoming and outgoing longwave radiation fluxes, the net radiation was small during the whole day at L1, showing little difference between day and night.

B. Wind speed, air temperature and humidity

The relative humidity (*RH*) was close to saturation at all levels during the first night, decreased from sunrise to late afternoon and then increased again reaching higher/smaller values below the canopy/above the net, respectively (Fig. 4a). During daytime, *RH* was always higher below the canopy, but quite similar above and below the net.

The air temperature (*TA*) was generally lower below the canopy compared to above it (Fig. 4b). During the first night, *TA* was similar at L1 and L2 and slightly lower than above the net, while during the second night, the difference between the three layers was more marked. During late morning, the highest values were observed below the net, but in the afternoon the temperature was very similar at L2 and L3. This was associated with a sharp increase in wind speed at these levels (Fig. 3c), resulting in a better mixing of air across the net. Nevertheless, the presence of the net was able to reduce the wind speed, especially during nighttime, when the values at L2 were quite small and similar to L1.

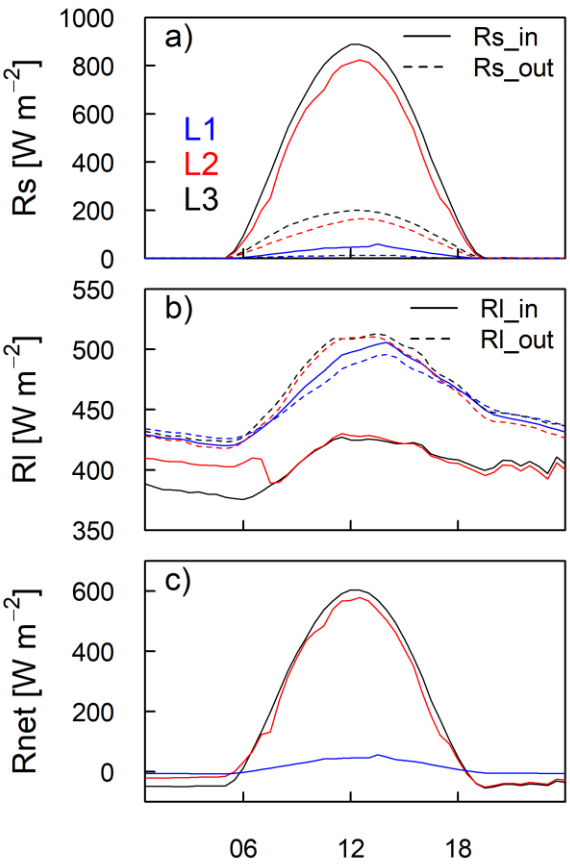

Fig. 3. Half-hour radiation fluxes measured below the canopy (L1, blue), between canopy and the net (L2, red) and above the net (L3, black) at different time during a summer day. a) Incoming (*Rs_in*) and outgoing (*Rs_out*) shortwave radiation fluxes. b) Incoming (*Rl_in*) and outgoing (*Rl_out*) longwave radiation fluxes. c) Net radiation (*Rnet*) computed as the difference between incoming and outgoing radiation fluxes.

C. Turbulent heat fluxes

The negligible shortwave radiation reaching the ground below the canopy resulted in very low values of latent (*LE*) and sensible (*H*) heat fluxes at L1 throughout the day (Fig. 5). Conversely, most of the available energy at the top of the canopy was used for transpiration of water through leaves, as shown by large and similar *LE* fluxes at L2 and L3, while only a small part of net radiation led to heating of the air by sensible heat flux. This behavior was likely sustained by a high canopy conductance under full light and no water stress, leaving only a minor amount of energy to sensible heat transfer. For an analysis of the carbon dioxide fluxes, we defer to an analysis by Reyes et al. [12].

