Proactive Producer and Processor Networks for Troodos Mountains Agriculture

3PRO-TROODOS

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Contents

Abstract

The cultivation of deciduous fruit trees is one of the main agricultural activities in the Troodos Mountains area, which is widely known to produce high-quality fruit. However, the effects of climate change have not left the tree-growing sector unaffected; in particular, the occurrence of extreme weather events with greater frequency and severity, such as hailing, during the flowering, growing and ripening fruit stages have a significant impact on yields and product quality and thus on the wellbeing of Troodos growers. The practice of orchard covering using protective nets is a common strategy, mainly to maintain the quality and quantity of production by providing protection from rain, hail, and birds. In addition to these advantages of this technology, the impact of protective nets extends to other important environmental orchards' parameters.

In the framework of 3PRO-TROODOS project, researchers from the Agricultural Research Institute (ARI; PA1) evaluated the use of protective nets (anti-hail nets combined with anti-rain covers), applied at a commercial cherry orchard in Potamitissa area in Troodos mountains and quantified their effects on orchard microclimate, tree functionality and growth, yield, and fruit quality for two consecutive growing seasons.

The use of anti-rain and anti-hail protective nets substantially altered the microclimate of the orchard by affecting various environmental parameters. In particular, protective nets shifted microclimate by reducing the incident solar radiation and in parallel enhancing the homogeneous distribution of photosynthetically active radiation within the canopy, by reducing wind speed and the temperature difference between day and night, which may in turn reduce the negative impacts of extreme weather events, such as heat waves. The reduction of incident solar radiation and, to a lesser degree, the reduction in wind speed resulted in lower evapotranspiration indicating reduced levels of water loss and thus reduced irrigation needs. Sunlit leaves showed lower daytime temperatures under protective nets compared to the open orchard. Strong positive effects of protective nets on yield efficiency as well as reduced external disorders on fruits (i.e., double fruits and bird damage) were recorded. No effects of protective nets on fruit quality (e.g., firmness or ascorbic acid content) were recorded except of a lower *L** chromatic value in fruit juice coloration. No statistically significant differences were found between treatments for tree vegetative growth concerning the following parameters: shoot growth, leaf number per shoot and fruit growth. Also, no effects of protective nets were observed on tree phenology from inflorescence emergence to fruit maturity stage.

The use of protective nets may contribute to sustainable fruit production in the Troodos mountains. However, amongst numerous options available, the choice of the type of net and its method of implementation should be made with great caution. The specific characteristics of each orchard and the objective set and/or the issue to be addressed by each producer, should be considered.

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1. Introduction

The cultivation of deciduous fruit trees is one of the main agricultural activities in Troodos Mountains area, which is widely known to produce high-quality fruit. These mountain agroecosystems are multifunctional landscapes, as they offer multiple ecosystem services beyond the provision of basic food products. (Ioannidou et al., 2022). Agricultural activity in the high nature value environment of the Troodos mountains therefore makes a substantial and decisive contribution to the conservation and protection of the natural environment, natural resources, and cultural landscapes of the countryside. However, several important physiological processes and agricultural practices take place during the fruit production process, which could not remain unaffected by climate change.

Adverse climatic events, such as hailstorms, have become a serious threat in recent years, endangering the productivity and quality of orchards and thus food security (Bogo et al., 2012; Mészáros et al., 2019; Punge et al., 2017). Although tree varieties adapted to the local environment are grown in the mountainous areas of Troodos, the occurrence of extreme weather events with greater frequency and severity (hail, frost, heatwave, humidity fluctuations, strong winds, heavy rainfall, high dust concentration in the atmosphere) during the flowering, growth and ripening stages of the fruit has a significant impact on yields and product quality (Kuden, 2020; Rodrigo, 2000). In addition to extreme weather conditions, deciduous fruit growing is highly dependent on the climatic conditions prevailing during the year, as mild winters, the early rise in temperatures in spring and the prolonged summer period disturb the physiology and development of the trees (change in phenology, unsatisfactory differentiation of buds, disturbances in the dormancy stage, etc.), causing significant problems in orchards. These issues are more pronounced in modern densely planted orchards, as the fruits are directly exposed and not adequately protected by the crown, thus various problems occur such as sunburn, fruit deformation due to hail, and yield reduction due to frost (Mészáros et al., 2019).

Ongoing continuation and development of agricultural activities is largely undermined by the impacts of the above climate changes. However, these adverse effects can be mitigated or even avoided by the application of appropriate agricultural management techniques (Teitel, M., Peiper, & Zvieli, 1996). Among various techniques, the use of protective nets (anti-hail, anti-rain, shading, insect, and bird control nets) represents one of the most effective and environmentally friendly methods, which significantly reduces product damage or losses (Amarantea, Steffensa & Argenta, 2011). Tree efficiency and variability in crop productivity can be maintained through the installation of a system of protection against adverse climatic events (Musacchi et al., 2015). On top of that, the application of crop protection netting in combination with high-density pedestrian orchards may result in increased crop yield and improvement of pomological and organoleptic fruit characteristics (Solomakhin, & Blanke, 2010). In addition, the use of nets positively contributes to the avoidance of some physiological anomalies like sunburn and rust in fruits like apples and pears, fruit cracking due to rainfall during the ripening period in fruits like cherries and grapes (Børve, Meland & Stensvand, 2007) and occurrence of double fruit in cherries due to high temperatures in the summer (Beppu, & Kataoka, 2000). Netting achieves an alteration of the microclimate of the orchard, which results in fewer insect and pest diseases hence it minimizes the use of pesticides (Børve, & Stensvand, 2003). A reduction in temperature fluctuations, conservation of irrigation water, improved regulation of wind intensity, the adjustment of solar radiation reaching the tree crown, a reduction in pests and diseases, and, in general, tree vigor is achieved.

The aim of the present study was to evaluate the use of protective nets, such as anti-hail and anti-rain nets, applied in cherry orchards and quantify their effects on orchard microclimate, tree functionality and development, fruit production and quality.

2. Materials and Methods

2.1. Site description

For the purposes of the study, a commercial cherry orchard was selected located in the mountainous area of Troodos, specifically in Potamitissa (latitude: 34.900947, longitude: 32.997383) and at an altitude 900 m above sea level, from 2020-2022. The local climate, according to Köppen – Geiger classification, is Csa or Hot-summer Mediterranean with mild winters and hot dry summers. The soil is moderately stony, and the soil texture analysis indicated 20% sand, 35.75% silt, and 44.25% clay classifying it as clayey (fine). The temperature and precipitation conditions of the area are shown in Figure 1.

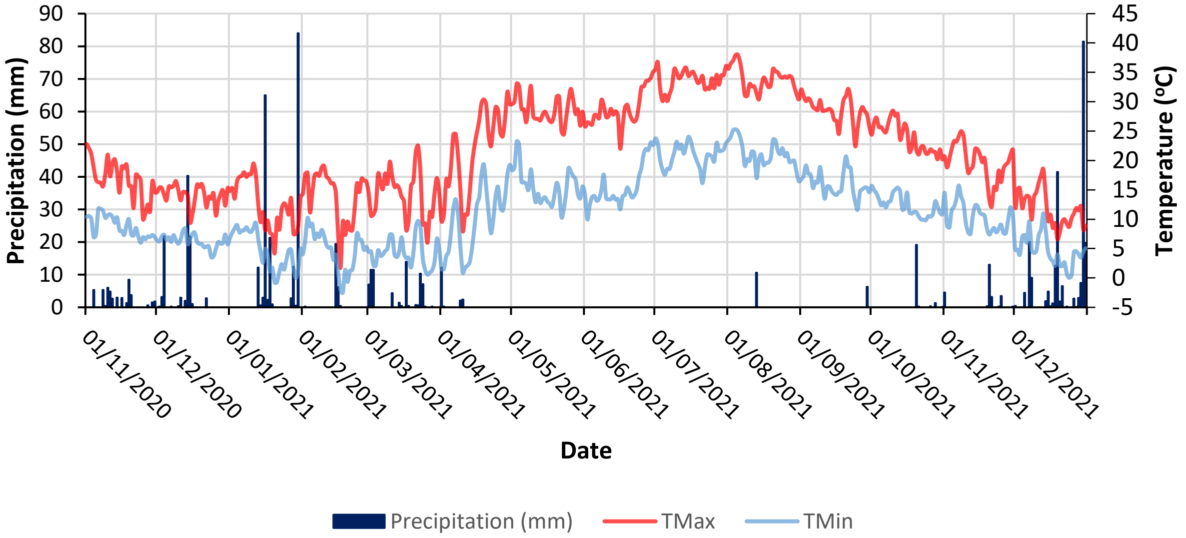

Figure 1 *Meteorological observations during the experimental period regarding precipitation (mm) and maximum and minimum air temperature (°C) from Agros meteorological station (Source: Department of Meteorology, Republic of Cyprus).*

2.2. Experimental design and treatments

The experiment was conducted in a five-year-old sweet cherry orchard consisting of trees of the cultivar SMS280 grafted on Gisela6 dwarfing rootstock, in a spindle training system, following 4x1 planting densities. The spacing between rows was equal to 4m, and the spacing between plants according to the training system was 1m.

