OS14-01

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Reduction of cover whitewashing of Mediterranean solar greenhouses using soil mulching with white marble gravel and the increase in the natural ventilation surface

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1. Introduction

The greenhouse area in the world has been estimated at 1.3 million hectares using satellite data combined with artificial intelligence techniques (Tong *et al*., 2024).

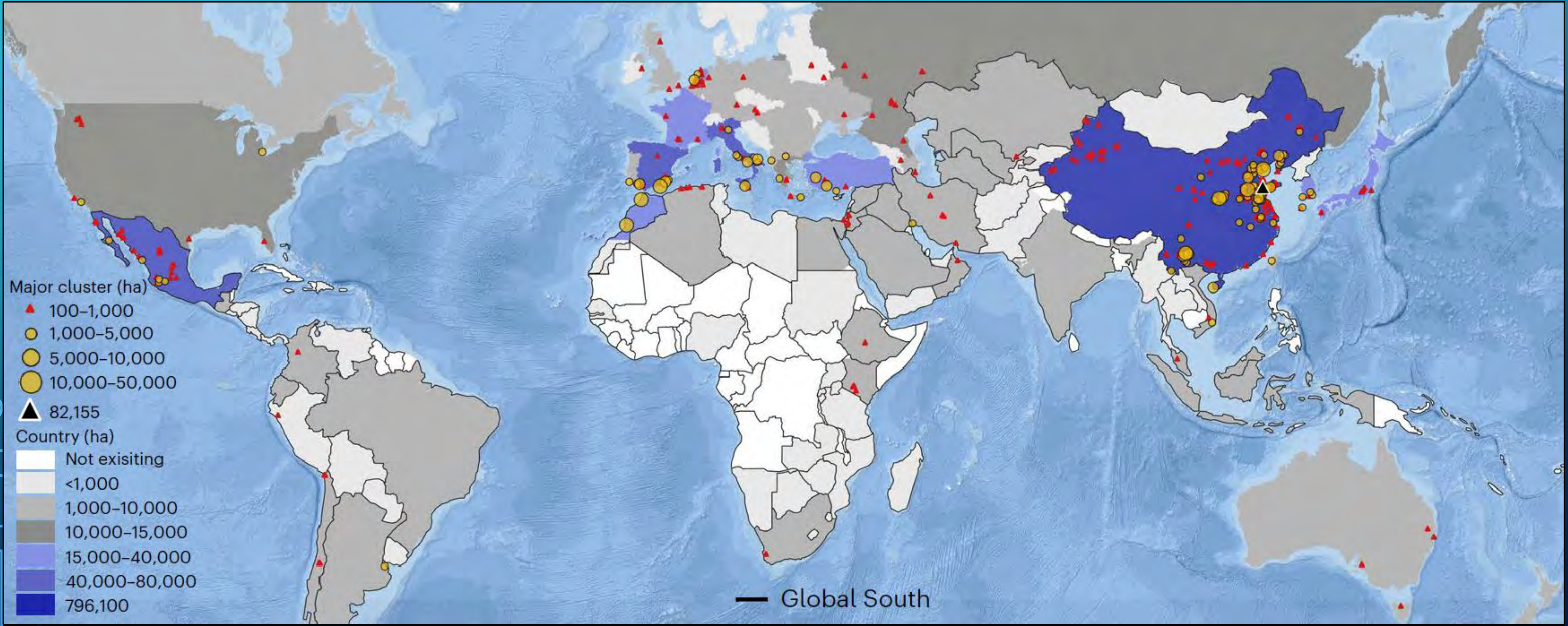

Figure 1. A global inventory of greenhouse cultivation (Tong *et al*., 2024).

The **second largest greenhouse cultivation region** identified in the world is **Almeria (Spain)**, after Weifang in China with 82 155 ha (Tong *et al*., 2024).

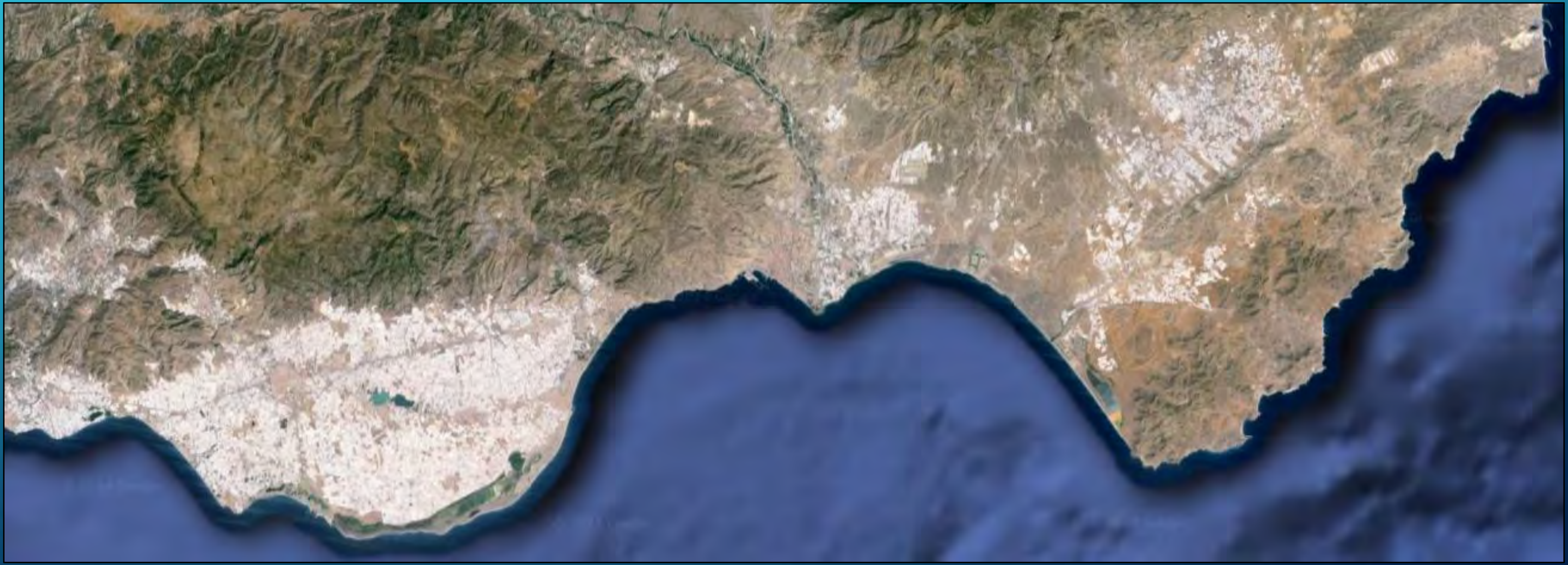

Figure 2. Images from NASA's Landsat 8 satellite showing the greenhouses in the province of Almería in Spain (Google Earht, 2024).

The area occupied by greenhouses in **Almería in 2023** has been determined as **33 634 ha** using SENTINEL 2 satellite images (JA, 2024).

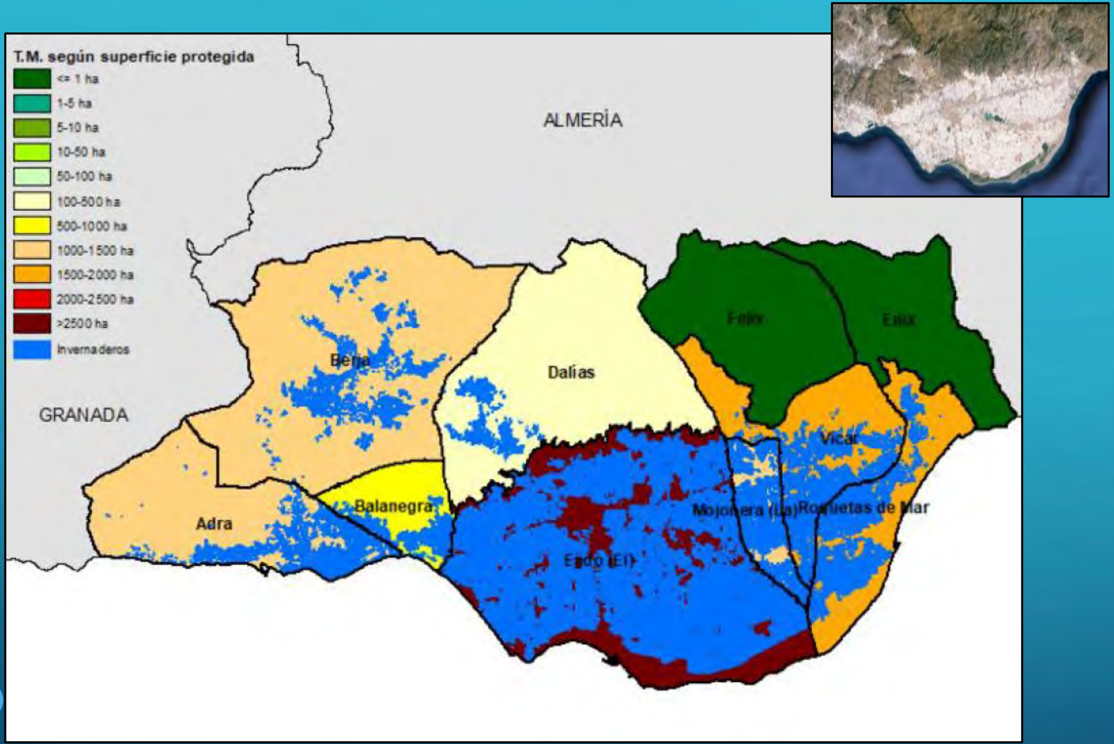

Figure 3. Distribution of protected surface and classification of municipal terms according to the surface detected in the ***Campo de Dalías*** region (JA, 2024).

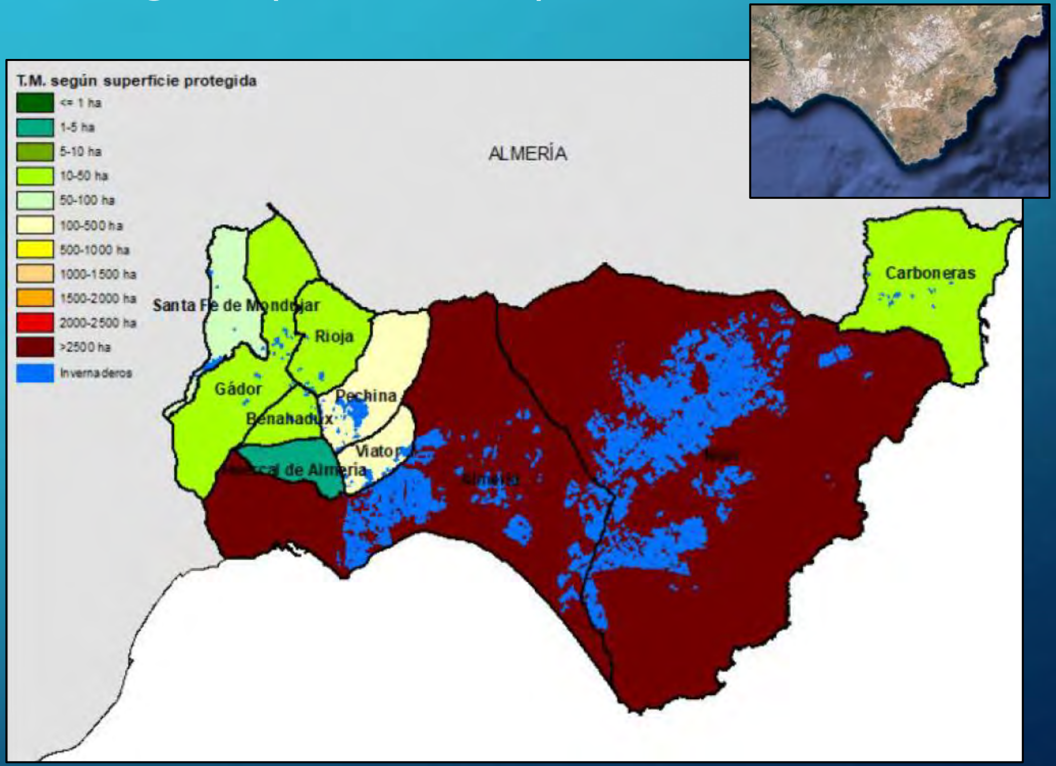

Figure 4. Distribution of protected surface and classification of municipal terms according to the surface detected in the region of ***Campo de Níjar*** and ***Bajo Andarax*** (JA, 2024).

Improving solar Greenhouses REsilience to CLIMate Change through digitization and optimization of light and ventilation (GRECLIM)

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Starting hypothesis

The combined use of **passive climate control techniques**, an **increase in photosynthetically active radiation (PAR)**, an **increase in CO_2** concentration, and a **reduction in temperature** inside greenhouses can be achieved **simultaneously**.

https://www.un.org/sustainabledevelopment/

Target 7.2. – **Increase use of renewable energy**

Efficient use of solar and wind energy in greenhouse climate control.

Target 12.2 – **Sustainable use of natural resources**

Target 12.5 – **Reduce waste generation**

Use of waste from marble production.

Target 13.1 – **Improve resilience to climate-change**

Protect vegetable crops from high temperatures.

Target 14.1 – **Reduce marine pollution**

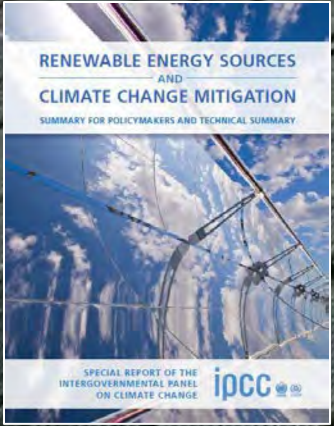
Reduce production of microplastic from mulch.

Target 7.2.

Increase global percentage of renewable energy.

Agriculture is the fundamental **pillar of the economy** of the province of Almería where solar greenhouses produced **3.5×10^6 t of vegetables** in the 2021/22 season with a value of **2 940 $\times10^6$ €** (CAJAMAR, 2022).

Almeria's solar greenhouses naturally ventilated are based on two **renewable energy sources**: solar energy and wind.



- **Wind** ➡ **Natural ventilation**
- **Solar** ➡ **Passive heating**
- Geothermal
- Hydroelectric
- Bioenergy
- Oceanic

TARGET 12·5

SUBSTANTIALLY REDUCE WASTE GENERATION

Target 12.5

Substantially reduce waste generation.

Reuse of waste from the marble industry in greenhouses

Marble extraction is the second economic pillar of the province of Almería.

Almería has over **6.6×10^3 ha of marble quarries** (Salinas *et al*., 2018).

In 2021, approximately **0.71×10^6 t** of marble was extracted in Almería, with a value of **12.1×10^6 €** (MTERD, 2023).

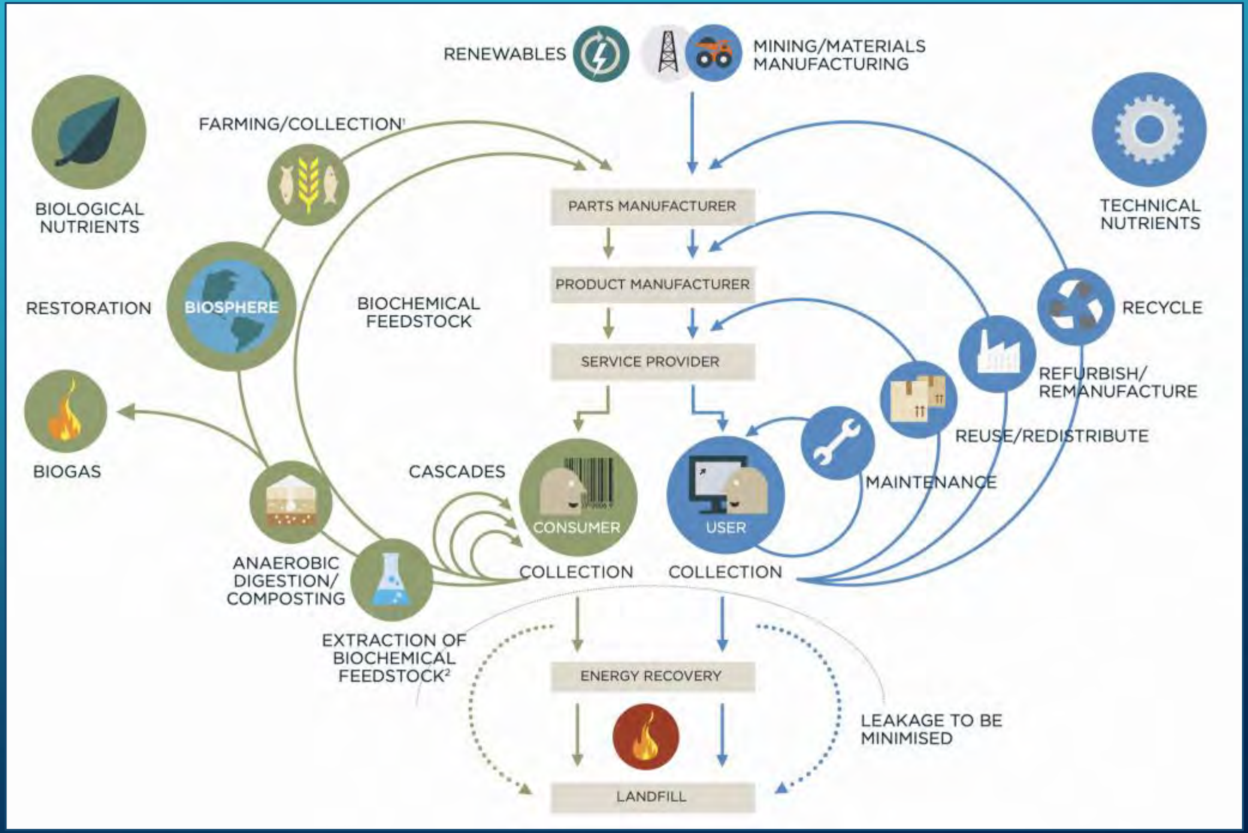
TARGET 12·2

SUSTAINABLE MANAGEMENT AND USE OF NATURAL RESOURCES

Target 12.2

Sustainable management and use of natural resources.