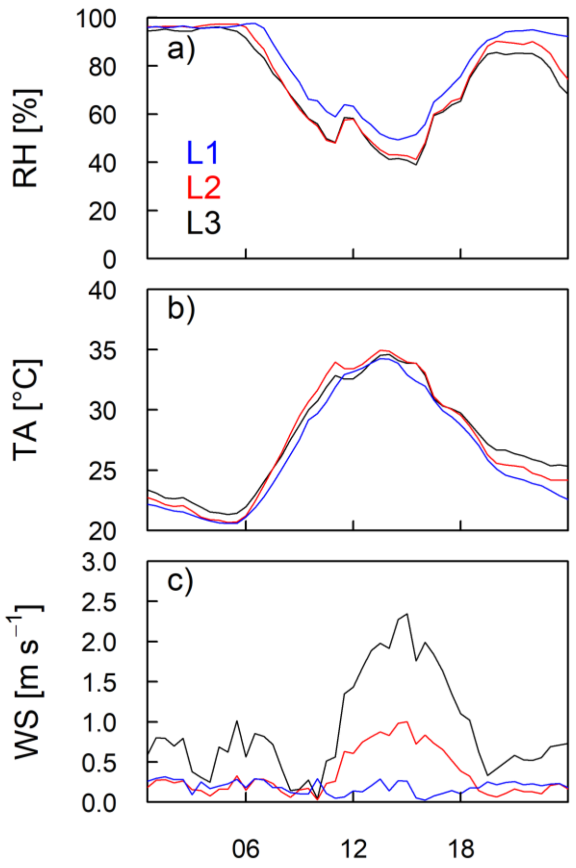

Fig. 4. Half-hour air relative humidity (*RH*, a), temperaure (*TA*, b) and wind speed (*WS*, c) measured below the canopy (L1, blue), between canopy and the net (L2, red) and above the net (L3, black) at different time during a summer day.

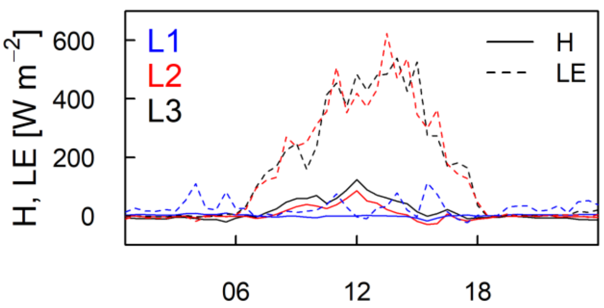

Fig. 5. Half-hour sensible (*H*) and latent (*LE*) heat fluxes measured below the canopy (L1, blue), between canopy and the net (L2, red) and above the net (L3, black), at different time during a summer day.

IV. DISCUSSION

The energy fluxes and meteorological conditions at the study site were partially influenced by the presence of the net. The latter was particularly effective in reducing wind speed, especially at night with low values also in the atmospheric layer above it, while had a less pronounced effect on the other variables when compared to the presence of the canopy itself.

Indeed, the shortwave radiation reaching the canopy top was only slightly reduced by the net, while most of it was absorbed by the canopy foliage layer. However, the net seemed to be very effective in increasing the longwave radiation reaching the canopy during conditions of high *RH*, developing an isolation layer that is able to trap most of the outgoing longwave radiation, resulting in a less marked temperature inversion at night close to the ground and within the canopy layer.

The strong reduction in wind speed below the net was linked to an increase of air temperature at canopy top in the morning, when the overall mixing of the atmosphere was small. Despite this undesired effect, the overall impact of the net on the other meteorological drivers of evapotranspiration (reduced net radiation and wind speed, increased *RH*), probably contributed to reduce irrigation demand, in respect to uncovered kiwifruit orchards, as already observed for other fruit trees [3], [13].

When comparing measurements at different levels, differences in the source area should be also taken into consideration. The measurements close to the canopy and below the canopy have a smaller fetch (generally tens of meters) compared to the upper layer (hundreds of meters), due to the proximity of the instruments to the canopy or the ground. So the representativeness of fluxes and meteorological measurements is limited to the area surrounding the instrument location. This might be a problem if the characteristics of the ground surface and the canopy are quite variable in space. However, agricultural crops are usually managed aiming at spatial homogeneity, so this should not be an issue for this type of ecosystems.

V. CONCLUSIONS

The results presented in this work provide a preliminary characterization of the microclimatic conditions at different layers of a kiwi orchard covered with a hail protection net. The presence of the net was able to limit the cooling of the canopy layer, by increasing the incoming longwave radiation, during periods of high relative humidity. This effect might be very important in agricultural areas endangered by frequent late frost events. Another significant aspect is the overall reduction in the meteorological drivers of evapotranspiration below the net, potentially leading to lower irrigation requirements. Both the reduction in wind speed and the increase in incoming longwave radiation at the crop level, as identified in this study, are crucial in the context of climate change, with a predicted intensification and increased frequency of extreme events, included late frosts, as well as higher vapor pressure deficit followed by an augmented water demand from all production sectors.

The use of canopy covers is becoming increasingly necessary to mitigate the impacts of extreme weather events. Nonetheless, given the large agricultural areas potentially hosting protection covers, it is highly important to deeply understand the impact of their use on mass (e.g. CO_2, H_2O) and energy fluxes, both relevant drivers of climate change, and thus their indirect influence on the ecosystem functioning.

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