Experiments were conducted in a completely randomized block design, with five replicates per treatment (two treatments; net: covered - without net: non-covered). Each replicate consisted of seven trees. The five central trees were used for monitoring and measuring vegetative growth and environmental parameters, while only the three central trees were used for measuring fruit morphological and qualitative parameters. The areas with non-covered and covered trees were in the same 400 m^2 of the selected orchard. Evaluations were carried out during the production/growing cycles of 2020/21 and 2021/2022. The same practices considering pruning, pest and disease management, drip irrigation and fertilization, were conducted for all treatments in accordance with the recommendations for SMS280 cultivar and the training system adopted.

The anti-hail net and anti-rain cover were applied to the orchard from 18/04/21 to November in 2021 and from 26/04/22 to 31/05/22 (end of the experiment) in 2022. The protective nets covered the three tree rows above the canopy (height approximately 4.5m from soil surface) and the anti-hail nets were extended lower to 2m above the soil surface at the margins of the two outer tree rows.

***Figure 2** The top of the tree canopy and the meteorological station installed under the protective nets at the commercial cherry orchard.*

2.3. Measured parameters

The analyzed variables were separated into vegetative, phenological, productive-qualitative and environmental components.

2.3.1. Vegetative and fruit growth

Vegetative growth was measured and expressed as canopy volume, trunk cross-sectional area and cumulate shoot and fruit growth, as well as number of leaves on annual vegetative growth. Canopy volume was calculated annually before pruning according to Hutchison (1978) based on canopy height and diameters (across and within rows) of the five central trees of each replicate. Trunk diameter (mm) of all trees was measured with a tape measure 15 cm above the grafting point at the end of the growing season. Thereafter trunk cross-sectional area (TCSA) was estimated as the circle area from the trunk diameter measured. Cumulate shoot, fruit and leaves growth was measured in a marked current season shoot per tree, 5 trees per replicate each week during vegetative growth with a tape measure (shoots and leaves) and a vernier caliper (fruits) in 2021 and 2022.

2.3.2. Phenological evaluation

Phenological observations of uncovered and covered trees, using appropriate descriptors, were determined by direct observations in the orchard (UPOV, 2006). The BBCH-scale (stone) identifies the phenological development stages of stone fruit, and it is a plant species-specific version of the BBCH-scale. For the phenological evaluation the growth stages shown in Table 1 and BBCH-identification keys of stone fruit were considered.

2.3.3. Orchard productivity, fruit qualitative – pomological characteristics

Regarding the productivity and fruit physical parameters the following were evaluated:

i. Total yield of the two treatments was measured at harvest time and expressed as: Yield efficiency = Yield per tree (Kg)/Diameter of trunk surface (TCSA in cm^2). For both treatments all yield per tree from 3 central trees per 5 replications was measured with an electronic scale immediately after harvest.
ii. Average fruit and stone diameters (mm); height (h), length (l), and width (w), were determined by a vernier caliper and subsequently,
iii. Fruit form index (FFI); shows the fruit shape and it was calculated from the 3 fruit diameters measured at (ii).
iv. Average fruit mass (g); Weight of fruit and stone were determined by a precision electronic weight scale, as simple diameter values are not adequate to describe fruit size.
v. Average petiole mass (g) and length (mm); were determined by a precision electronic weight scale and a vernier caliper respectively.
vi. Fruit skin color; determined by directly reading using chroma meter (and expressed in color of surfaces' values [L* (brightness/darkness), a* (redness/greenness), and b* (yellowness/blueness)].
vii. Fruit firmness (kg/0.5 cm^2); the force required to rupture the fruit exocarp was measured by a Penetrometer Microprocessor force gauge with a 0.5 cm^2 pressure seal.

***Table 1** Growth stages used for the phenological evaluation.*

Principal growth stage 5: Inflorescence emergence	
51	Inflorescence buds swelling: buds closed, light brown scales visible
53	Bud burst: scales separated; light green bud sections visible
54	Inflorescence enclosed by light green scales if such scales are formed (not all cultivars)
55	Single flower buds visible (still closed) borne on short stalks, green scales slightly open
56	Flower pedicel elongating; sepals closed; single flowers separating
57	Sepals open: petal tips visible; single flowers with white or pink petals (still closed)
59	Most flowers with petals forming a hollow ball
Principal growth stage 6: Flowering	

60	First flowers open
61	Beginning of flowering: about 10% of flowers open
62	About 20% of flowers open
63	About 30% of flowers open
64	About 40% of flowers open
65	Full flowering: at least 50% of flowers open, first petals falling
67	Flowers fading: majority of petals fallen
69	End of flowering: all petals fallen
Principal growth stage 7: Development of fruit	
71	Ovary growing; fruit fall after flowering
72	Green ovary surrounded by dying sepal crown, sepals beginning to fall
73	Second fruit fall
75	Fruit about half final size
76	Fruit about 60% of final size
77	Fruit about 70% of final size
78	Fruit about 80% of final size
79	Fruit about 90% of final size
Principal growth stage 8: Maturity of fruit and seed	
81	Beginning of fruit coloring
85	Coloring advanced
87	Fruit ripe for picking
89	Fruit ripe for consumption: fruit have typical taste and firmness

Furthermore, samples of 100 fruits/tree (from the three central trees in each of the five replications per treatment) were randomly collected and assessed for chemical, electrochemical and nutritional parameters. Cherry fruit juice (when necessary) for each sample was prepared using a juice extractor and juiced samples were filtered to obtain pure supernatant for evaluation in terms of:

viii. Total soluble solids (TSS) content (◦Brix); TSS were measured using a digital refractometer (Model: TCR 15-30, Index Instruments U.S., Inc.) and expressed in ◦Brix at 20^{o}C. Each sample was made from 100 randomly selected cherry fruits of the same tree. Cherry fruit juice for each cultivar was prepared using a juice extractor and juice samples were filtered to obtain pure supernatant for TSS.
ix. Titratable Acidity (TA), (% malic acid); Total titratable acidity content was measured using an automatic titrator. The juice supernatant sample was titrated to an endpoint of pH 8.1 using 0.1N NaOH.
x. Ripening index; calculated as the ratio of TSS/TA.
xi. Juice acidity (pH) (0-14 scale); was measured using a benchtop pH meter.
xii. Juice coloration (McGuire, 1992), determined by direct reading using chroma meter (and expressed in color of juice values [L* (brightness/darkness), a* (redness/greenness), and b* (yellowness/blueness].
xiii. Ascorbic acid (AsA) expressed as mg/100 ml; measurements were made with the reflectometer set of Merck Co. (Merck RQflex).
xiv. Dry matter of fruit (gr/ d.w.); It was measured by drying 5 g of cherries (without pits) per sample at 104^{o}C for 24 h (until constant weight) according to Muskovics et. al, (2006). Dry matter was expressed as the difference of fruit weight before and after drying.

xv. Juice index (ml/gr); samples of 100 randomly selected cherries were processed with a juice extractor, and thereafter juice index per treatment was estimated by dividing juice volume with fruit weight.

2.3.4. External fruit disorders/damages

Regarding the external fruit disorders/damages the following were evaluated:

i. Fruit cracking (percentage of cracked fruit after 4 and 6 h) and Cracking index; With the aim of assessing if protective net treatment can affect fruit susceptibility to crack, cracking index was measured from the fruits harvested in growing cycles 2020-2022. Following a modified procedure as described by Christensen (1972), 20 fruits per replicate, (five replicates per treatment), were immersed in 2 L distilled water (pH 7) at 20 °C. Cracks presence on the fruit was evaluated after 2, 4 and 6 h.
ii. Double fruits (%); presence of double fruits on a percentage basis on a sample of 100 fruits.
iii. Bird damage (%); occurrence of fruits with bird damage on a percentage basis on a sample of 100 fruits.
iv. Hail damage (%); occurrence of fruits with hail damage on a percentage basis on a sample of 100 fruits.