The **Circular Economy** is an economic system that **minimizes resource input** into and **waste out of the system** to mitigate negative environmental impacts (Geissdoerfer *et al*., 2018).



TARGET 13·1

STRENGTHEN RESILIENCE AND ADAPTIVE CAPACITY TO CLIMATE RELATED DISASTERS

Target 13.1.

Strengthen resilience and adaptive capacity to climate-change.

Protect vegetable crops from high temperatures.

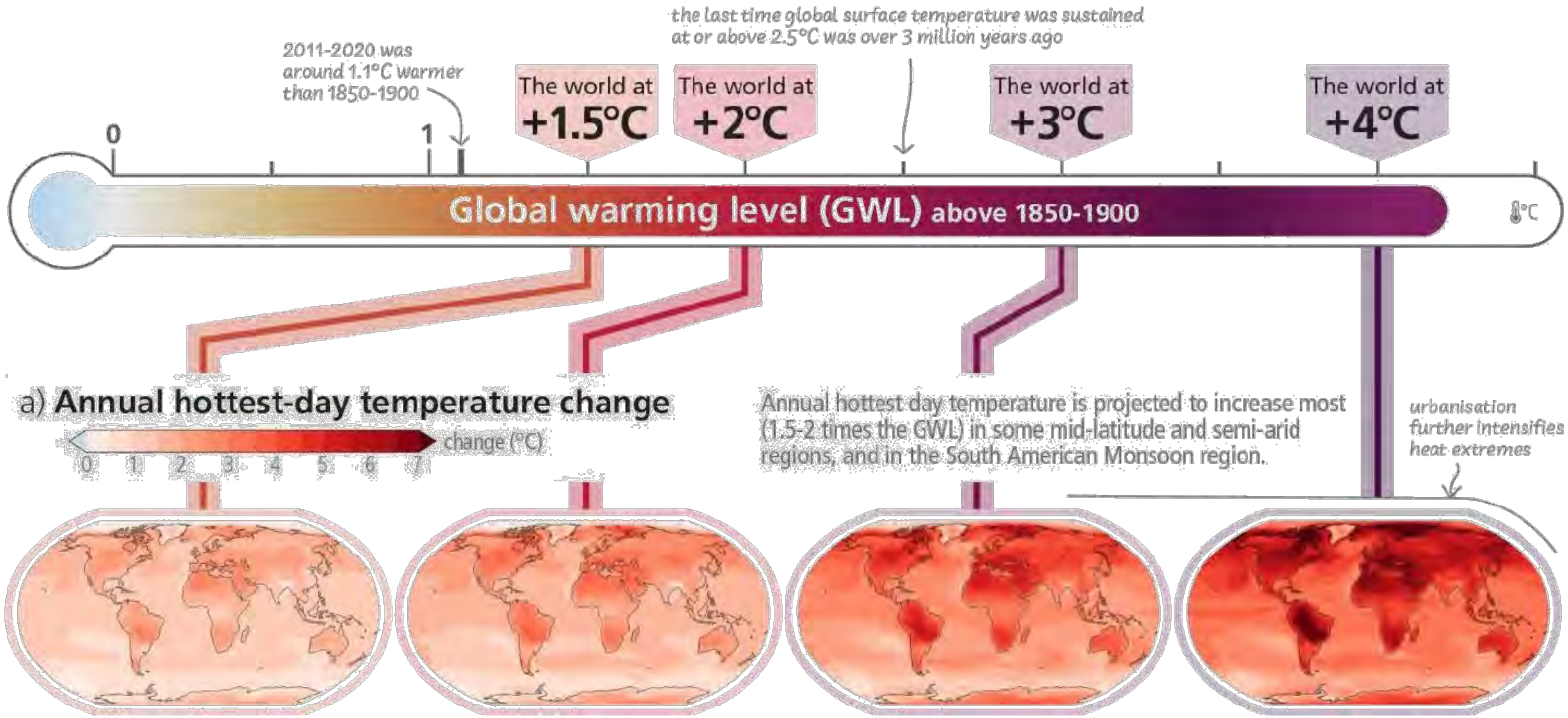


Figure 1. Projected changes in maximum daily maximum temperature at global warming levels of 1.5°C, 2°C, 3°C, and 4°C relative to 1850–1900 (IPCC, 2023).

Reduce inside temperature modifying the greenhouse energy balance

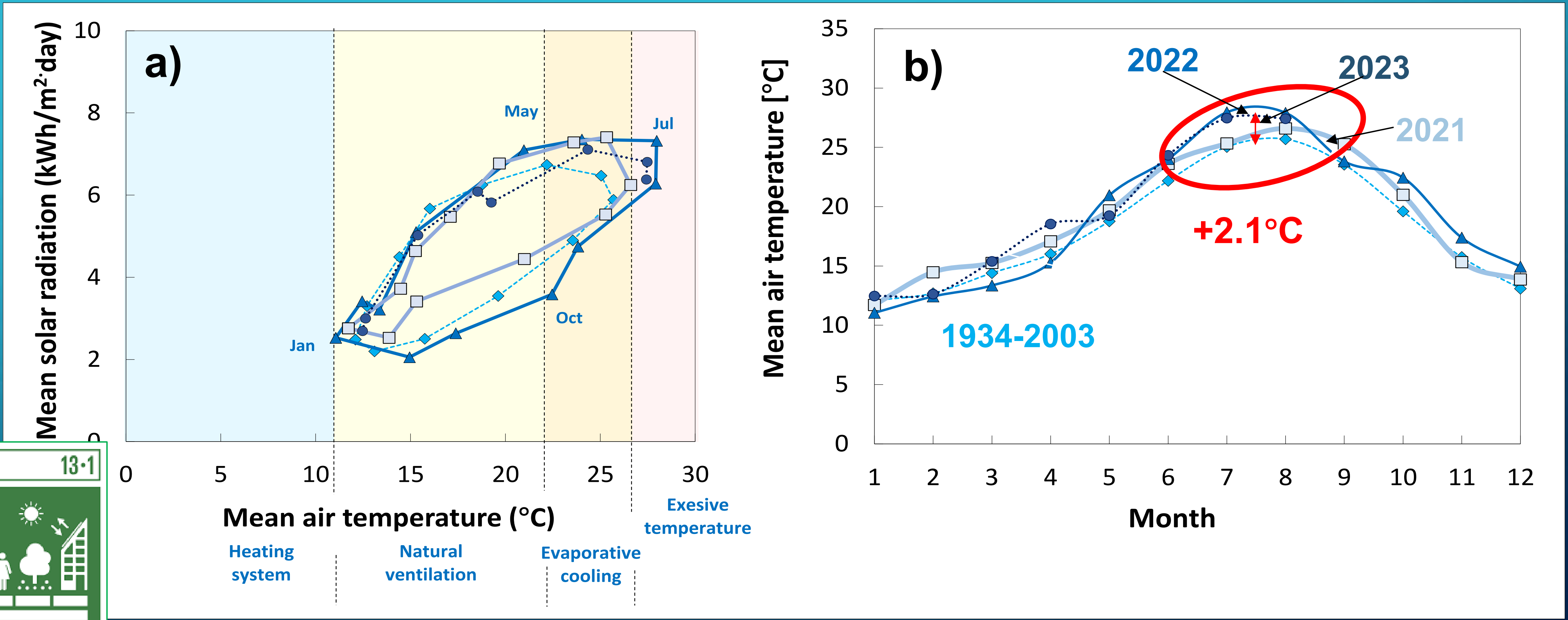
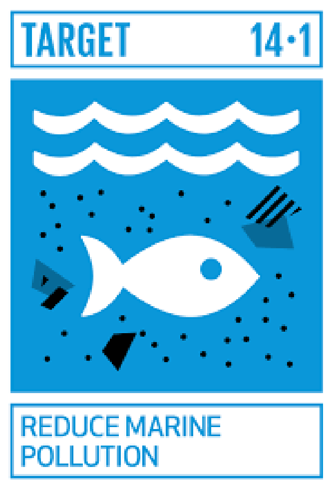


Figure 5. Average daily solar radiation relative to the average daily temperature (a) and evolution around the year of mean outside air temperature (b) corresponding to the cities of: Almería in Spain (---◆---) during the period 1934-2003 (Molina-Aiz, 2010), in 2021 (— □ —), in 2022 (—▲—) and in 2023 (···●···).



Target 14.1.

Prevent marine pollution from land-based activities.

Reduce production of microplastic form plastic mulch

Plastic film mulch can cause severe plastic pollution of the environment producing around **5000 particles/kg of microplastics** in 0–100 cm depth soil (Li *et al.*, 2022).

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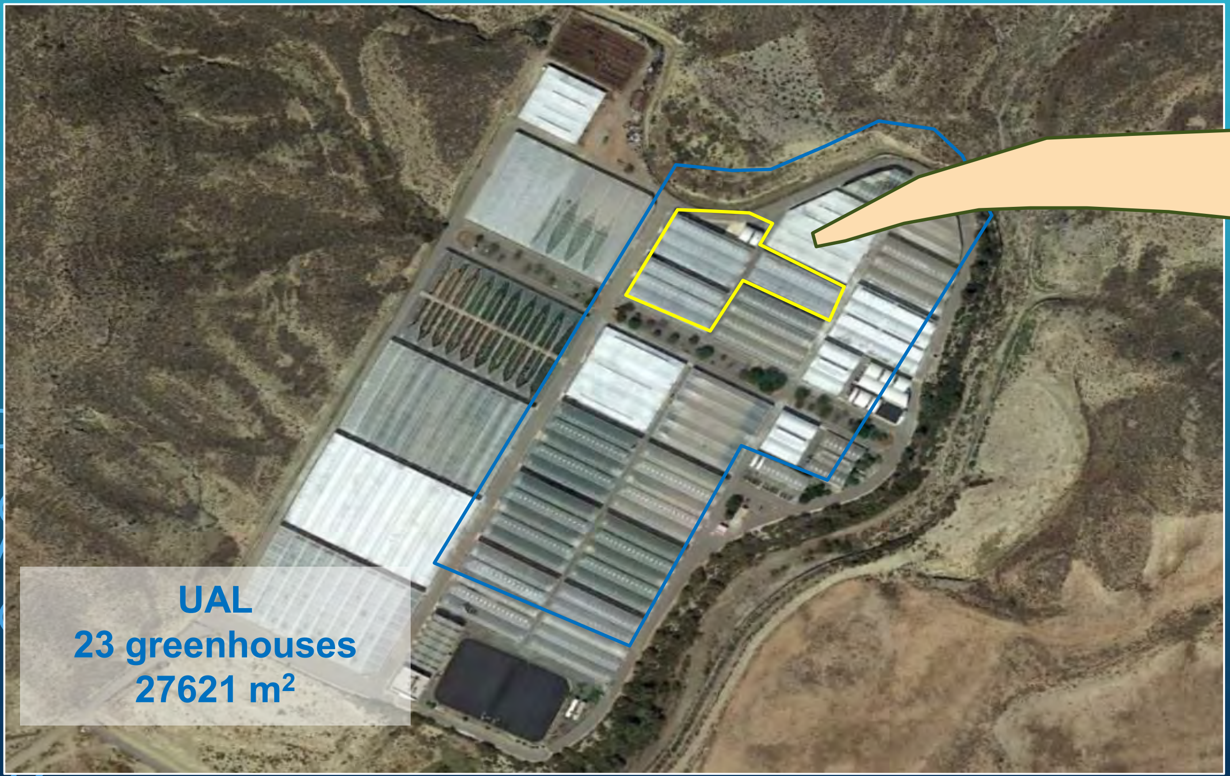
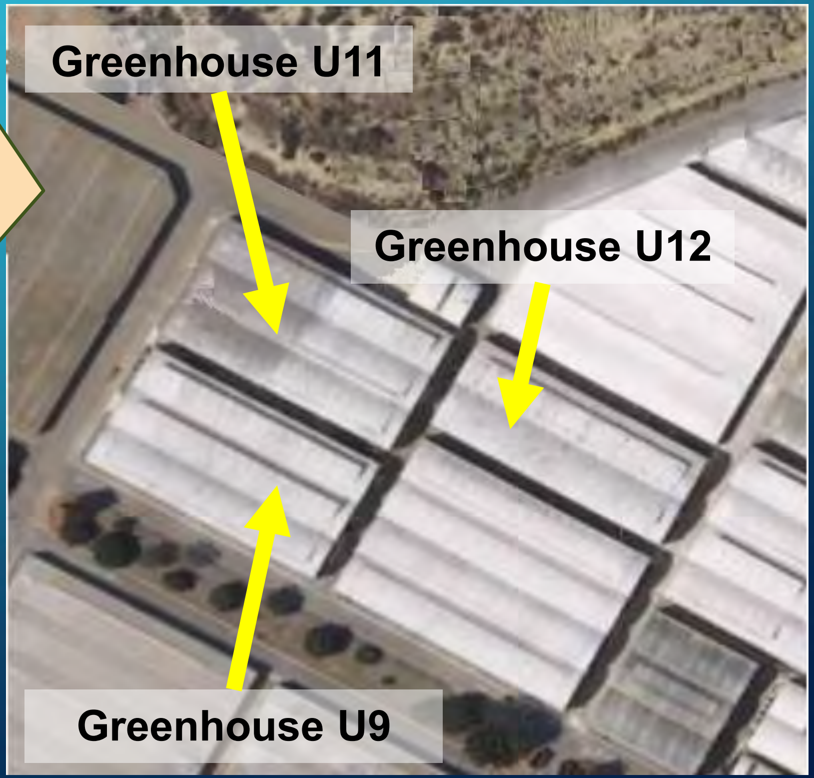
RINFOC - Objective

Analyze the effect of the **increase of the ventilation surface** combined with the use **of reflective soil mulching** and **reduction of cover whitewashing** in the **photosynthetic activity** and **production** of greenhouse crops.

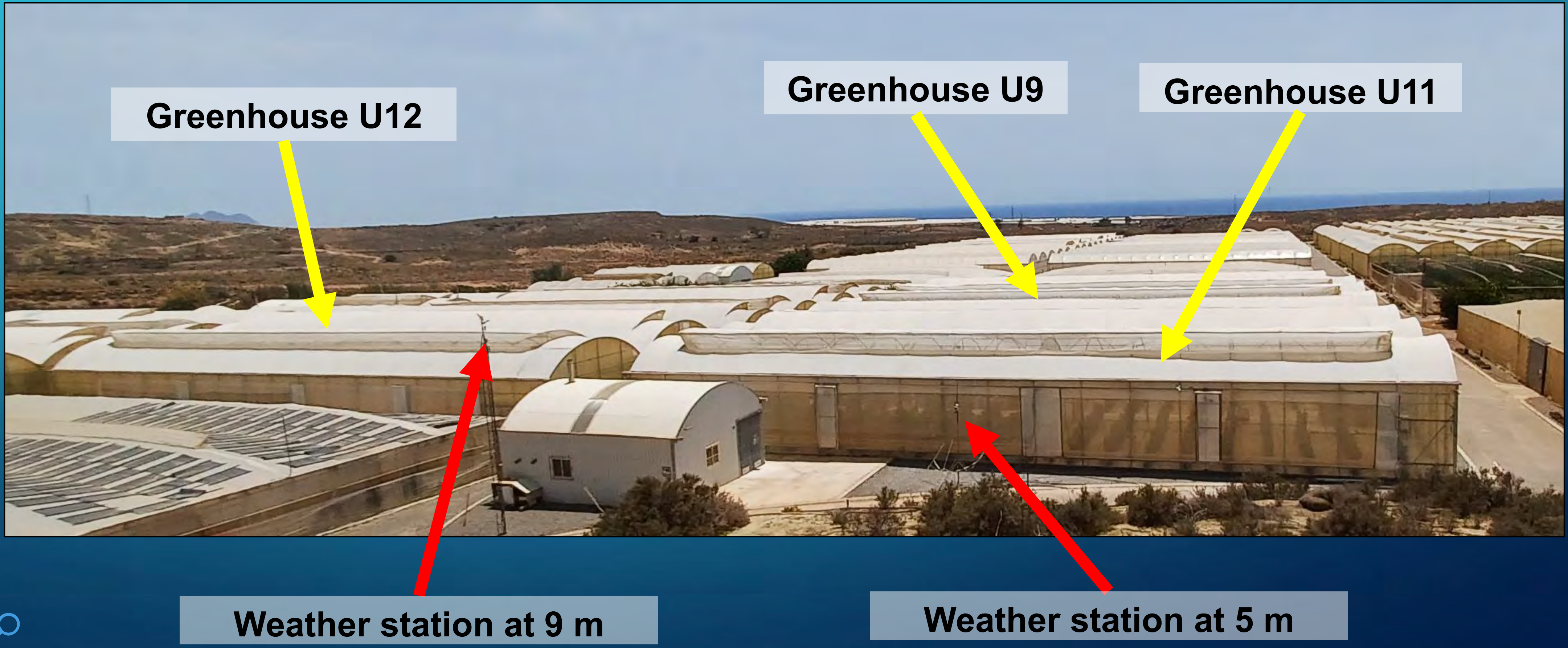
2. Materials and methods

Two crops were cultivated in three multispans greenhouses located in the "*Professor Eduardo Fernández*" Experimental Farm of the Center for Innovation and Technology (CIT) UAL-ANECOOP Foundation in Almería, Spain (Longitude: 2º 17' W, Latitude: 36º 51' N and Altitude: 90 m).





Outdoor climate data was measured at **two stations** adjacent to the three greenhouses.



Greenhouse surface ventilation

In the last years, the **side openings** were **enlarged from** the original **opening** height of **1 m** until **3 m height** to increase **ventilation capacity**.

Table 1. Characteristics of the two sectors into which the three experimental greenhouses were divided. Floor area covered by the greenhouse ***Sc***, number of roof N_{VR} and side N_{VS} vent openings. S_{VR} roof ventilation surface, ventilation surface of the north side S_{VSN} and of the south side S_{VSS} openings.