2.3.5. Microclimate and canopy temperature monitoring

Two identical meteorological stations were installed in the two orchard compartments, the non- covered and the covered parts. Each meteorological station was equipped with a pyranometer to quantify solar (shortwave) radiation, an anemometer to quantify wind speed and direction and sensors for quantifying air temperature and humidity. The data were collected per hour by data loggers and uploaded to an online database. The FAO Penman-Monteith equation was then utilized to calculate using Microsoft Excel, based on the above-mentioned weather variables, the reference evapotranspiration per hour for the two orchard compartments separately.

The photosynthetic active radiation (PAR) was quantified as photosynthetic photon flux density (μmol PAR $m^{-2}s^{-1}$) at noon during a cloudless day in July 2021 for both treatments using a Quantum meter (Apogee Instruments). PAR was measured on the top of the canopy under covered and non-covered conditions and on the orchard floor in five positions from the tree trunk (or tree row) towards the row middles (i.e., between the tree rows). The percentage of the light transmitted through the orchard canopy was then calculated by dividing the orchard floor values with the ones measured on the top of the canopy and then multiplying by 100.

For measuring leaf temperatures, all thermal (i.e., infrared, IR) and RGB images were obtained with a thermal camera (TiR1, FLUKE®). Leaf emissivity was set at 0.95 (Jones, 2004). Images of sunlit and shaded leaves at a height between 1.5 and 2m from the soil surface in both treatments were captured around noon during five cloudless days of the first experimental period (2021) from May to June after harvest.

The temperature of the selected leaves was quantified using FLUKE CONNECT^{TM} software by identifying the leaf surface using the RGB images and then selecting the leaf area on the IR image.

2.3.6. Statistical analysis

Statistical analysis was carried out using SPSS v.20 and Microsoft excel. Specifically, descriptive statistics and one-way analysis of variance or T-tests were performed to determine whether there were statistically significant differences between treatments, after first, checking whether the ANOVA assumptions (normality, heterogeneity of variances) were satisfied.

3. Results and Discussion

3.1. Orchard microclimate

Protective nets, as every object placed between the crop and the atmosphere, is expected to change the local orchard microclimate (Szabó et al., 2021). The level of change, however, depends on the object properties, the environmental conditions, and other factors shaping the microclimate of the area (Lulane et al., 2022).

3.1.1. Micrometeorological parameters & reference evapotranspiration

The two meteorological stations placed in the covered and non-covered area of the orchard did not display significant differences in any meteorological variable in March, before the nets were applied (Fig 2-3). The nets deployment in April yielded significant reduction in solar radiation (Fig 2a, f) and wind speed (Fig 2d, i) but no differences on mean air temperature (Fig 2b, g) and air vapor pressure deficit (Fig 2c, h) were observed during both the experimental periods irrespective the differences observed in the local microclimate between 2021 and 2022. The reduction in incident solar radiation was expected due to the significant shading effect, especially of the anti-rain cover applied on the top of the canopy, as observed in previous studies (Mupambi et al., 2018), while wind speed reduction was expected mainly due to the site coverage of the orchard (Mupambi et al., 2018), (above 2m from the soil surface) by the anti-hail net. No differences in air temperature and humidity can possibly be attributed to the substantial air exchange between the covered orchard and the surrounding environment.

The reduction primarily in solar radiation and secondly in wind speed resulted in a significant reduction in the calculated reference evapotranspiration both in 2021 (Fig 2e) and 2022 (Fig 2j). The previously mentioned potentially indicates that orchard water loss is largely reduced when protective nets are applied in agreement with previous studies (Bastias and Boini, 2022). However, the level of reduction depends on tree-related properties potential influencing orchard evapotranspiration and the protective nets properties.

Even though the deployment of protective nets did not yield significant differences in diel minimum (Fig 3a, d) and maximum air temperatures (Fig 3b, e), statistically significant differences were observed in 2021 concerning the difference between maximum and minimum diel air temperatures (Fig 3c). The minimum temperatures were slightly higher and the maximum temperatures slightly lower under protective nets resulting at smaller maximum-minimum difference under covered than non-covered conditions. The latter indicates that depending on the ambient environmental conditions, the presence of protective nets may reduce the diel air temperature fluctuation within the orchard.

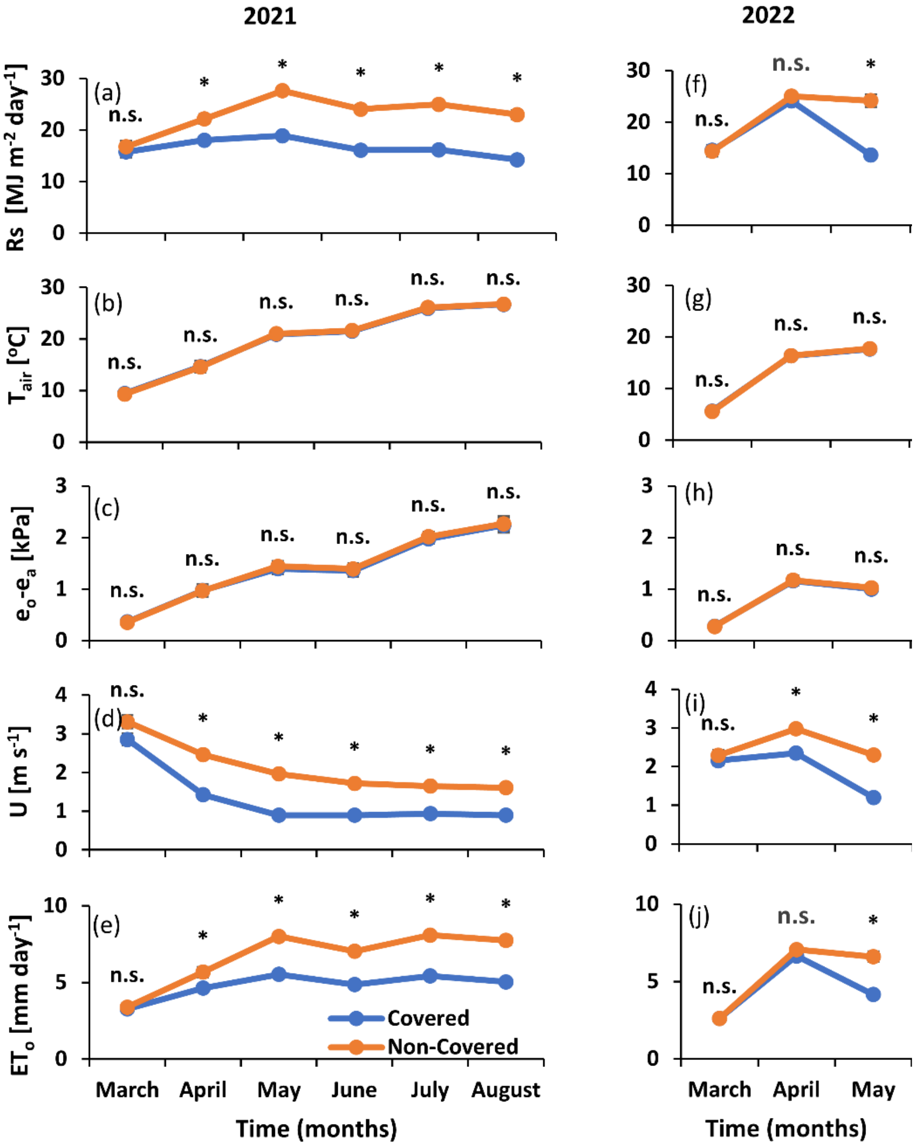

Figure 3 *Diel shortwave radiation (R_S), mean deal air temperature (T_{air}), vapor pressure deficit (e_o-e_a), wind speed (U) and reference evapotranspiration per day (ET_o) during the first uear (2021) and second year (2022) of experimentation under covered (blue) and non-covered conditions (orange). Star (*) indicates statistically significant differences ($P \leq 0.05$) between the treatments and n.s. indicates no statistical significance. The nets were applied from 18/04/21 and 27/04/2022 onwards for 2021 and 2022 respectively.*