Greenhouse	Dimensions	S_c [m²]	N_{VR}	N_{VS}	S_{VR} [m²]	S_{VSN} [m²]	S_{VSS} [m²]	S_{VR}/S_c [%]	S_{VS}/S_c [%]	$(S_{VR}+S_{VS})/S_c$ [%]
U9 – East	24 m × 25 m	600	3	1	60.75	-	48.06	10.1	8.0	**18.1**
U9 – West	24 m × 20 m	480	3	1	47.25	-	39.84	9.8	8.3	**18.1**
U11 – East	24 m × 25 m	600	3	2	60.75	49.25	41.18	10.1	15.1	**25.2**
U11 – West	24 m × 20 m	480	3	2	47.25	43.61	30.40	9.8	15.4	**25.3**
U12 – East	18 m × 25 m	450	2	2	40.50	43.40	43.40	9.0	19.3	**28.3**
U12 – West	18 m × 20 m	360	2	2	31.50	35.20	35.20	8.8	19.6	**28.3**

■ Greenhouse surface ventilation

Greenhouse U9

Greenhouse U11

Greenhouse U12

Soil mulching

We have compared three type of **soil mulching** with different **reflection to the solar radiation**. **White materials** were installed in the **East sectors** and a **black polypropylene** was maintained in the **West sector**.

Table 2. Reflection to solar radiation of soil surface measured at 20 cm over the greenhouse soil.

Greenhouse	Material	Format	Colour	Reflection (%)
U9 – East	Polypropylene	Geotextile	Black	11.3
U9 – West	Marble	Gravel	White	44.2
U11 – East	Polypropylene	Geotextile	Black	11.3
U11 – West	Marble	Gravel	White	44.2
U12 – East	Polypropylene	Geotextile	Black	11.3
U12 – West	LDPE (40 µm)	Plastic film	White	42.5

Crops developed

In the three greenhouses a **tomato crop** was developed in **autumn-winter** time followed by a **short cycle** of **pepper crop in spring-summer.**

Table 3. Crops grown in the 2023/24 season in the experimental greenhouses.

Crop	Transplant	First yield	Last yield	Number of yields	Growing days
Tomato`*Fleming*´ (HM.Clause Iberica., Almeria, Spain).	02/09/2023	20/11/2023	23/2/2024	13	174
Pepper 'Bemol RZ' (Rijk Zwaan Iberica, S.A	08/03/2024	23/06/2024	2/7/2024…	1	116…

Greenhouse U9

Tomato crop

East sector: **Black PP soil mulch**

West sector: **Marble gravel soil mulching**

Pepper crop

Greenhouse U11

Tomato crop

East sector: **Black PP soil mulch**

West sector: **Marble gravel soil mulching**

Pepper crop

Greenhouse U12

Tomato crop

East sector: **Black PP soil mulch**

West sector: **White polyethylene mulching**

Pepper crop

Measurement of climatic parameters

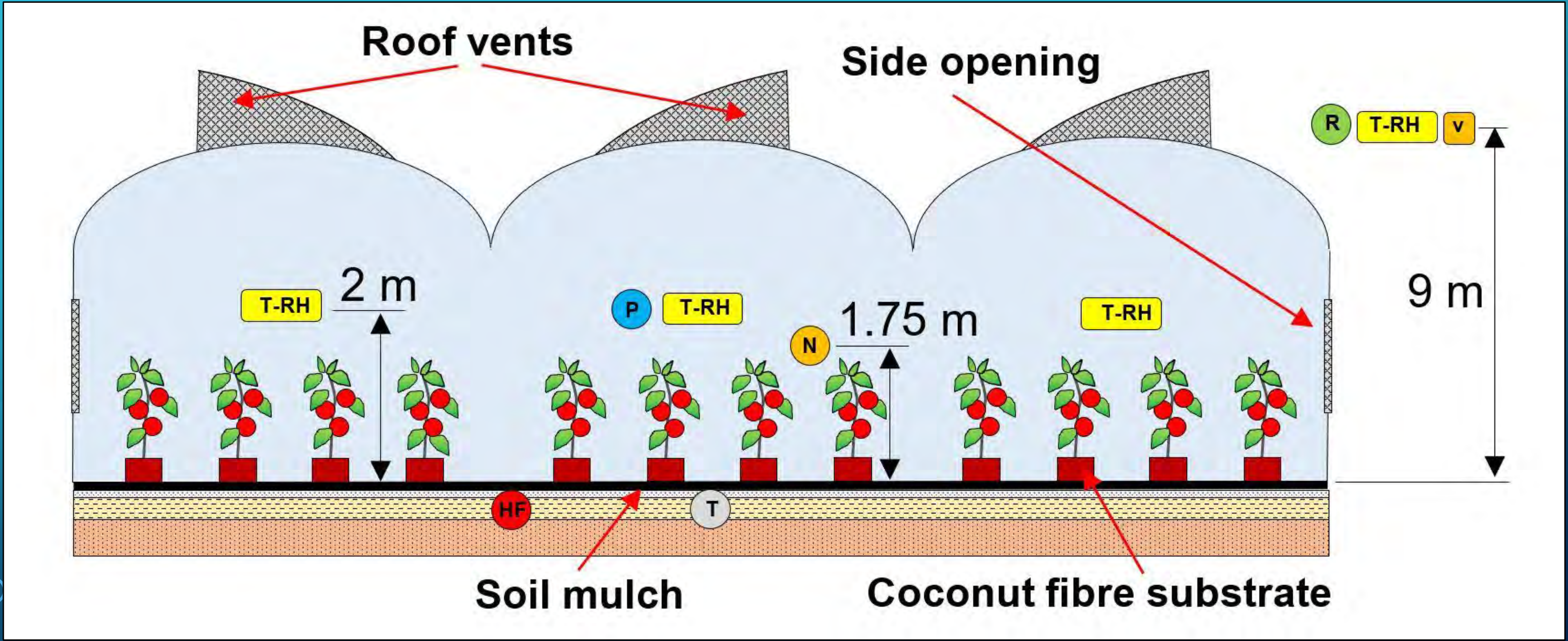
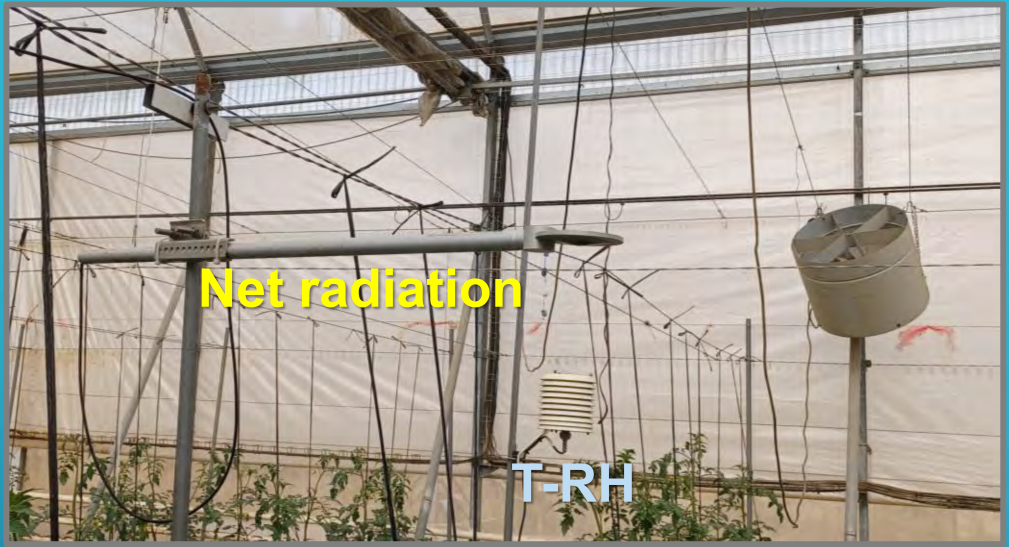
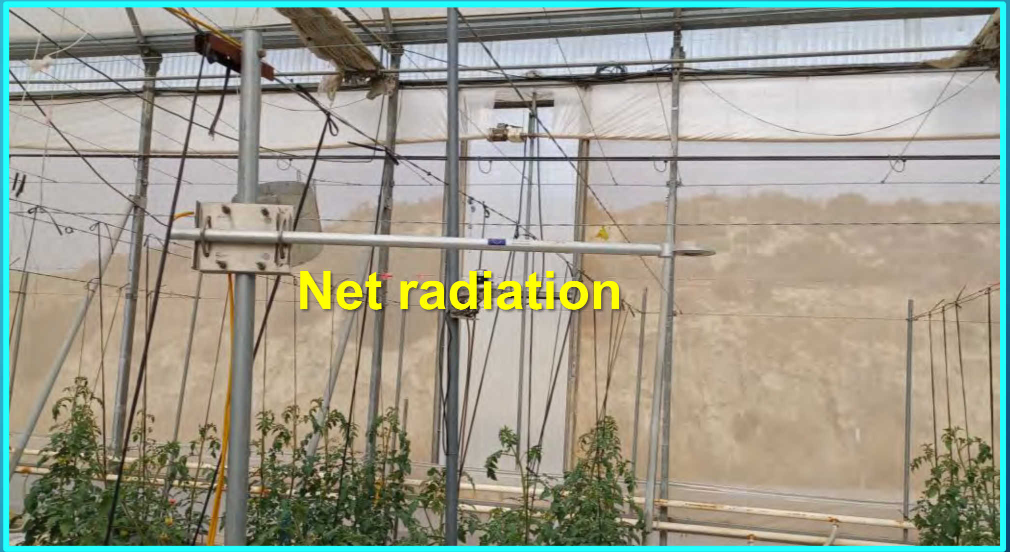


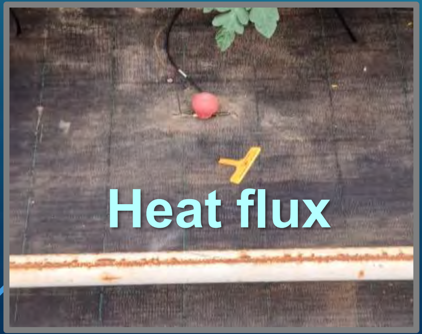
Figure 6. Distribution of sensors located inside and outside the greenhouse for the measurement of climatic parameters: Temperature and relative humidity sensors (**T-RH**), pyranometers (**R**), PAR sensor (P), net radiation (N), heat flux (HF), thermocouples (**T**) and wind anemometers (**v**).

Measurement of climatic parameters



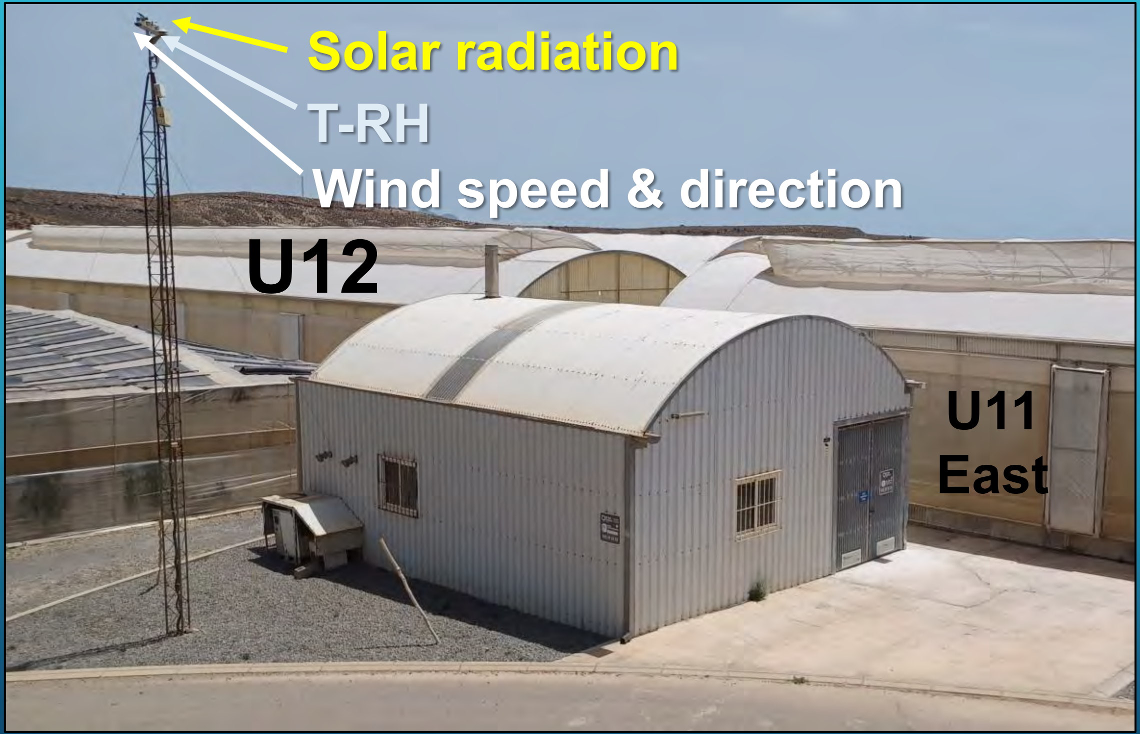


U11 – East

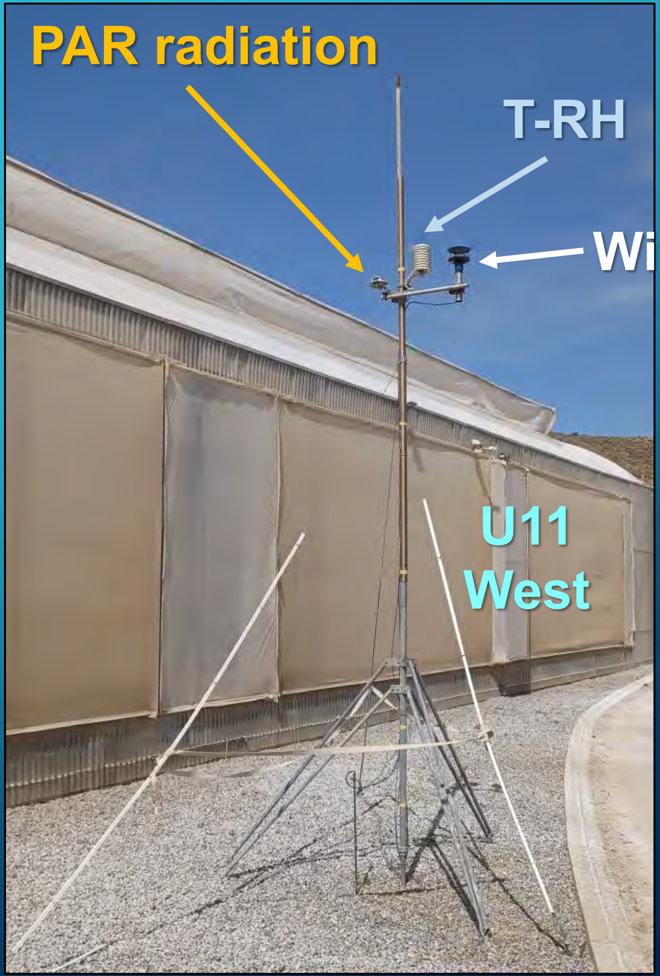


U11 – West

Outside climatic parameters



Weather station at 9 m



Weather station at 5 m

Table 4. Main sensors (64) used for the measurement of climatic parameters.

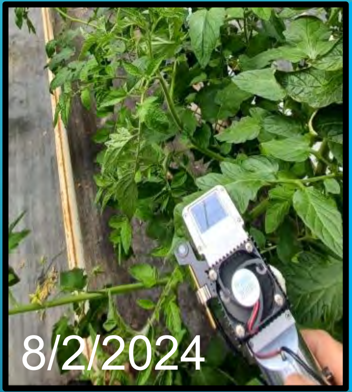
Parameter	Sensor	Company	Measuring range	Accuracy
Outdoor climate parameters measured at the weather station				
R0 – Global Outdoor Solar Radiation	Kipp Solari - Meteostation II	HortiMax B.V. (Maasdiijk, Netherlands)	±2000 W m^{-2}	**±5% o ±20 W m^{-2}**
Uo – Outside Wind Speed	Anemometer - Meteostation II		0 - 40 m s^{-1}	**±5%**
θ_w – Wind Direction	Weather Vane - Meteostation II		0 - 360°	**±5°**
Te – Outdoor Air Temperature	Pt1000 IEC 751 1/3 class B	Vaisala Oyj (Helsinki, Finland)	–25 - 75 °C	**±0.2 °C**
HRe – Outdoor Air Humidity	HUMICAP HMT100		0 - 100%	**±2.5%**
Indoor climate parameters measured by the climate control system sensors				
Ti – Indoor Air Temperature	Pt1000 Clase A – Ektron III	Eleltronik Ges. M.b.H. (Engerwitzdorf, Austria)	–10 - 60 °C	**±0.6 °C**
HRi – Indoor Relative Humidity	EE07-04 PFT6 – Ektron III		0 - 100%	**±2% (0 - 90%)**
Ci – Concentration of CO_2 in indoor air	Sonda digital CO2 GMM222	Vaisala Oyj	0 - 2000 ppm	**±30 ppm + ±2%**
Centralized system for data collection	MultiMa Series II	HortiMax B.V.	**Software Synopta**	
Indoor climate parameters measured by sensor chains placed in the vertical section of each sector				
RSi – Global Indoor Solar Radiation	3 × SP1110 Pyranometers	Campbell Scientific Spain (Barcelona, Spain)	350 – 1100 nm	**±5%**
QSi – RPA Sensor	6 × SKP215 Quantum Sensor		440 – 700 nm	**±5%**
Ts – Soil temperature at 0.05 m	6 × Betatherm 100K6A Thermistors		-5 - 95 °C	**<±0.16 °C**
qs – Heat flux in the soil (at 10 cm)	4 × HFP01	Hukseflux Thermal Sensors B.V. (Delft, The Netherlands)	±2000 W $^{m-2}$	**-15 - 5%**
Ti – Indoor Air Temperature	18 × CS215 Sensirion SHT75	Sensirion AG. (Staefa, Switzerland)	–40 - 70 °C	**±0.4°C (5 - 40 °C)**
HRi – Indoor Relative Humidity			0 - 100%	**±2% (10 - 90%)**
Photosynthesis measured in the leaves of plants				
C_L – CO_2 concentration in leaves	TARGAS 1 Photosynthesis Analyzer	PP Systems (Amesbury, USA)	**0 – 2000 ppm**	**1 ppm**

Measurement of photosynthesis

To analyze the **effect of microclimate** on **plant activity** we have measured **transpiration** and **photosynthesis** every two weeks.