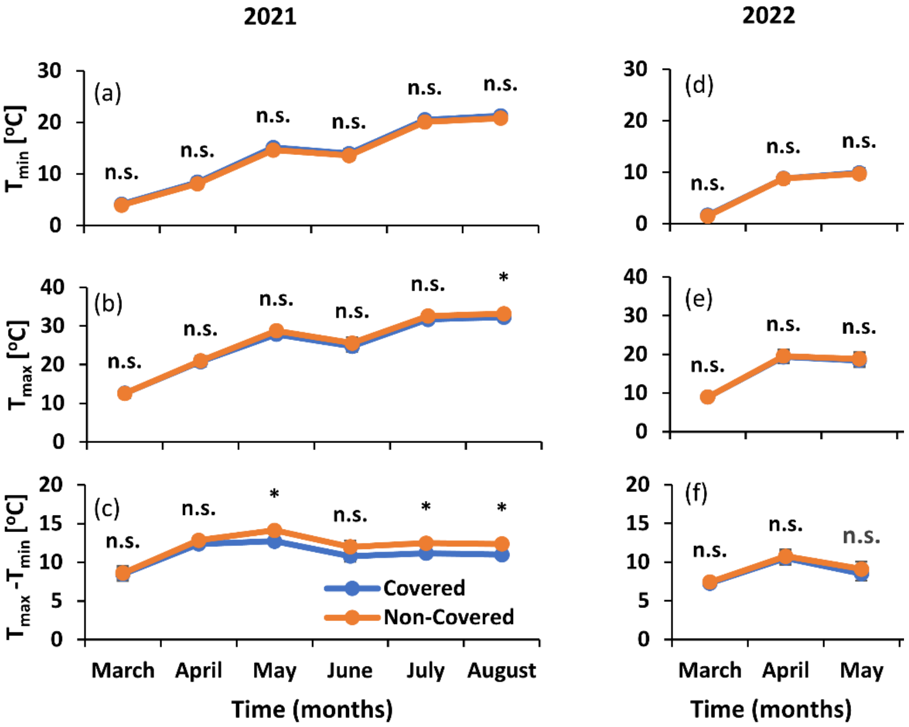

Figure 4 *Diel minimum (mean) temperature (*T_{min}*), diel maximum (mean) temperature (*T_{max}*), and the mean diel difference between maximum and minimum temperature (*$T_{max} – T_{min}$*) for the two experimental periods in 2021 and 2022 respectively under covered (blue) and non-covered conditions (orange). Star (*) indicates statistically significant differences (*$P \leq 0.05$*) between the treatments and n.s. indicates no statistical significance. The nets were applied from 18/04/21 and 27/04/2022 onwards for 2021 and 2022 respectively.*

3.1.2. Photosynthetically active radiation: levels and distribution

Photosynthetically active radiation (PAR) is driving leaf photosynthesis and thus growth (Roper et al., 1988). The application of the anti-hail and anti-rain nets resulted in more than 30% reduction for the incident-to-the upper canopy PAR in July 2021 (Fig. 4a). Concerning the incident PAR on the orchard floor, it showed significantly higher values when measured close to the tree row middles (i.e., between the tree rows) in the non-covered part than the covered part of the orchard and significantly lower values when moving towards the trees' trunks (Fig. 4a). The above mentioned resulted in significantly higher light transmission through the tree canopies in the non-covered part than the covered part of the orchard closer to the row middles and significantly lower light transmission as moving closer to the trees' trunks (Fig. 4b). The protective nets applied are significantly reducing the levels of PAR incident to the tree canopy but, on the other hand, they are contributing to a more homogeneous light distribution within the canopy possibly due to the increased light diffusion (Murambi et al., 2018).

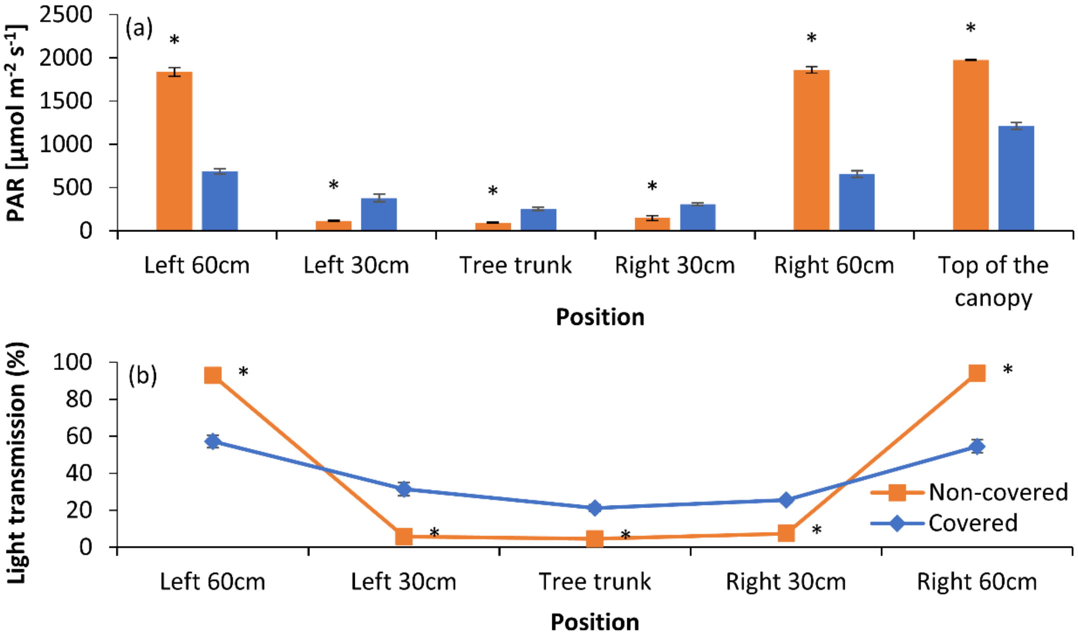

Figure 5. *(a) The photosynthetically active radiation (PAR) measured on the top of the canopy and on the orchard floor in five positions from the tree trunk (or tree row) towards the row middles (i.e., between the tree rows) in the covered (blue) and non-covered (orange) part of the orchard during a cloudless day in July, 2021. (b) The light transmission (i.e., fraction of top canopy PAR penetrating towards the orchard floor) for the five positions in the covered (blue) and non-covered (orange) part of the orchard. Star (*) indicates statistically significant differences (P ≤ 0.05) between the treatments.*

3.1.3. Leaf temperatures

Leaf temperature highly influence leaf transpiration and photosynthesis but also other important metabolic processes within the leaf (Dusenge et al., 2019). It was expected that changes in the orchard microclimate and especially incident solar radiation, would greatly influence leaf temperature. Temperature measurements during cloudless days in the first experimental period (2021) indicated that the leaves exposed to direct sunlight (i.e., sunlit) under non-covered conditions are always significantly warmer (>2°C) than under covered conditions (Fig. 5a). On the other hand, shaded leaves did not show persistent significant differences between the two environments (Fig. 5b). Higher sunlit leaf temperatures indicate that other plant parts, such as light-exposed fruits and shoots, may also have higher temperatures under non-covered conditions. That may imply different developmental and metabolic rates as well as a higher possibility for physiological stress during excessive heat events.