Tomato

U9 - East



U6 - West

U11 - East

U11 - West

U12 - East

U12 - West

Pepper

U9 - East

U6 - West

U11 - East

U11 - West

Measurement of photosynthesis

The **net photosynthetic rate**, **PAR radiation**, **leaves temperature** and **transpiration rate** were measured with a **portable photosynthesis system TARGAS 1** (PP Systems, Amesbury, USA) . in condition of inside natural light and air CO_2 concentration.

3. Results and discussion

Effect of mulch in net radiation

White **marble gravel mulching reduced –14%** the **net radiation** inside the greenhouse as consequence of **soil reflection** of solar radiation.

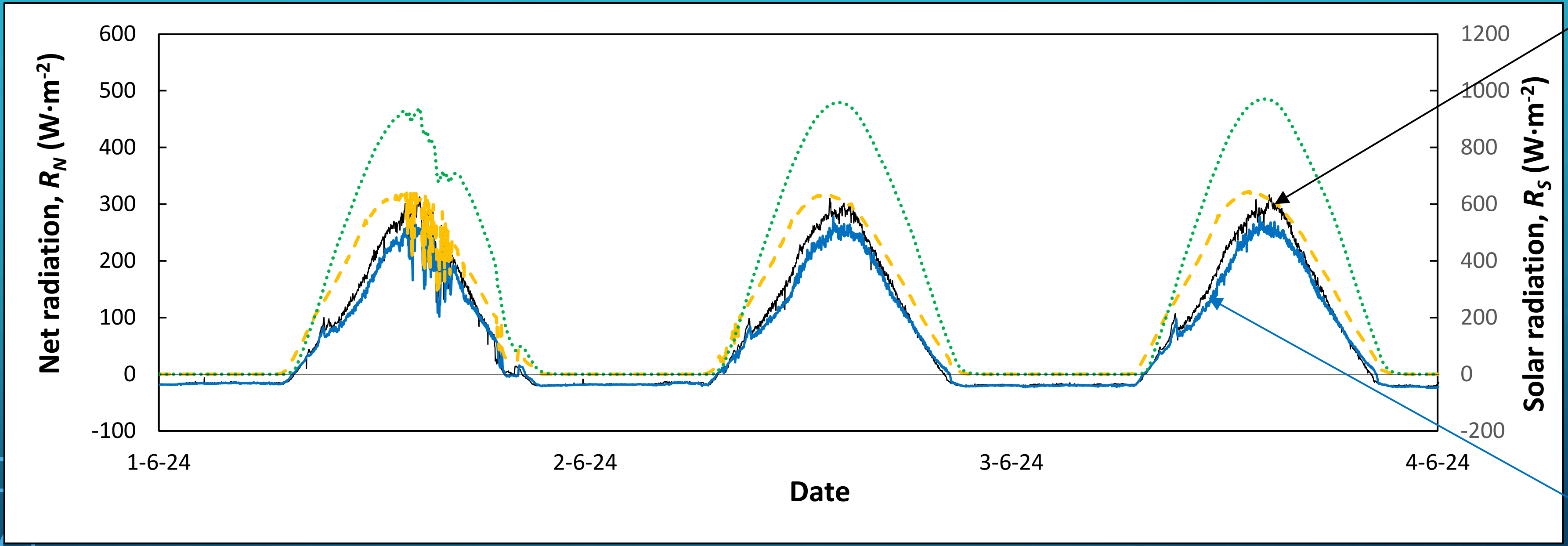


Figure 7. Net radiation in the sector with white marble gravel mulch (—) and with black polypropylene geotextile mulch (—) inside greenhouse U11. External (····) and inside solar radiation in U11W (- - -).

Effect of mulch in net radiation

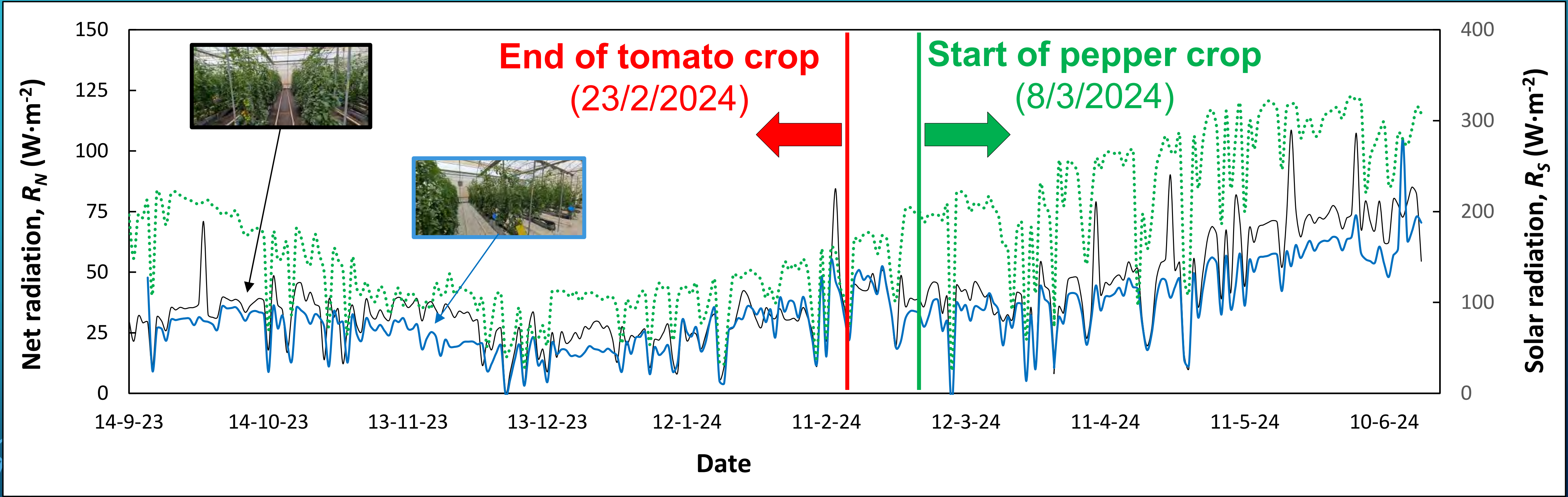
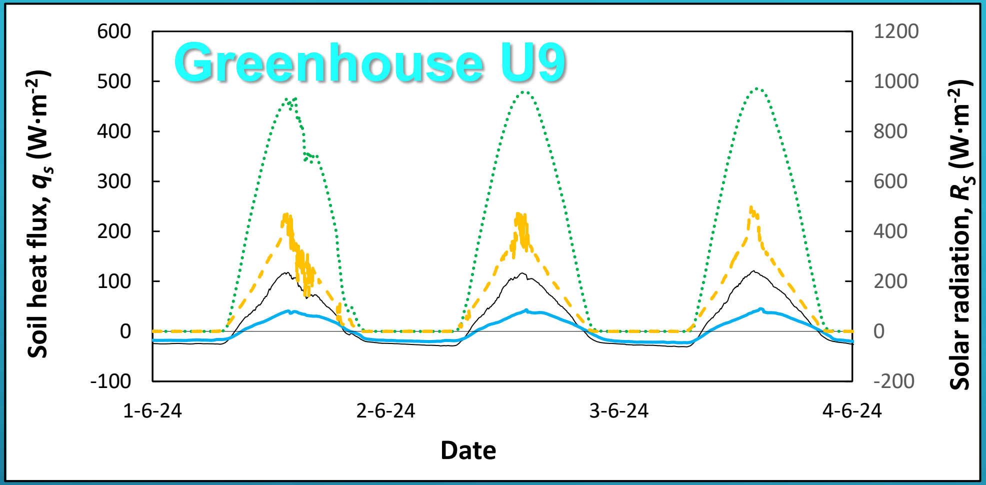
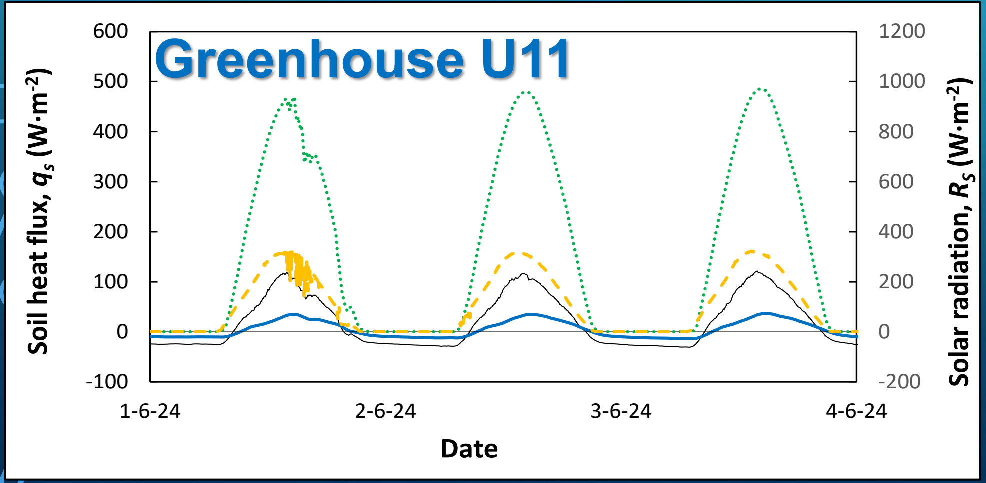


Figure 8. Maximum values of net radiation in the sector with white marble gravel mulch (—) and with black polypropylene geotextile mulch (—) inside greenhouse U11. External solar radiation (····).

Effect of mulch on soil heat flux

White marble gravel mulching **reduced –65% soil heat flux** and **with plastic –45%** as consequence of **soil reflection** of solar radiation.





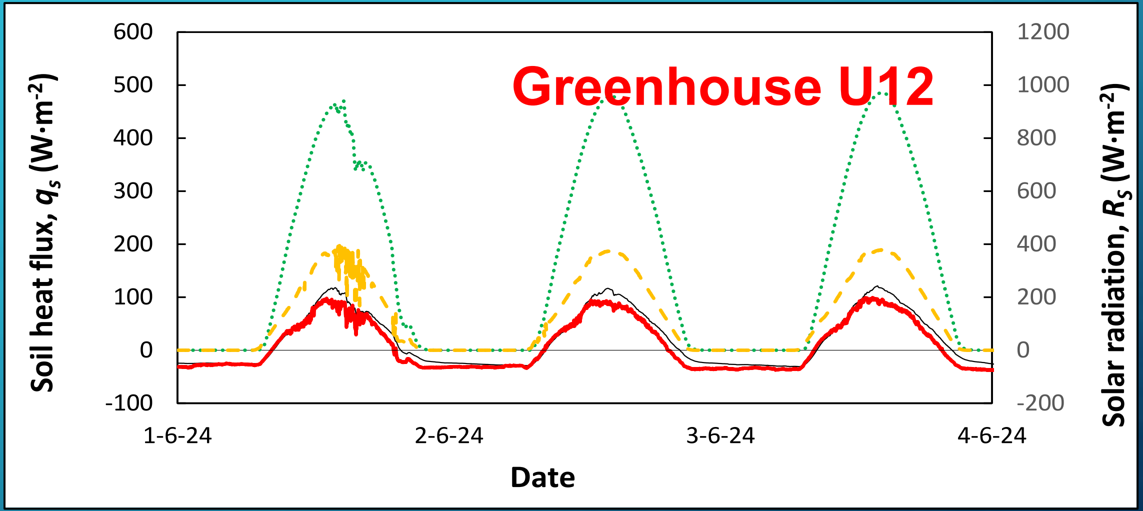
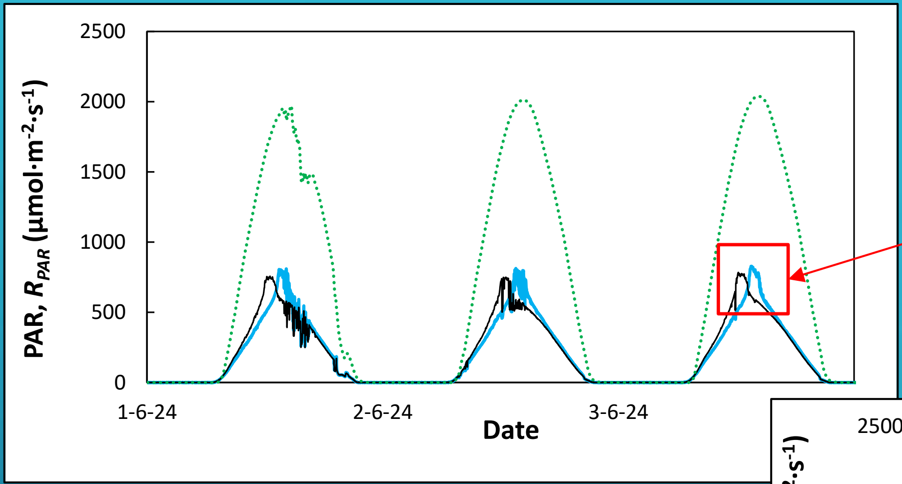
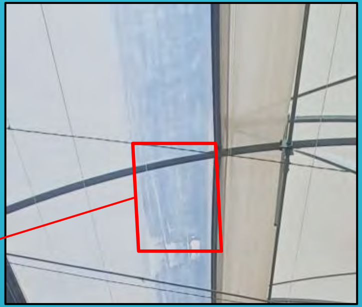


Figure 9. Soil heat flux in June 2024 in the sectors with white marble gravel mulch U9W (—) and U11W (—), white plastic U12W (—) and with black polypropylene geotextile mulch (—). External (····) and inside solar radiation in West sectors (- - -).

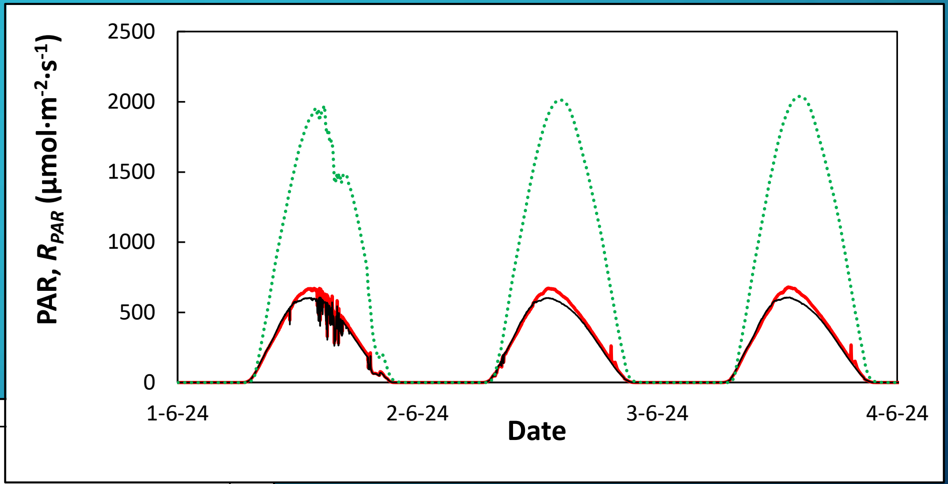
Effect of mulch in PAR radiation

White mulching **increased +5-10%** as consequence of double **soil-cover reflection** of PAR.

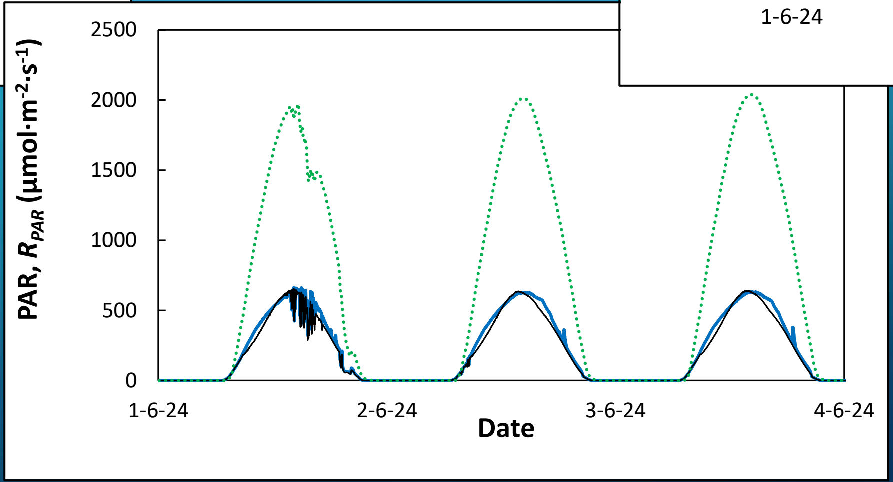




Greenhouse U9



Greenhouse U12



Greenhouse U11

Figure 10. PAR radiation in the sectors with white marble gravel mulch U9W (—) and U11W (—), white plastic U12W (—) and with black polypropylene geotextile mulch (—). External PAR radiation (····).

Effect of mulch in PAR radiation

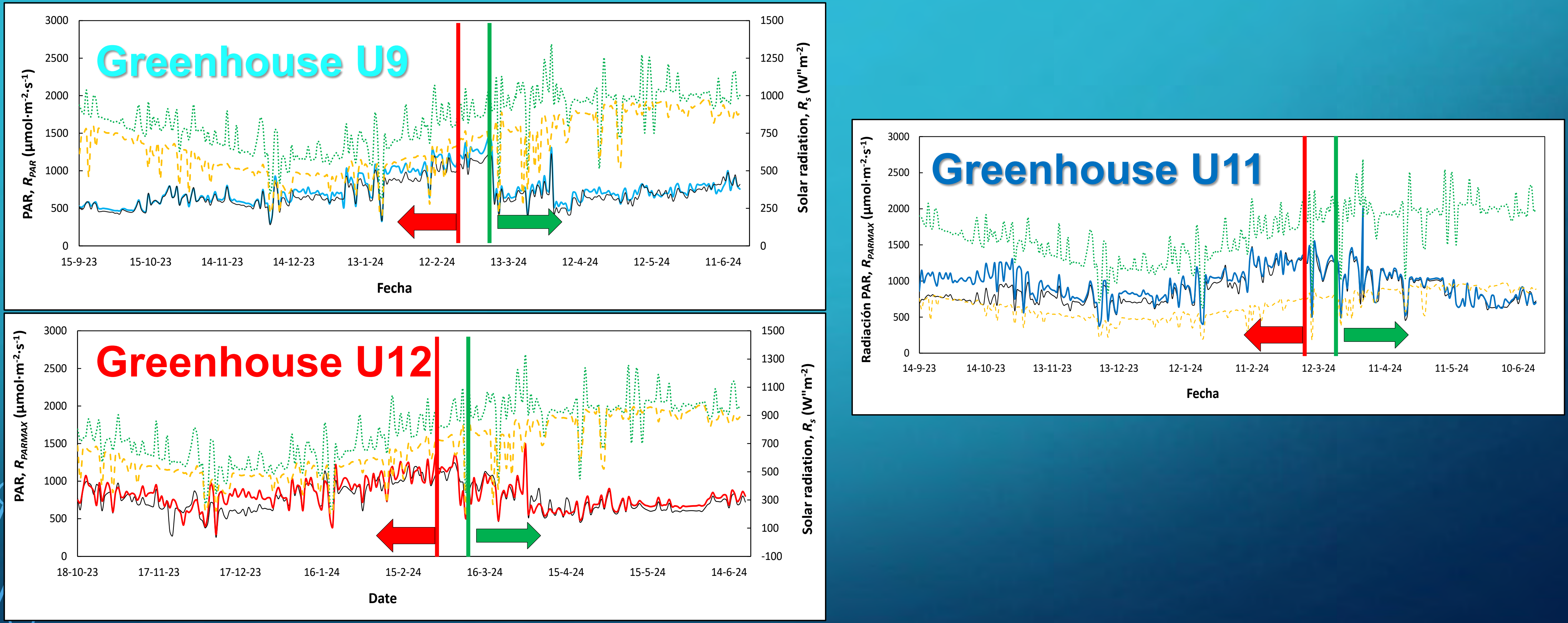
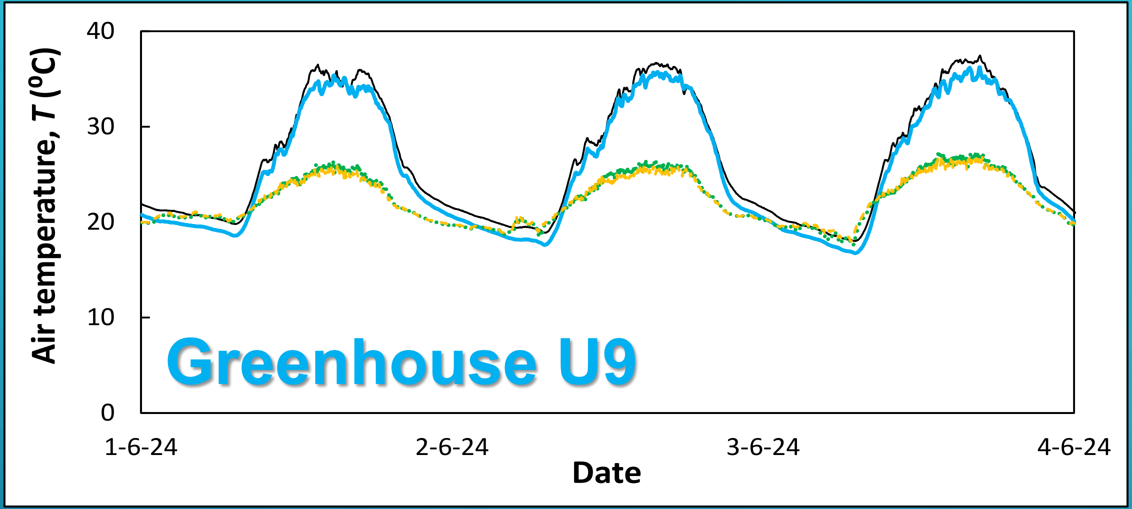
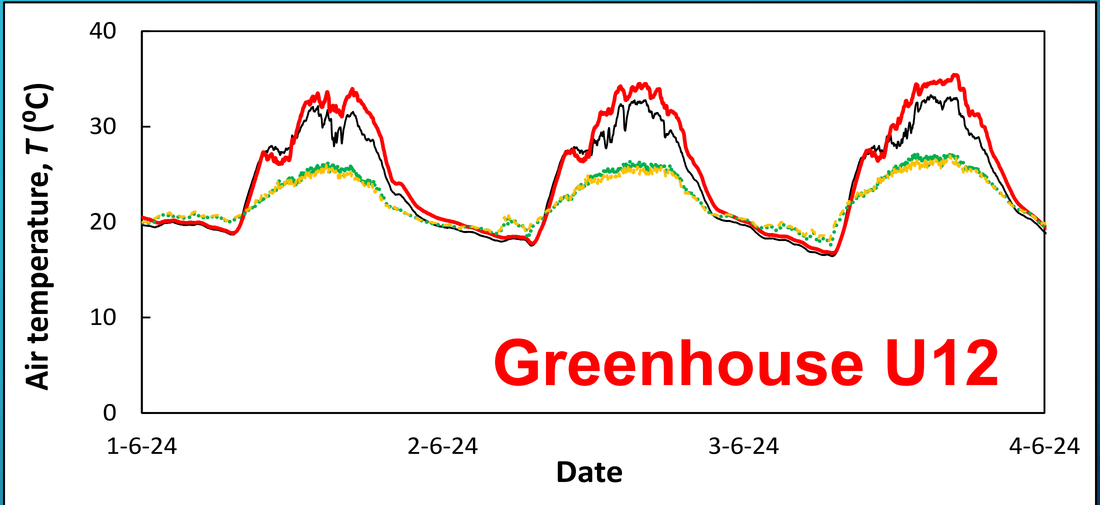


Figure 11. Maximum values of PAR radiation in the season 2023-24 in the West sectors with white marble gravel mulch U9W (—) and U11W (—), white plastic U12W (—) and in the East sectors with black polypropylene geotextile mulch (—). External (····) and inside solar radiation in West sectors (- - -).

Effect in air temperature

The **soil marble mulching** allows reduce maximum inside **air temperature** by **– 0.5ºC** in **hot period**.





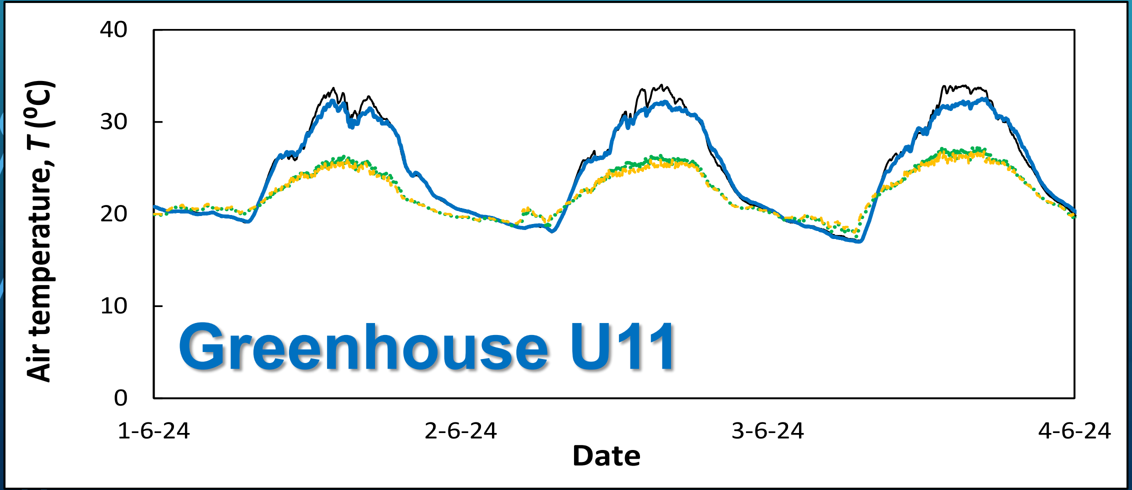
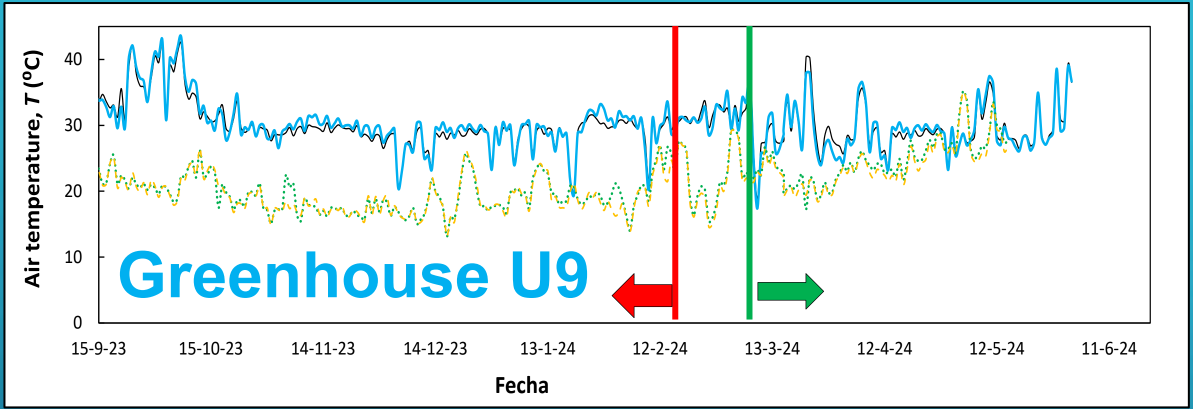
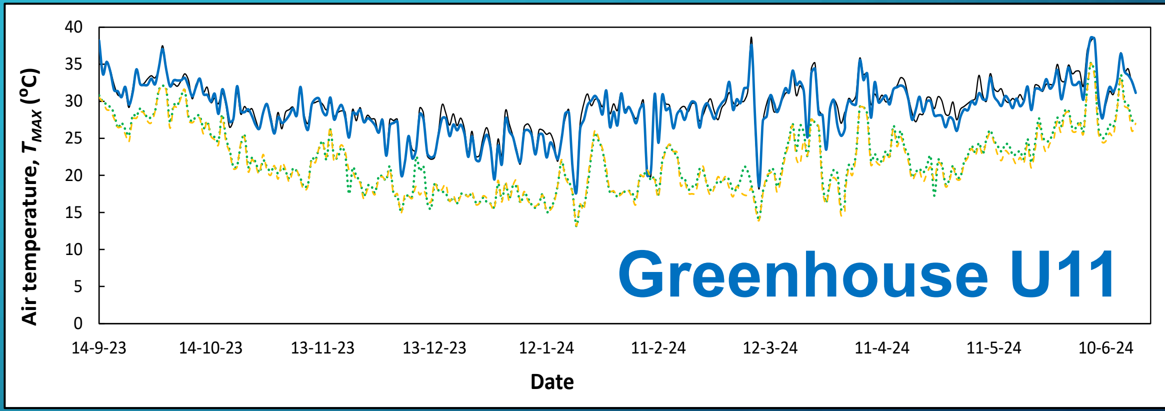


Figure 12. Evolution of air temperature inside the West sectors with white marble gravel mulch U9W (—) and U11W (—), white plastic U12W (– –) and in the East with black polypropylene geotextile mulch (—) and outside at 5 m (····) and 9 m (- - -).

Effect in air temperature

In **cold period** the **cooling effect** of **white marble mulching** in the West sector is **counterbalanced** by the climate controller **opening** the **side vents** of the East sector.





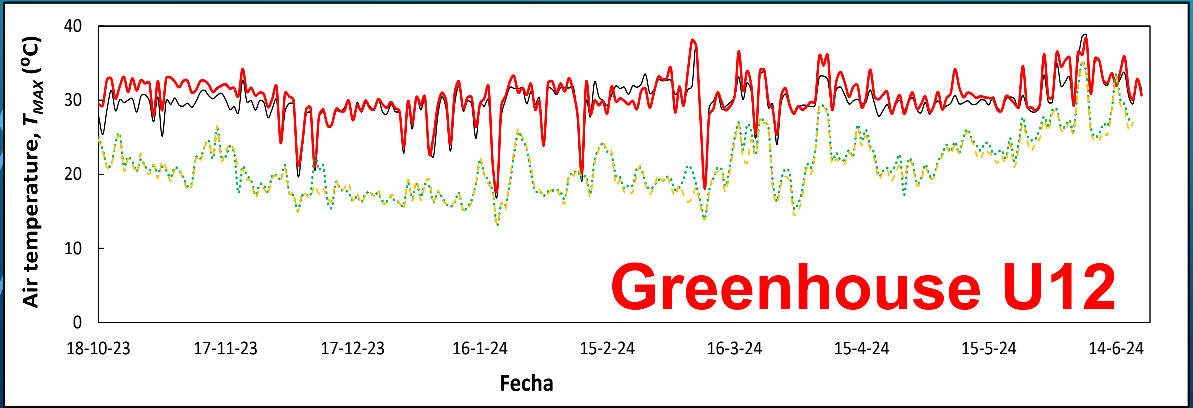
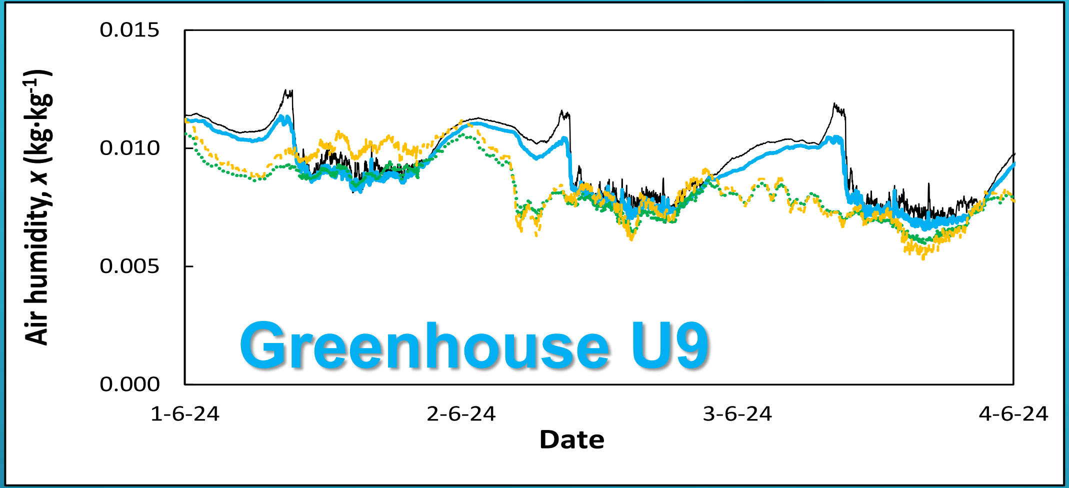
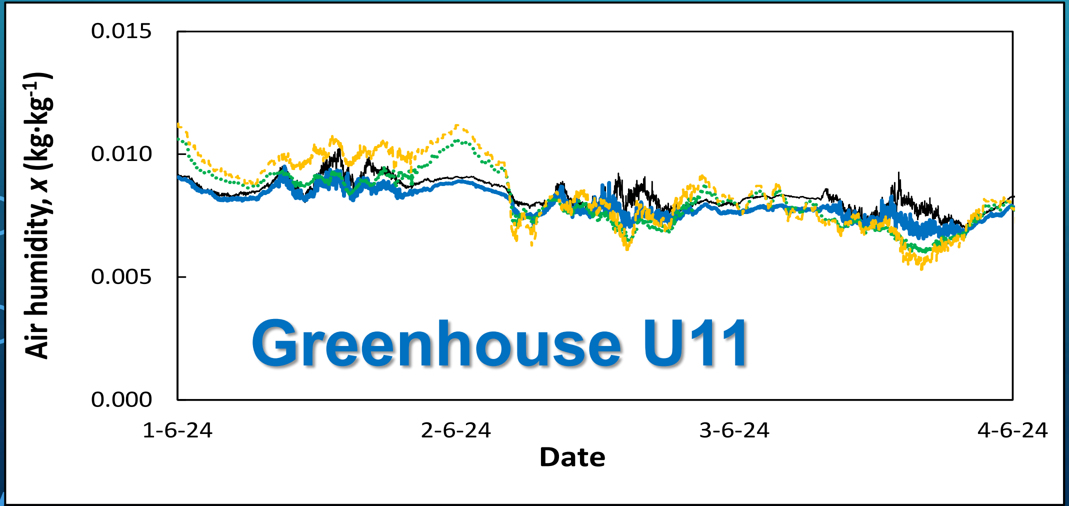


Figure 13. Evolution of maximum air temperature along the season 2023-24 inside the West sectors with white marble gravel mulch U9W (—) and U11W (—), white plastic U12W (—) and East sectors with black polypropylene geotextile mulch (—) and outside at 5 m (····) and 9 m (- - -).

Effect in air absolute humidity

The **white mulching** reduced inside **air humidity** by **– 5-10%** in **hot period**.