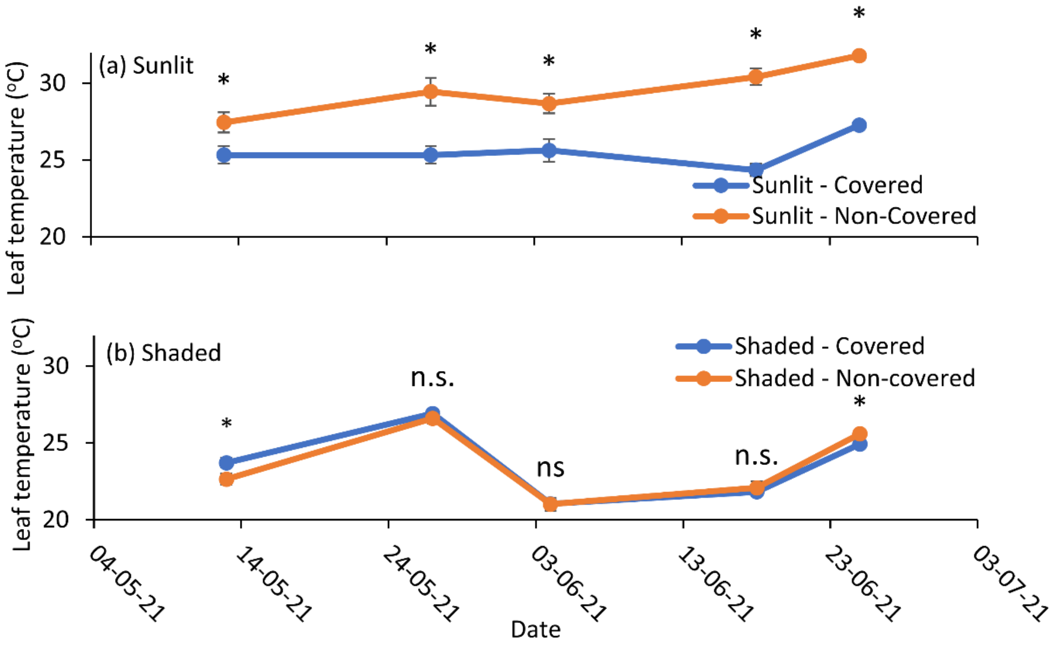

Figure 6. *(a) Sunlit leaf temperatures in the covered (blue) and non-covered (orange) part of the orchard during noon of clear sky days. (b) Shaded leaf temperatures in the covered (blue) and non-covered (orange) part of the orchard during noon of clear sky days. Star (*) indicates statistically significant differences (P ≤ 0.05) between the treatments.*

3.2. Vegetative and fruit growth

3.2.1. Canopy volume and Trunk cross-sectional area (TCSA)

Covering the trees did not have a significant effect on trunk diameter in either of the productive cycles evaluated (Table 2). TCSA and canopy volume obtained smaller values for non-covered in 2020/21 cycle, than covered trees. The same results were observed in the 2021/22 cycle. Overall, a 12.81% increase regarding canopy volume was recorded between the two growing cycles: (covered: 15.37%, non-covered: 10.05%). Also, a 30% increase regarding TCSA was recorded between the two growing cycles: (covered: 42.19%, non-covered: 23.12%). However, non-significant statistical difference was found between treatments and among years ($P \leq 0.05$).

Table 2. *Canopy and TCSA for both treatments during the experimental period (average values).*

		2021		2022		2021-2022
		Mean	St. Dev.	Mean	St. Dev.	2021-2022 increase rate (%)
Truck Cross-Sectional Area (cm^2)	Non-covered	23.93	5.26	29.46	5.73	23.12
	Covered	25.74	4.26	36.6	5.86	42.19
	All	24.83	4.8	33.03	6.76	33
Canopy volume (m^3)	Non-covered	10.25	2.47	11.28	3.22	10.05
	Covered	11.02	4.06	12.72	3.9	15.37
	All	10.64	3.33	12	3.59	12.81

3.2.2. Shoot, number of leaves, and fruit growth

Measurements regarding shoot growth and the number of leaves in time were performed as described in materials and methods section (see paragraph 2.3.1) for both the growing cycles of the experiment (Fig. 7a-d). During the first (2020/2021) growing season a higher accumulated shoot growth and number of leaves for non-covered in relation to covered trees was recorded (Fig. 7a, c). The same pattern was not repeated during the second (2021/2022) growing season (Fig. 7b, d). The differences observed during the first growing period cannot be attributed to mean diel air temperature as no significant differences were recorded between the covered and non-covered concerning mean diel air temperature (Fig. 3b). However, significantly larger T_{max}-T_{min} was observed during May 2021 under non-covered in relation to covered conditions (Fig. 4c). Differences in temperature between day and night as well as day solely or night temperatures may influence shoot growth (Smeets, 1957).

Field measurements were performed on selected fruits in the orchard (see paragraph 2.3.1) in combination with fruit development (principal growth stage 7) phenological observations. Higher average fruit growth was recorded for covered than non-covered trees during the first growing season (Fig. 8a). The same pattern was observed during the second growing season; however, the difference between the treatments diminished prior harvest (Fig. 8b). This is in accordance with the non-significant differences observed in fruit dimensions and fruit weight (see paragraph 3.4).

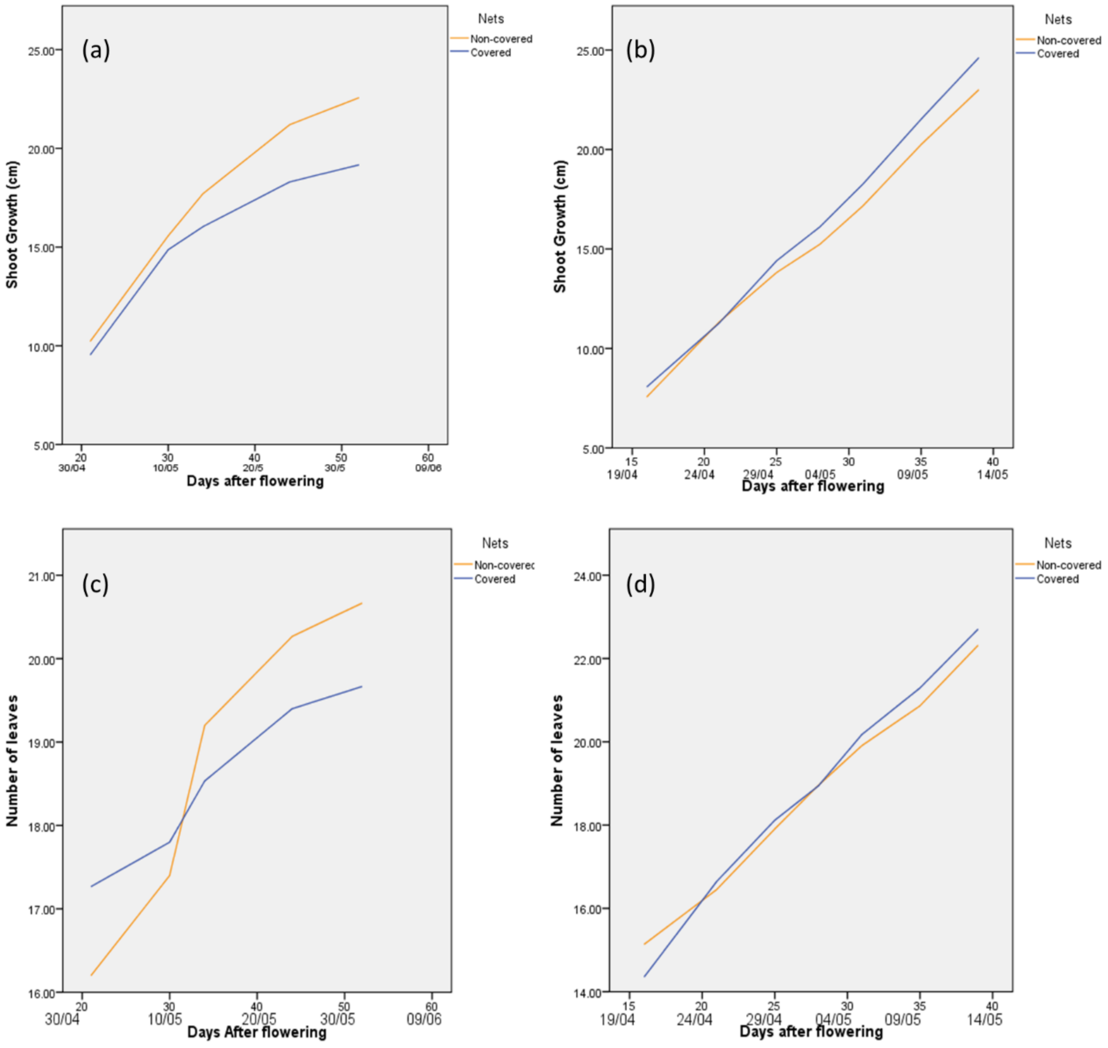

Figure 7. *Average shoot growth for covered and uncovered trees; (a)2020/2021 growing cycle and (b) 2021/2022 growing cycle. Average number of leaves for covered and uncovered trees; (c) 2020/2021 growing cycle and (d) 2021/2022 growing cycle.*