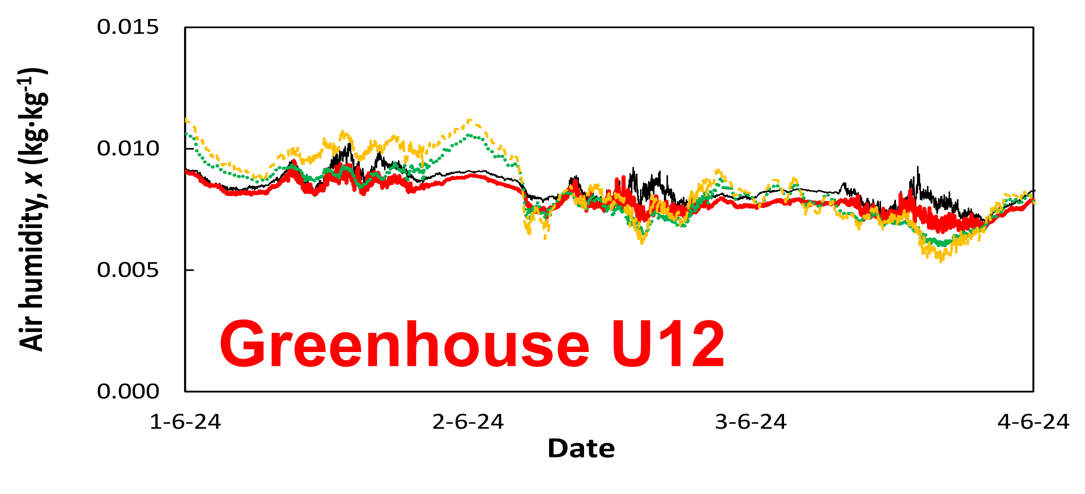
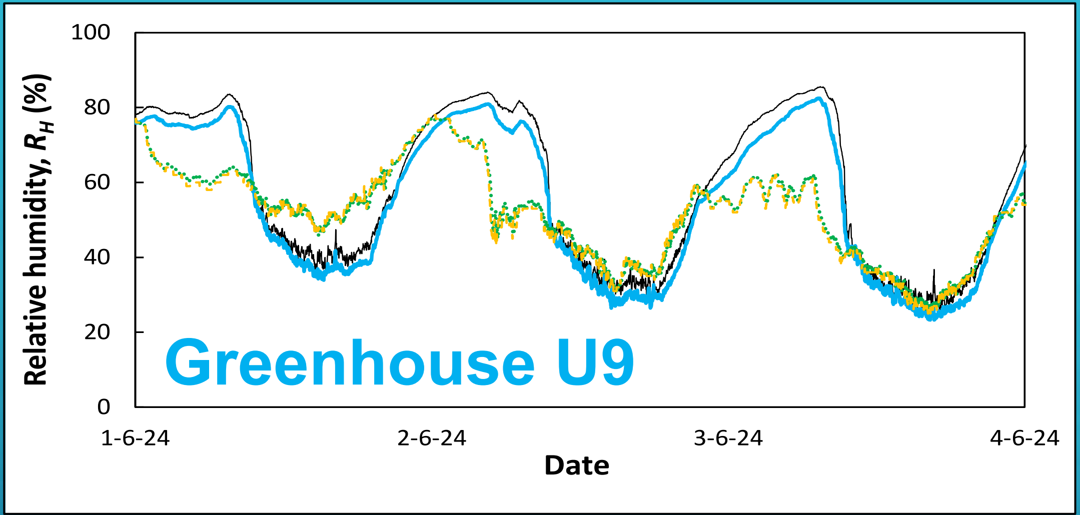
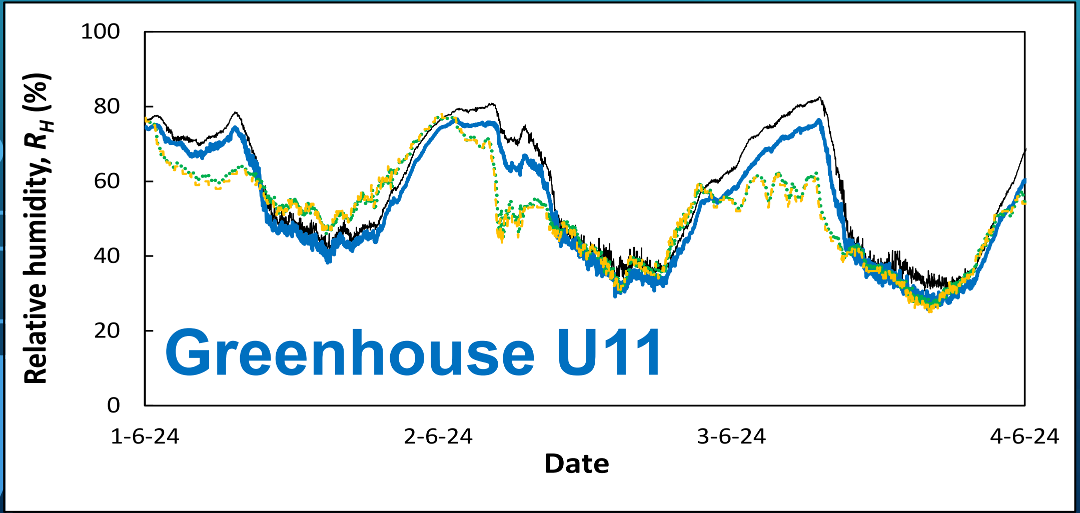


Figure 14. Evolution of absolute air humidity inside the West sectors with white marble gravel mulch U9W (—) and U11W (—), white plastic U12W (—) and the East sectors with black polypropylene geotextile mulch (—) and outside at 5 m (····) and 9 m (- - -).

Effect in air relative humidity

The **soil marble mulching** reduced inside **air humidity** by **– 2-10%**, but **not the white plastic**.





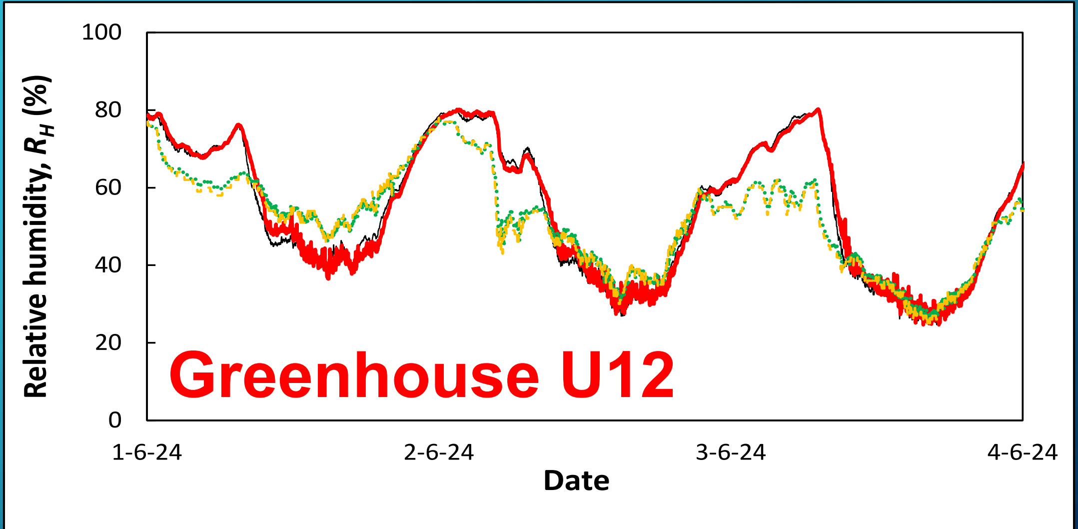
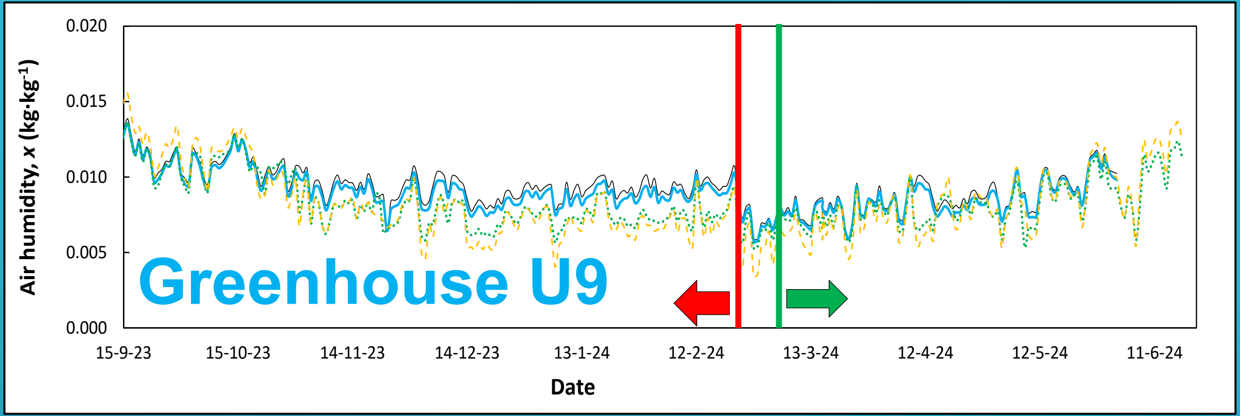
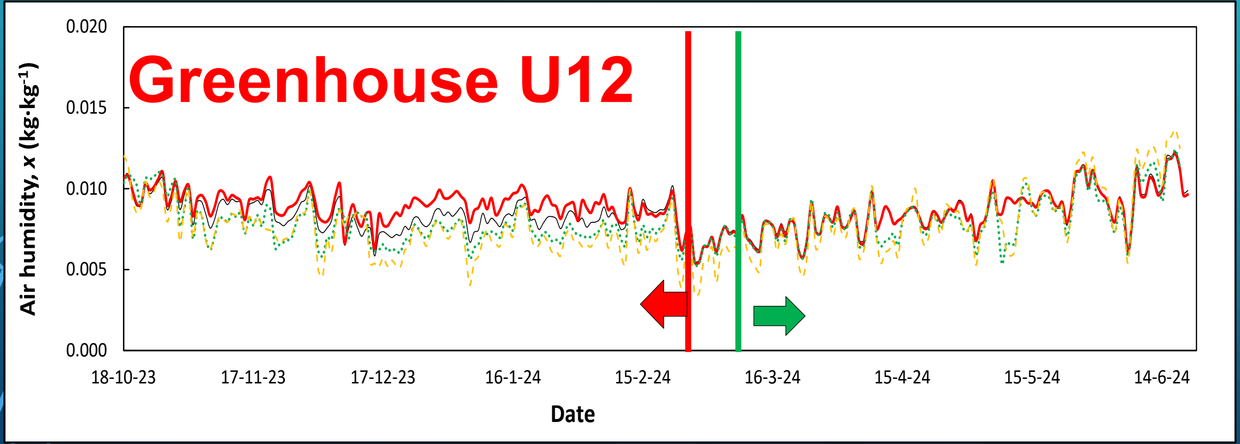


Figure 15. Evolution of relative air humidity inside the West sectors with white marble gravel mulch U9W (—) and U11W (—), white plastic U12W (—) and the East sectors with black polypropylene geotextile mulch (—) and outside at 5 m (····) and 9 m (- - -).

Effect in air humidity





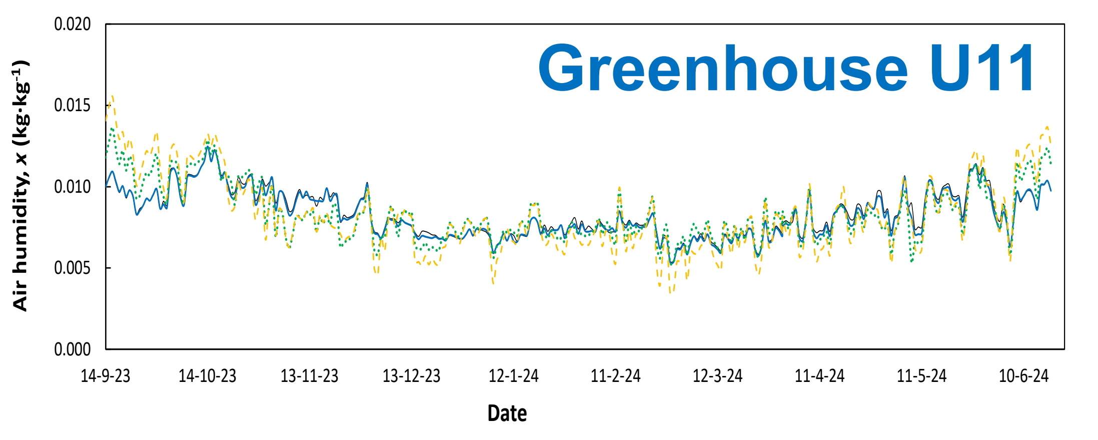


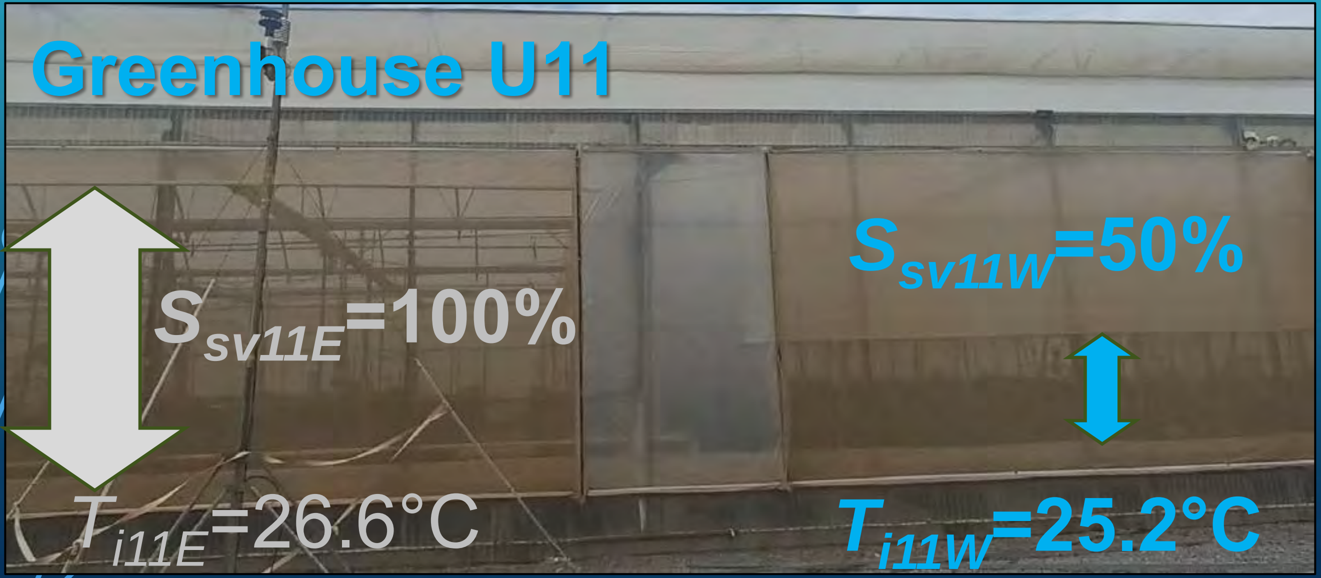
Figure 13. Evolution of average air humidity along the season 2023-24 inside the sectors with white marble gravel mulch U9W (—) and U11W (—), white plastic U12W (—) and with black polypropylene geotextile mulch (—) and outside at 5 m (····) and 5 m (- - -).

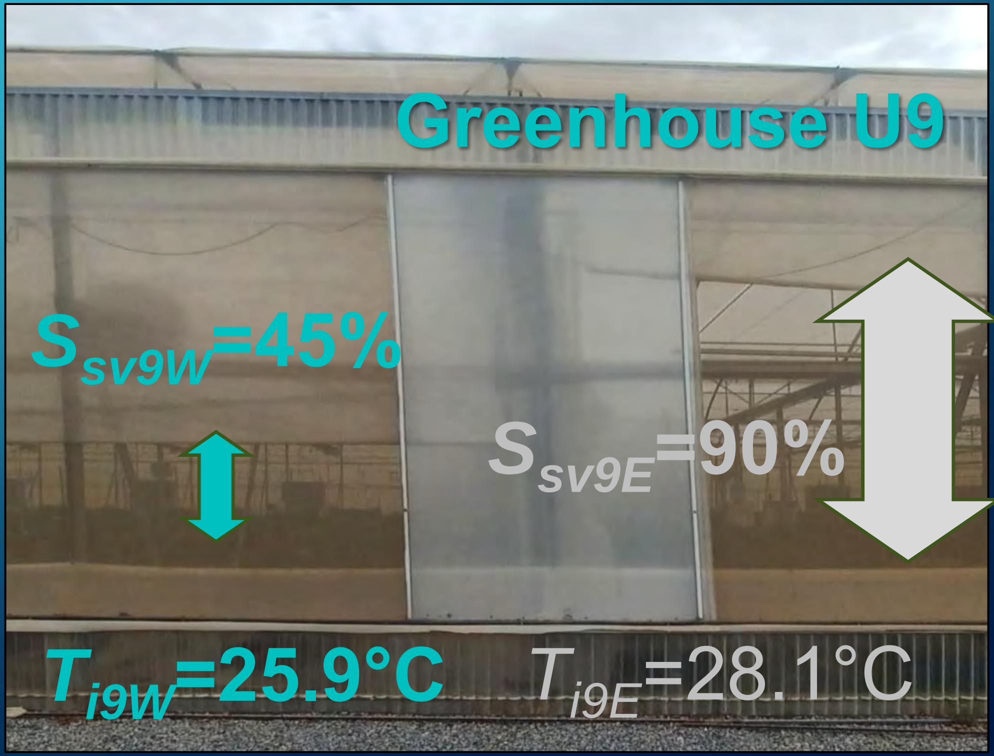
Microclimate

In **hot periods**, when the **windows are fully opened** in the sector East with the **black mulching**, **temperature increase**, whereas in the West sector with **gravel marble mulch** temperatures is **lower** with the **side windows 50% opened** in both greenhouses **U9** and **U11**.

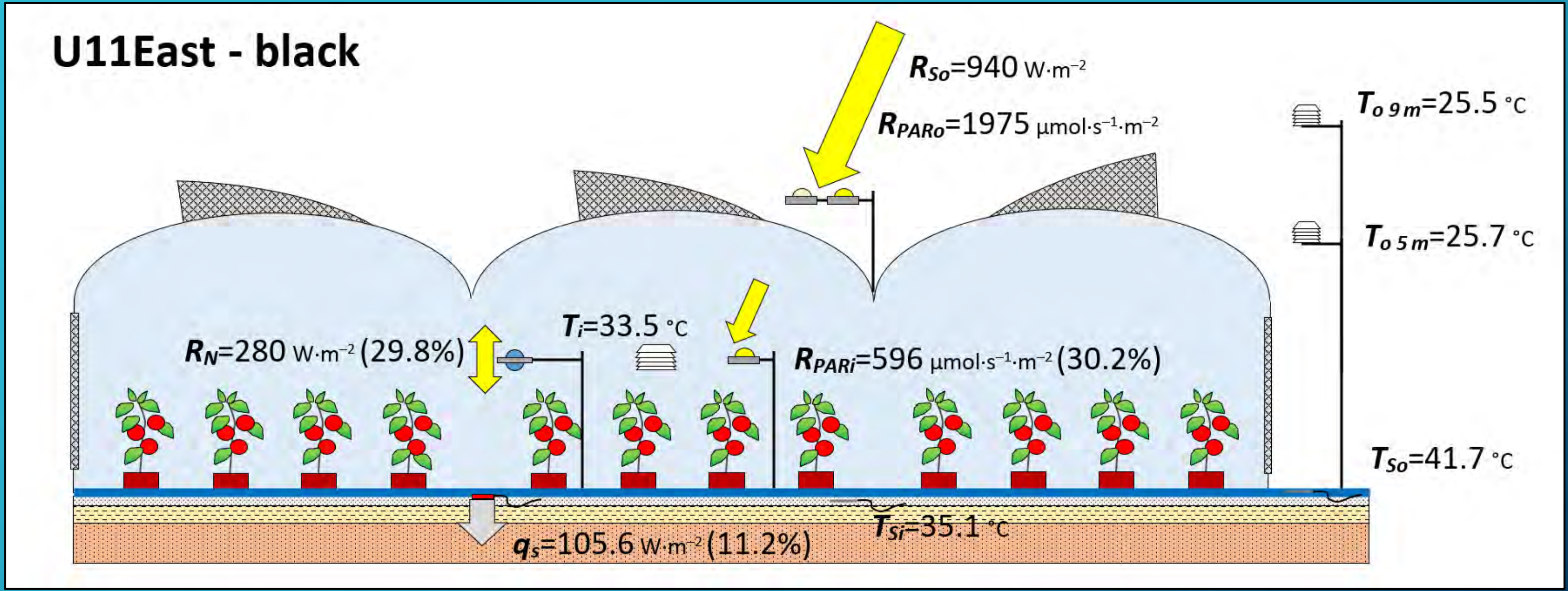
19-06-2024 at 11:30 h

T_o=23.3°C





Microclimate



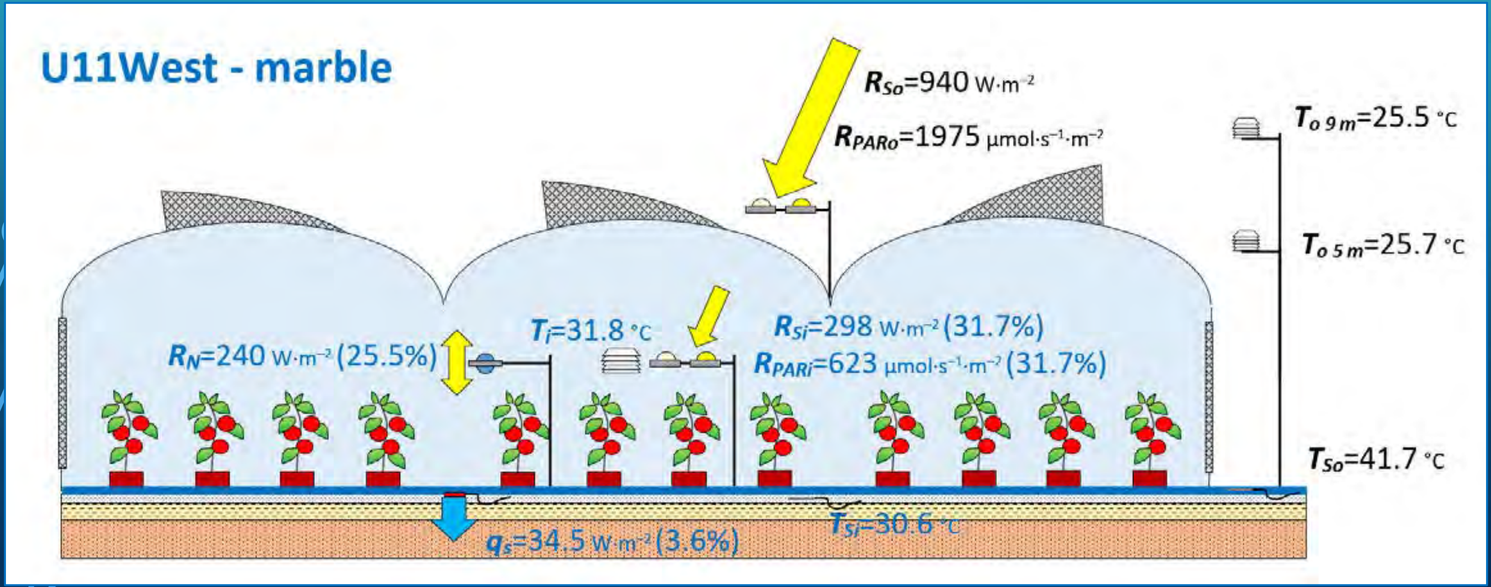


Figure 17. Radiation and heat flux in the greenhouse U11.

Effect soil mulching in PAR radiation measured in leaves

The **reflection** produced by the **marble mulch increased PAR radiation** in greenhouse **U11** at plant leaves but not in the other two greenhouse.

Tomato

a) b) c)

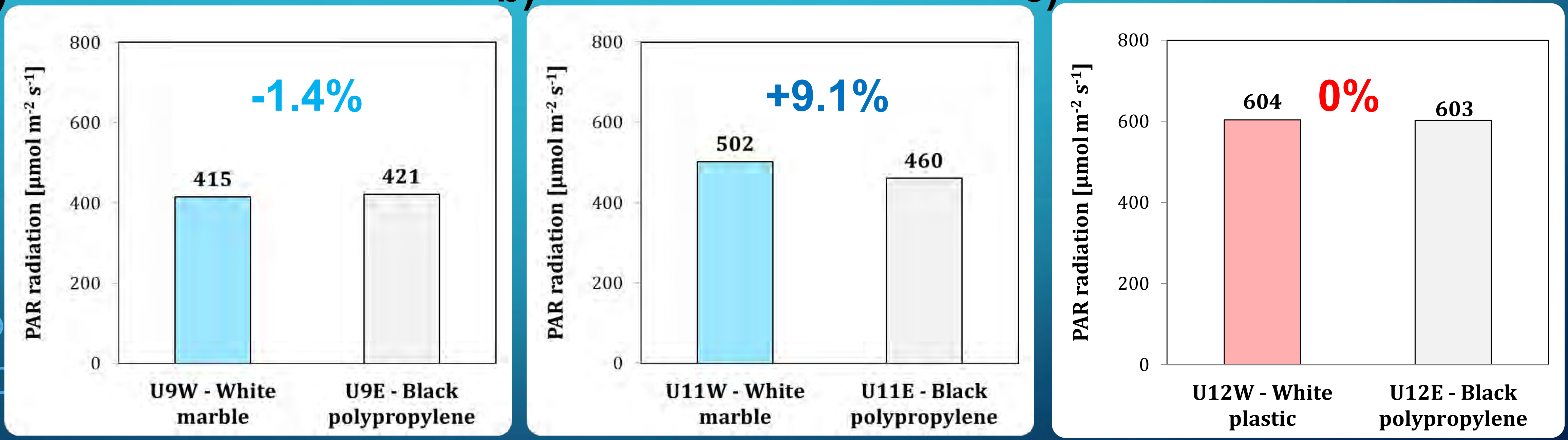


Figure 18. PAR radiation measured in leaves of tomato in greenhouses U9 (a), U11 (b) and U12 (c) in the marble (■), white plastic (■) and propylene (■) mulched sectors of greenhouses.

Effect soil mulching in PAR radiation measured in leaves

For the **pepper** crop **PAR radiation increased** in both greenhouses with the gravel marble.

Pepper

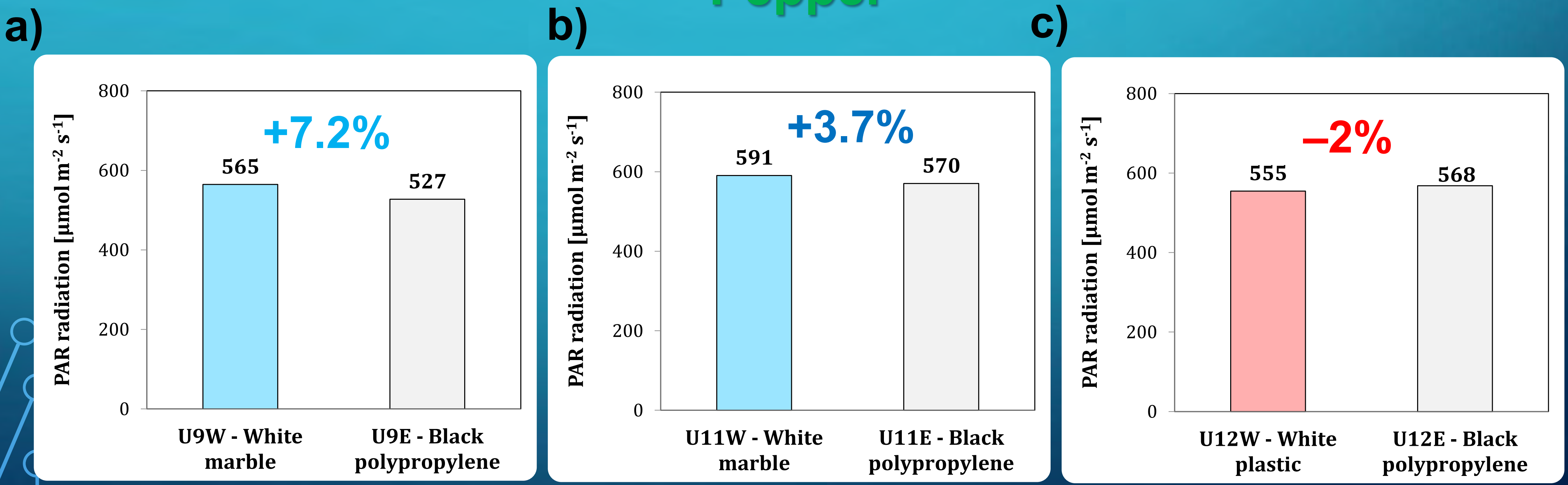


Figure 19. PAR radiation measured in leaves of pepper in greenhouses U9 (a), U11 (b) and U12 (c) in the marble (■), white plastic (■) and propylene (■) mulched sectors of greenhouses.

Effect in crops temperature

In the **tomato** crop, the **white mulching produced reduction** of **plant temperature.**

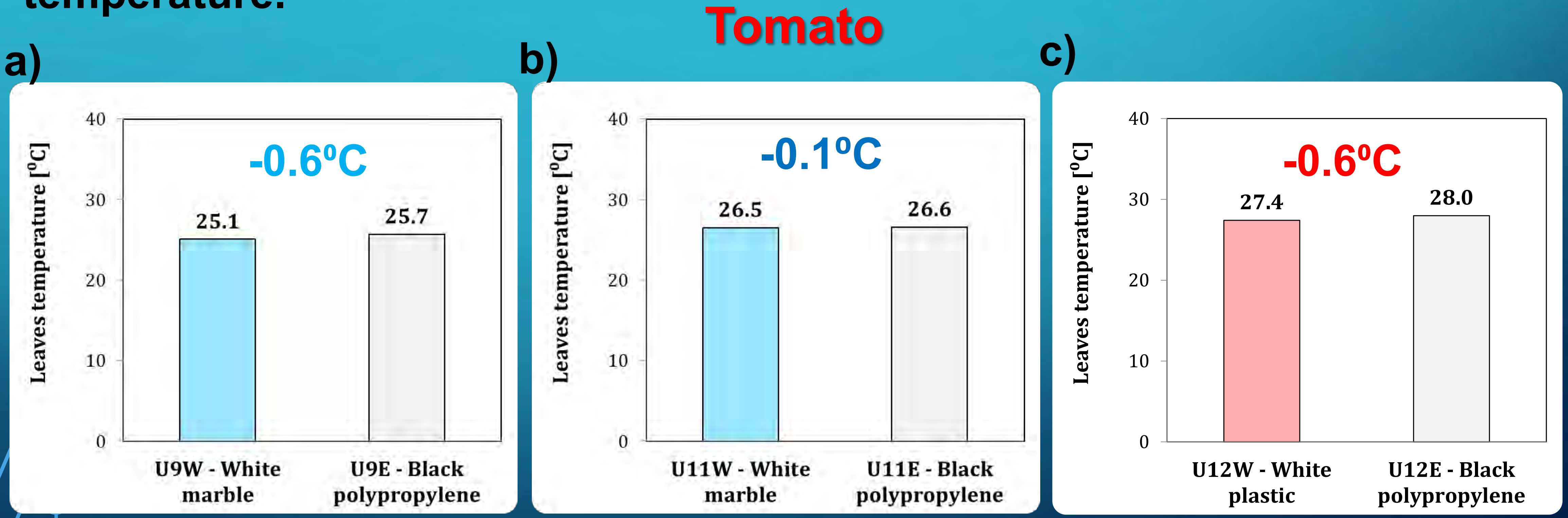


Figure 20. Temperature measured in leaves of tomato in greenhouses U9 (a), U11 (b) and U12 (c) in the marble (■), white plastic (■) and propylene (■) mulched sectors of greenhouses.

Effect in crops temperature

In the **pepper** crop **plant temperatures** were **similar** inside the **two sectors** of each **greenhouse.**

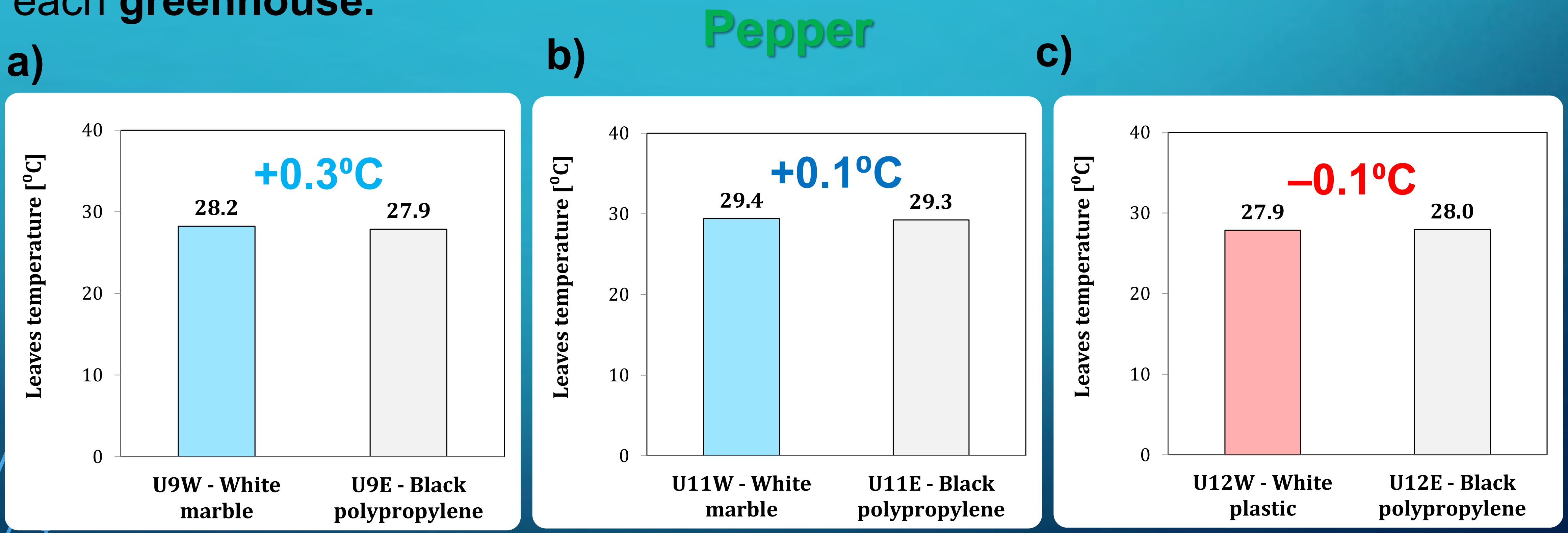


Figure 21. Temperature measured in leaves of pepper in greenhouses U9 (a), U11 (b) and U12 (c) in the marble (■), white plastic (■) and propylene (■) mulched sectors of greenhouses.