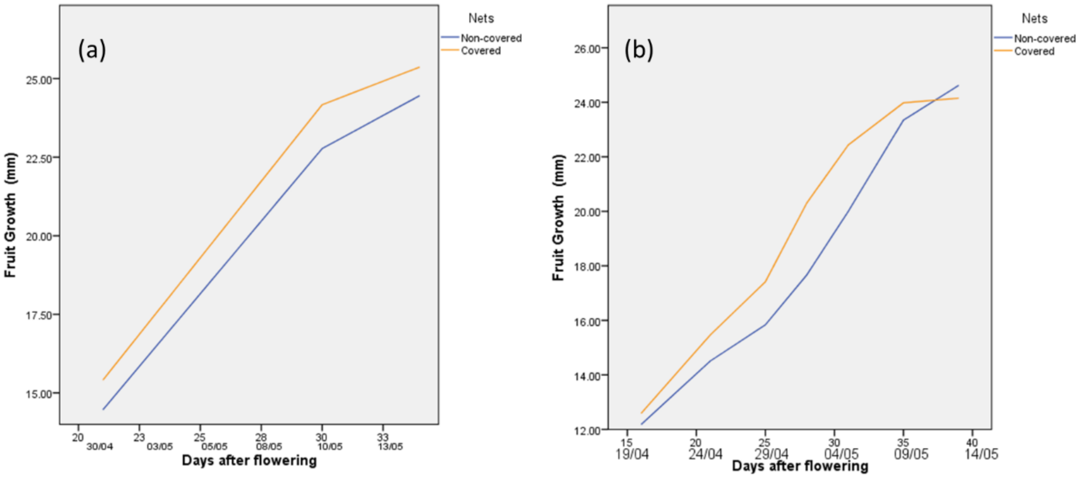

Figure 8. *Average fruit growth for covered and uncovered trees; (a)2020/2021 growing cycle and (b) 2021/2022 growing cycle.*

3.3. Phenological profile

Concerning phenology, no differences were observed between the covered and non-covered trees during both growing seasons. Distinct differences were obtained between the different growth stages and growing seasons (Fig. 9) resulting in shorter (by 8 days) duration between the inflorescence emergence and harvest during the first growing season in relation to the second growing season (Table 4). The shorter duration is possibly related to the highest air temperatures recorded during the period in 2021 (18°C) in relation to 2022 (16.7°C). The air temperature was substantially higher during the fruit development stage in 2021 (22°C) than in 2022 (17.08°C).

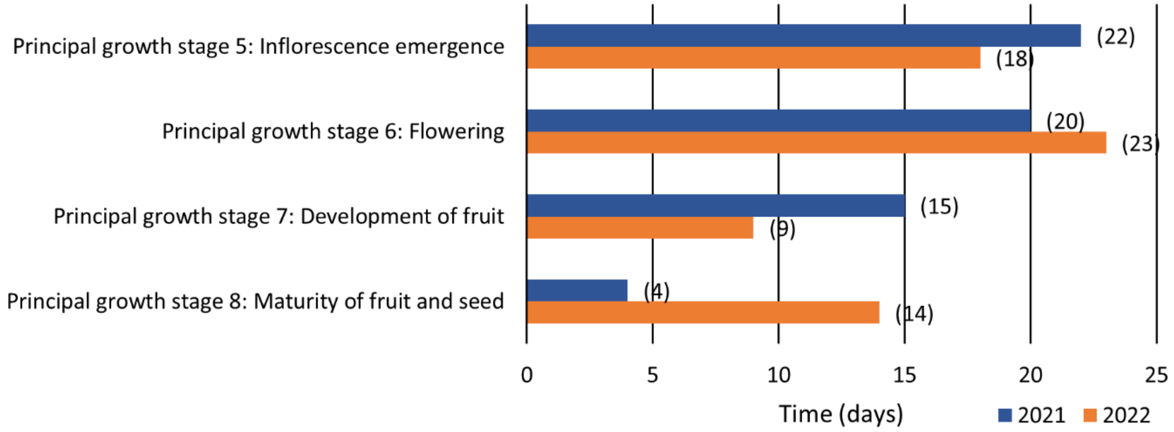

Figure 9. *Duration of phenological stages; Inflorescence emergence, flowering period, fruit development and maturity of fruit and seed for covered and non-covered trees in cherry cultivar SMS280 in the productive cycles of 2020/21 (blue) and 2021/22 (orange). The number in parenthesis is the total number of days for each stage.*

Particularly, inflorescence emergence and flowering stage where the longest stages when compared to fruit development and maturity of fruit and seed (Fig. 9), Inflorescence emergence and fruit development stages were longer while flowering and maturity of fruit and seed stages were shorter during the first in comparison to the second growing season respectively.

Table 3. *The total cycle (days) from the beginning of the flowering stage until harvest day or the two growing seasons.*

Total Cycle (days): Beginning of flowering until harvest day	Date started	Date finished	duration	DOY started	DOY finished
2020/2021	08/04/2021	17/05/2021	40	97	136
2021/2022	04/04/2022	21/05/2022	48	93	140

3.4. Orchard productivity, fruit qualitative/pomological characteristics

Orchard productivity, fruit qualitative and pomological characteristics analysis was conducted at the end of both growing cycles. However, due to significantly low yield in 2020/2021 and the insufficient small samples obtained making the laboratory analysis non-representative, the results in this section refer only to the second cultivation period (2021/2022).

Total yield expressed as yield efficiency (Kg/m^2) was significantly higher for covered in relation to non-covered threes (Fig. 11). An increase of 58.40 % in yield efficiency was recorded for the covered treatment indicating a substantial positive effect of protective nets on sweet cherry orchard productivity despite the large reduction in solar radiation observed under the protective nets in relation with the non-covered treatment (Fig. 3 and Fig. 5).

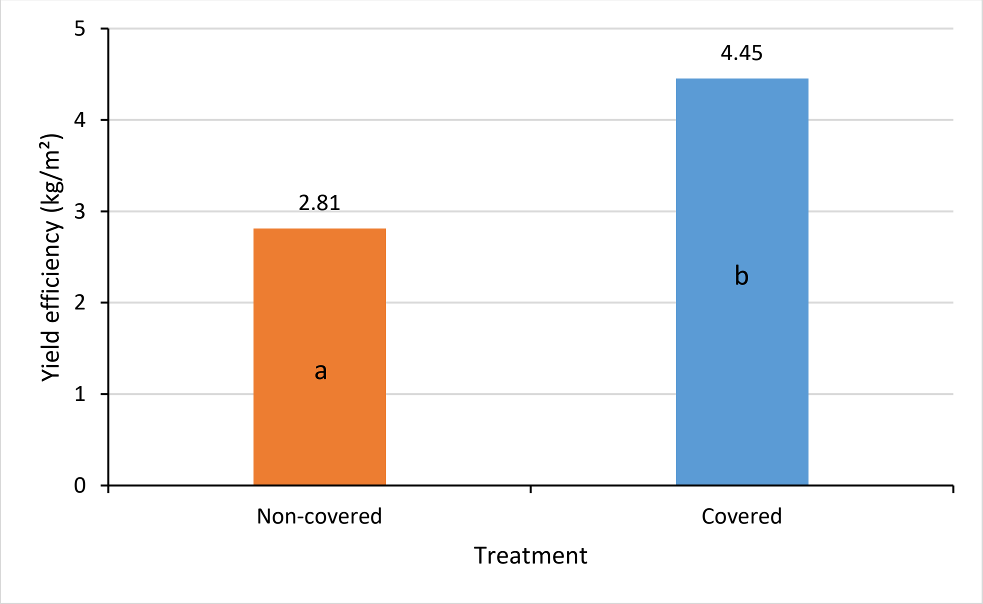

Figure 10. *Yield efficiency (Kg/m²) for covered and non-covered trees during 2021/2022 growing cycle. Different letters indicate significant statistical differences between the treatments (P ≤ 0.05).*

However, the increase in yield efficiency increase was possibly related to a higher number of fruits per m^2 and not so related to an increase in fruit weight (Fig. 12). No statistically significant differences occurred between the two treatments for the parameters mean fruit mass and mean petiole mass (Fig. 12).