Effect in crops transpiration

The two types of **white mulching** produced an **important increase** of **plant transpiration.**

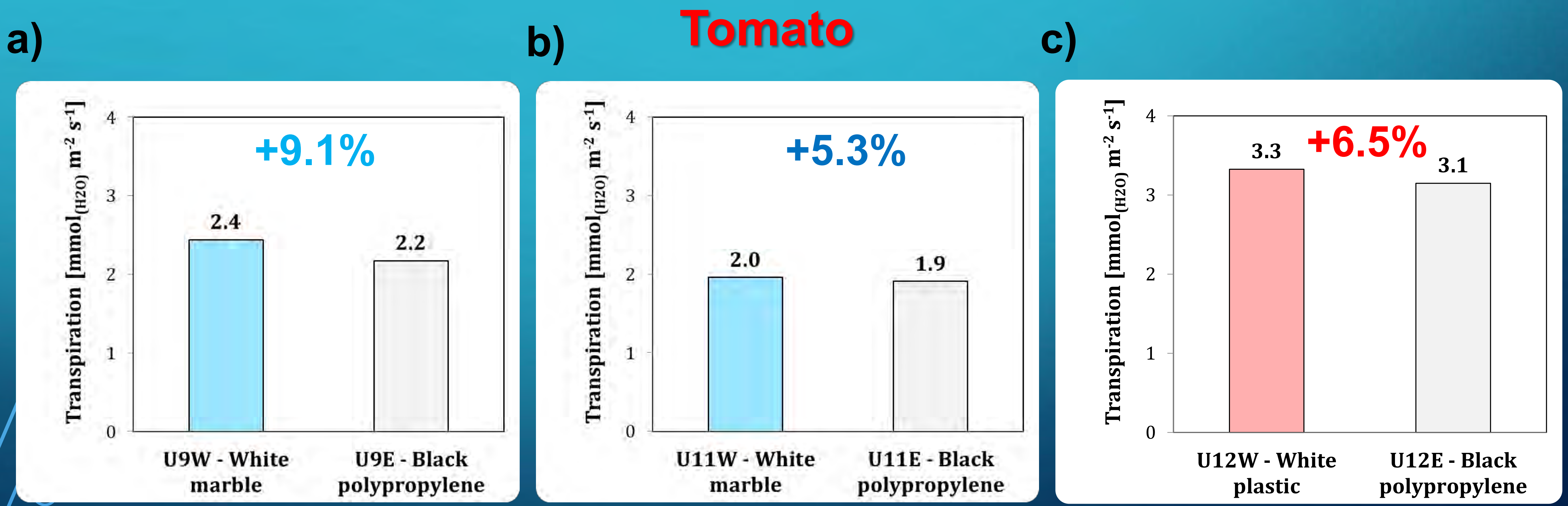


Figure 22. Plant transpiration measured in leaves of tomato in greenhouses U9 (a), U11 (b) and U12 (c) in the marble (■), white plastic (■) and propylene (■) mulched sectors of greenhouses.

Effect in crops transpiration

The **increase in transpiration** was **greater** in the **spring-summer** period with the **pepper** crop.

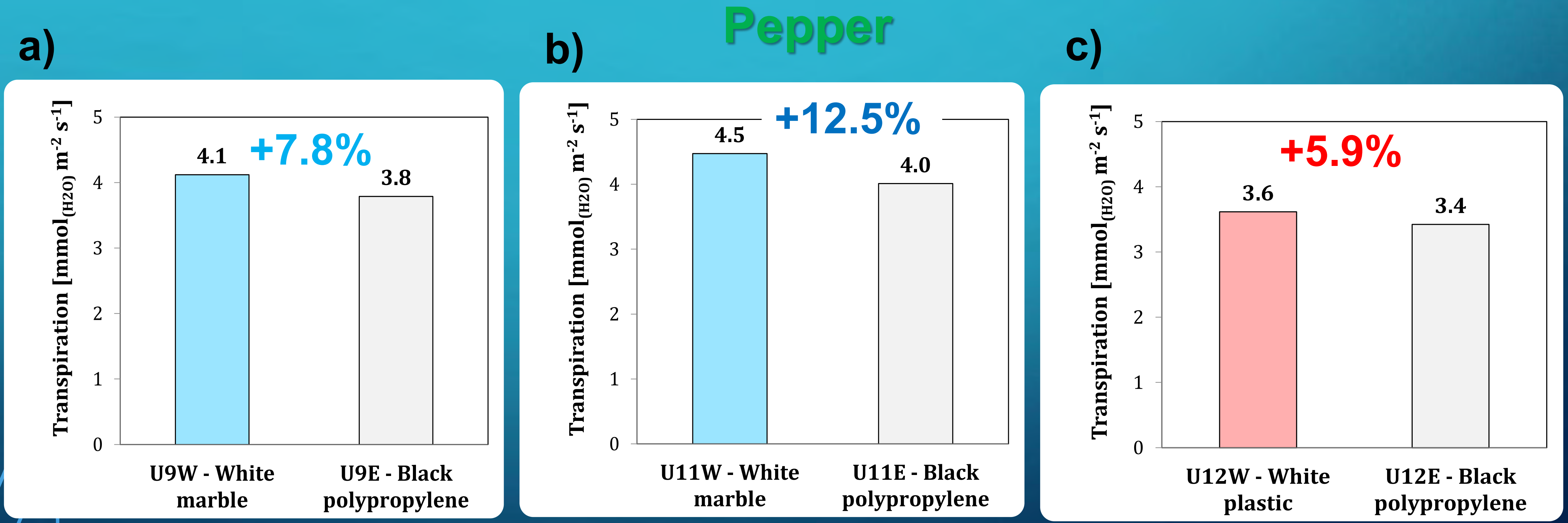


Figure 23. Plant transpiration measured in leaves of pepper in greenhouses U9 (a), U11 (b) and U12 (c) in the marble (■), white plastic (■) and propylene (■) mulched sectors of greenhouses.

Effect in crops photosynthesis

The **soil marble mulching** increased **photosynthesis** in the leaves of **tomato** crop.

Tomato

a) b) c)

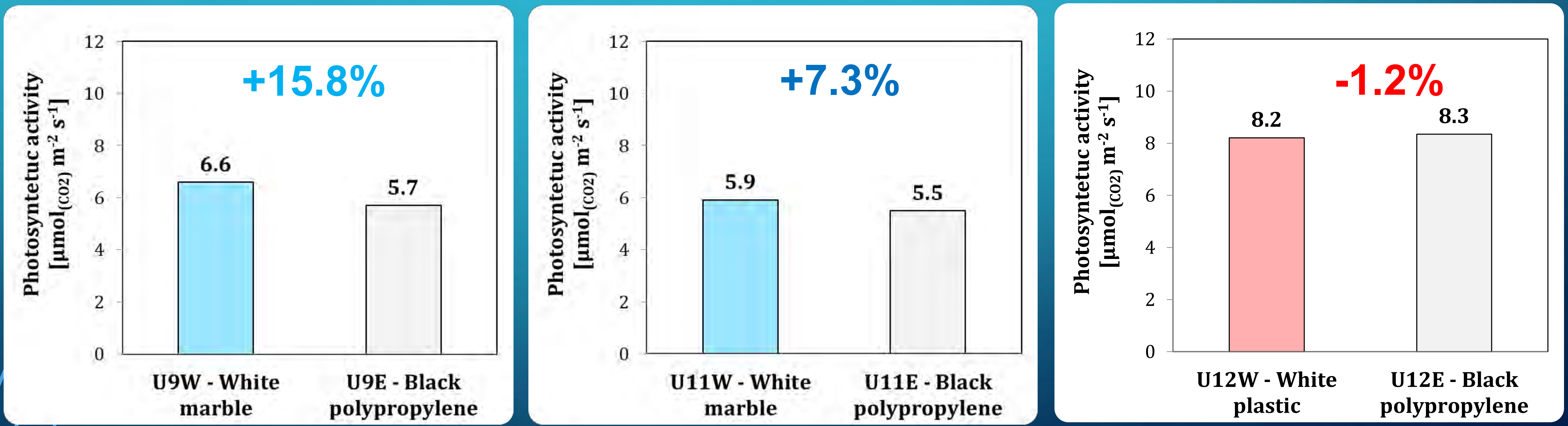


Figure 24. Photosynthetic activity measured in leaves of tomato in greenhouses U9 (a), U11 (b) and U12 (c) in the marble (■), white plastic (■) and propylene (■) mulched sectors of greenhouses.

Effect in crops photosynthesis

Similar increases were observed in **photosynthesis** in the leaves of **pepper** crop.

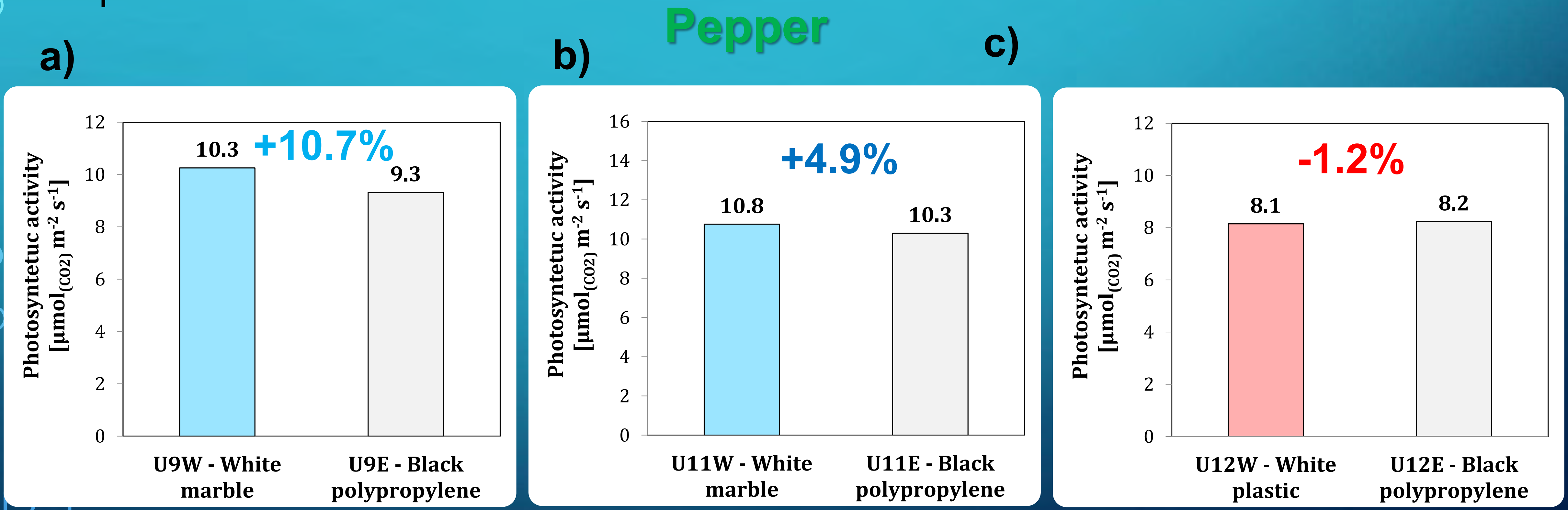


Figure 25. Photosynthetic activity in leaves of pepper in greenhouses U9 (a), U11 (b) and U12 (c) in the marble (■), white plastic (■) and propylene (■) mulched sectors of greenhouses.

Combined effect in crops production

The use of **white mulching** allowed to **increase tomato production**.

Tomato

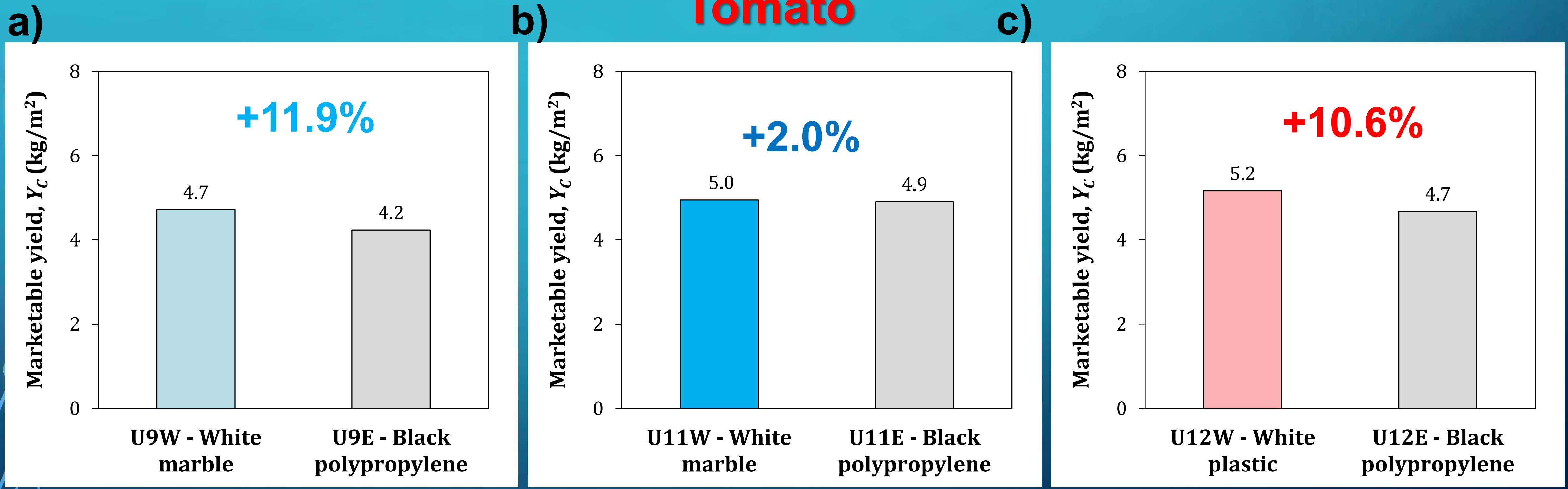


Figure 26. Marketable yield of tomato obtained in greenhouses U9 (a), U11 (b) and U12 (c) in the marble (■-■), white plastic (■) and propylene (■) mulched sectors of greenhouses.

Effect in crops early production (3 yields)

The **increases in production** produced by the **white mulching** has been also observed in the **three first yields** of the **pepper crop** (that has not finished).

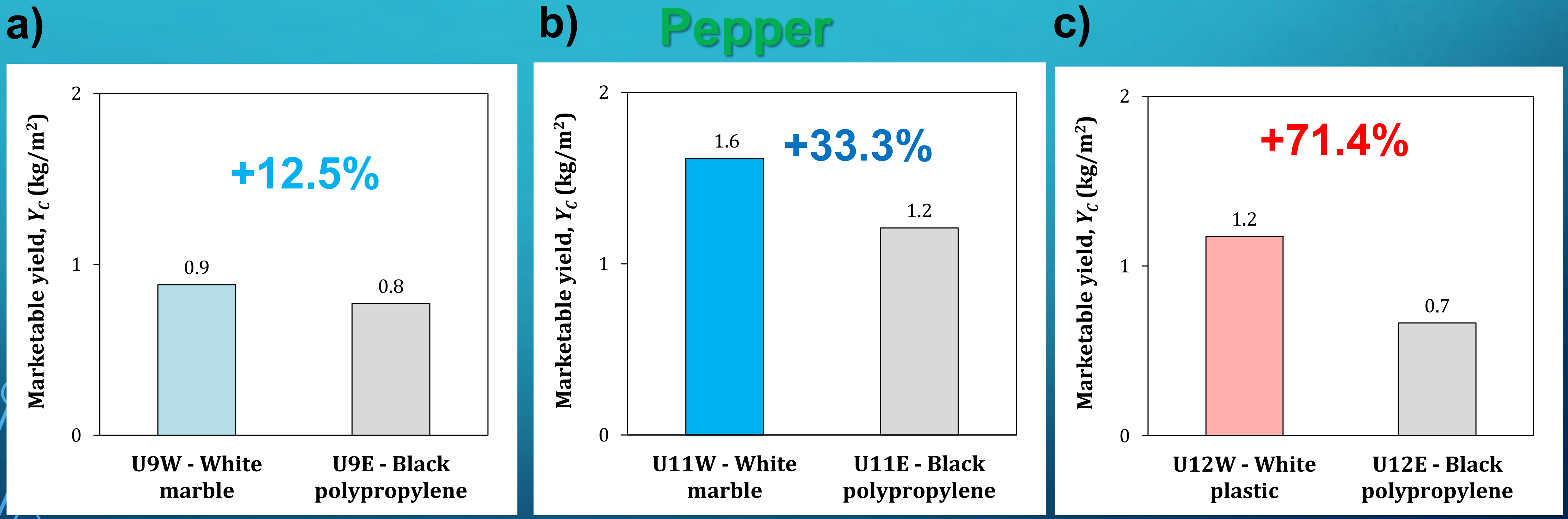


Figure 27. Early marketable yield of pepper obtained in greenhouses U9 (a), U11 (b) and U12 (c) in the marble (-), white plastic ( ) and propylene ( ) mulched sectors of greenhouses.

Effect on pest and diseases

The use of **soil marble mulching** seem to **increase** resistance of **crops** to **fungal diseases** as **powdery mildew** (*Leveillula taurica* (Lev.) Arnaud.) and **pests** as **tomato russet mite** (*Aculops lycopersici*) and **aphis** [*Myzus persicae* (Sulzer), *Aphis gossiipy* (Glover), *Macrosiphum euphorbiae* (Thomas) and *Aulacothum solani* (Kaltenbach)].

Table 6. Percentages of leaf damage in tomato and pepper crops grown in the 2023-24 season.

Greenhouse	U9-East	U9-West	U11-East	U11-West	U11-East	U11-West
Tomato cultivation autumn-winter 2023 (02/09/2023 - 23/02/2024)						
Tomato russet mite	**25.6**	16.0	**17.1**	7.5	18.8	21.9
Spring-summer pepper cultivation 2024 (08/03/2024 - .../07/2023)						
Aphids	**4.0**	0.0	**31.7**	2.3	-	-
Powdery mildew	**18.8**	0.0	2.1	**10.9**	-	-

Tomato russet mite
(15/2/2024)

Powdery mildew
(14/6/2024)

Aphis
(18/6/2024)

Conclusions

- The **soil marble mulching** allows **reduce maximum** inside **air temperature** by **–0.5ºC** in hot period, as result of the **reduction** of **–14%** on **net radiation** and **–65%** on **soil heat flux**.
- The two types of **white soil mulching** (**plastic** and **marble gravel**) produced an increase in **transpiration** of **tomato** and **pepper** crops of **+5.3-12.5%**.
- The augmentation in the **photosynthetic activity** of **+4.9-15.8%** produce an increases in **marketable production** of **+2-11.9%** of **tomato** in **autumn-winter cycle** and in **early production** of **+12.5-33.3%** of a **pepper** crops in **spring-summer cycle**.
- The use of **white marble gravel mulch** seems to have a **positive effect** on **plants resistance** to **fungal diseases** and **insect pests**, as consequence of **increases** in **photosynthetic activity.**
- **Marble gravel** can be a **sustainable alternative** in **Almería** to the use of white plastic mulching as passive system to **reduce air temperature** inside greenhouses.

Thank you for your attention

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Acknowledgements

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