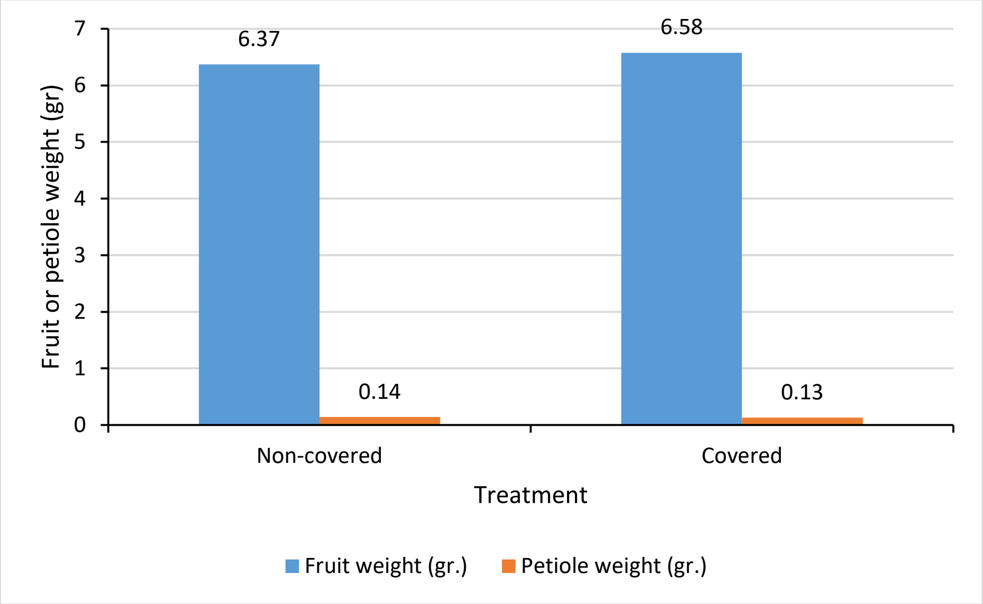

Figure 11. *Fruit and petiole weight of covered and non-covered trees during the 2021/2022 growing cycle.*

Concerning fruit dimensions, no statistical differences were observed between the treatments tested. On average, covered and non-covered trees showed 2.02 and 1.75mm in fruit height, 2.36 and 2.13 mm in fruit length, and 2.00 and 1.73mm fruit width, respectively. FFI index scored 0.84 for non-covered and 0.88 for covered trees.

Fruit firmness (Fig. 13) and all fruit skin color values measured for both treatments (Fig. 14) did not show significant differences between covered and non-covered trees.

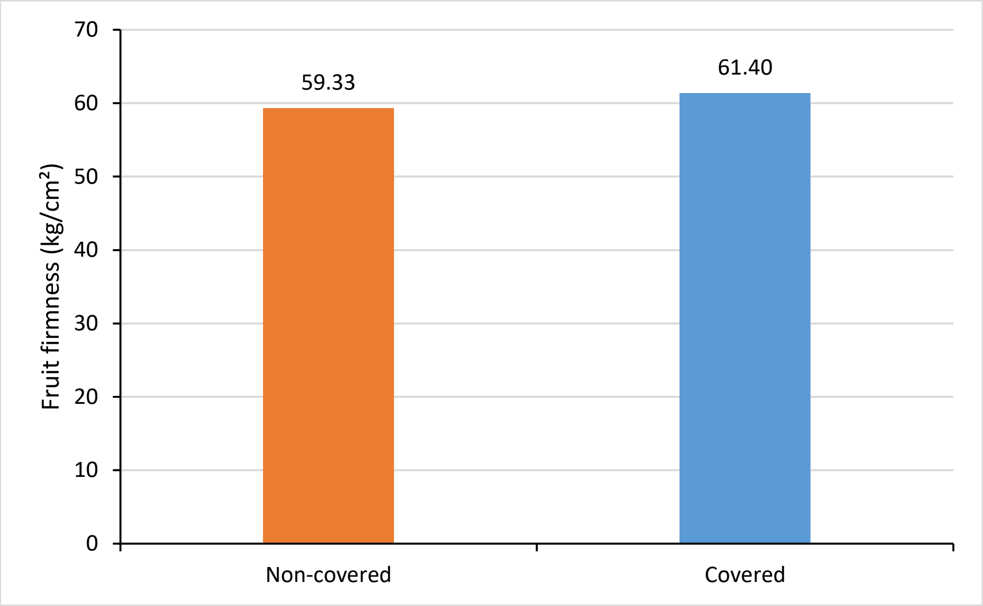

Figure 12. *Fruit firmness(kg/cm²) of covered and non-covered trees during the 2021/2022 growing cycle.*

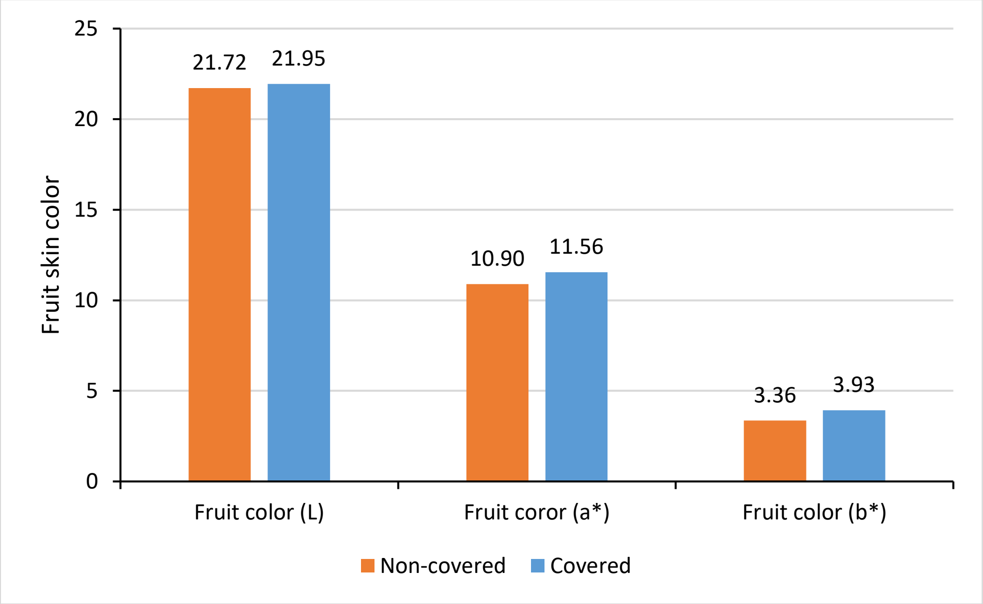

Figure 13. *Fruit skin color (average; L, a*, b*) ²) of covered and non-covered trees during the 2021/2022 growing cycle.*

No significant differences were observed concerning TA, TSS and the maturity index between the covered and non-covered trees (Fig. 15) indicating that protective nets did not cause a delay at ripening when fruits were harvested at the same time with the fruits from non-covered trees.

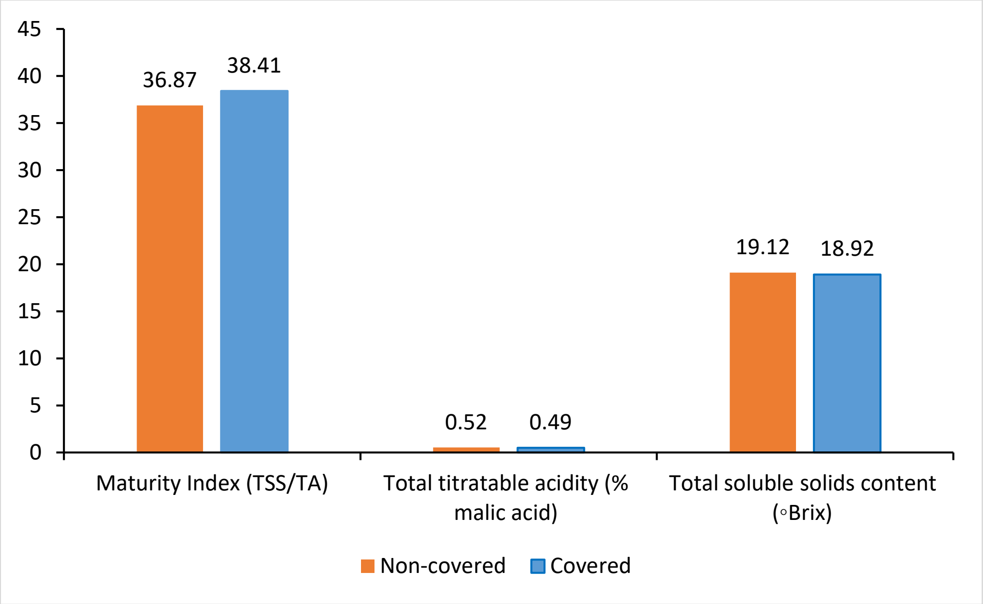

Figure 14. *Total soluble solids (TSS) content (◦Brix); Total titratable acidity (%malic acid), Ripening index for covered and non-covered trees during the 2021/2022 growing cycle.*

In relation to the calculated parameter "Juice acidity (pH) (mol/L)", the two treatments obtained similar values.

A statistically significant difference was recorded for juice color parameter L between the two treatments for the crop year 2021/2022 (Table 4), while the parameters ascorbic acid content, dry matter and fruit juiciness did not significantly differ between the treatments (Table 5). However, an increase of 16.7 % in juice volume for fruits obtained from covered trees and a decrease of 4.82 % in the corresponding treatment was recorded in terms of ascorbic acid content. Juice Index was similar in both treatments (0.59 ml/gr for covered, 0.60 ml/gr for non-covered).

Table 4. *Juice coloration (expressed in color of juice values [L* (brightness/darkness), a* (redness/greenness), and b* (yellowness/blueness] for covered and non-covered trees during the 2021/2022 growing cycle.*

Juice coloration	**Non-covered**	**Covered**
L	22.12 ±3.90*	19.10 ±1.52*
a*	23.15 ±1.81	24.22 ±1.89
b*	17.85 ±3.84	15.89 ±1.45

* Star indicates significant statistical difference between the treatments ($p \leq 0.05$).

Table 5. *Ascorbic acid, dry matter, and juice volume for covered and non-covered trees during the 2021/2022 growing cycle.*

Treatment	Ascorbic acid (mg/100 gr of juice)	Dry matter content (gr)	Juice volume (ml/100 fruits)
Non-covered	249.63	0.76	324.00
Covered	237.60	0.82	378.00

3.5. External disorders/damages

Even though hailing did not occur to measure the ability of nets to reduce hail damage, the presence of the protective nets greatly reduced the appearance of double fruits and bird damage on fruits (Fig. 16-17) and did not influence the appearance of fruit cracking (pericarp rupture).

More specifically, the protective nets reduced by 55% the appearance of double fruits (from 44 to 24%; Fig. 16) and by 46% the bird damage (from 6% to 3%; Fig. 17). Similar reductions were recorded in literature for double fruits appearance (Kuden et al., 2020) and birds damage (Simon, 2008). The results obtained for external disorders/damages reduction significantly add to the value of introducing protective nets in sweet cherry orchards.

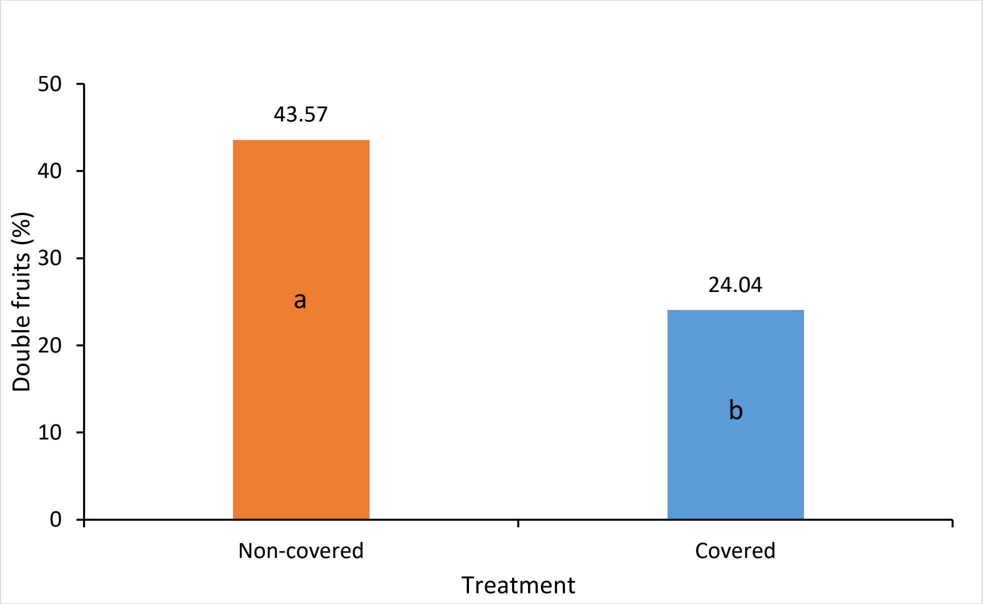

Figure 15. *Double fruits (%) occurrence for covered and non-covered trees during 2021/2022 growing cycle. Different letters indicate significant statistical differences between the treatments (p ≤ 0.05).*

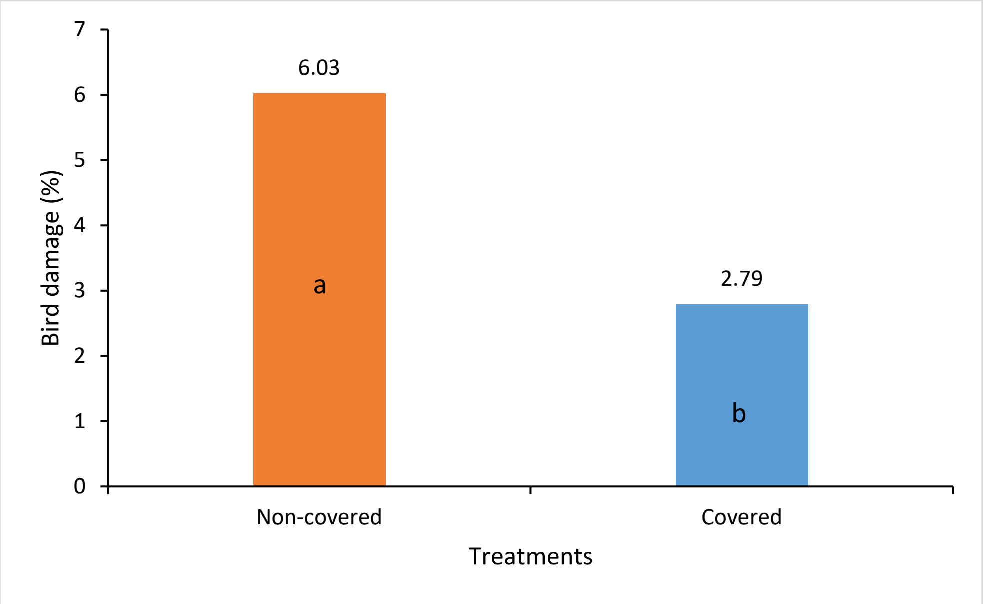

Figure 16. *Bird damage fruits (%) occurrence for covered and uncovered trees during 2021/2022 growing cycle. Different letters indicate significant statistical differences between the treatments (p ≤ 0.05).*

Conclusions

The two-year research on the application of protective nets in Troodos orchards resulted in distinct and important outcomes:

- The use of anti-rain and anti-hail protective nets substantially altered the orchard microclimate by:
    - Reducing the incident solar radiation but enhancing the homogeneous distribution of photosynthetically active radiation within the canopy.
    - Reducing wind speed.
    - Reducing the temperature difference between day and night may reduce the negative impacts of extreme weather events, such as heat waves.
- The reduction of incident solar radiation and, in a lesser degree, the reduction in wind speed resulted in reduced calculated reference evapotranspiration indicating reduced levels of water loss from the orchard to the atmosphere. The latter may reduce the needs for irrigation.
- Sunlit leaves showed lower temperatures during the day under protective nets in relation to the open orchard. Lower sunlit leaves temperature may contribute to lower leaf water loss and photosynthetic machinery damage avoidance due to extreme temperatures.
- No consistent effects of protective nets were observed in shoot growth and leaf number per shoot as well as on fruit growth.
- No effects of protective nets were observed on tree phenology from inflorescence emergence to fruit maturity.
- Product quality was not affected by the application of protective nets (e.g., firmness or ascorbic acid content except a lower brightness/darkness value in fruit juice coloration.
- Substantial positive effects of protective nets on fruit yield efficiency (Kg/m^2) as well as reduced external disorders and damages were recorded indicating that even when hailing does not occur, yield may be enhanced using protective nets.

The use of protective nets may contribute to sustainable fruit production, as a practice for better management of natural and synthetic resources to the advantage of both society and the environment. However, amongst numerous options available, the choice of the type of net and the method of its implementation should be made with great care, taking into consideration the particularities of each orchard (type of crop, location, topography, microclimate, cropping pattern, etc.) and the objective set and/or the issue to be addressed by each grower.

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