EVALUATION OF THE AGRONOMIC EFFECTS PRODUCED BY A PHOTOVOLTAIC PANEL DURING A TOMATO CROP DEVELOPED IN GREENHOUSE

P096_2022

Crop Production Area

Almería, November 14th, 2023

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Content

1. OBJECTIVE

The objective of this trial consists in the evaluation of the agronomic effects produced by photovoltaic panels during a tomato crop developed in greenhouse.

2. MATERIAL AND METHODS

2.1. Location

This trial has been carried out in the Experimental Centre of the National Technologic Centre of the Auxiliary Industry of Agriculture, TECNOVA Foundation, located in Majada Ortigas Site (36˚53'N; 2˚22'W, 184 m elevation above the sea level), in the Municipal District of Viator, in the province of Almeria, in the southeast coast of Spain **(Figure 1).** This trial has been developed by technical staff of the National Technologic Centre of the Auxiliary Industry of Agriculture, TECNOVA Foundation.

Figure 1. General view of the Experimental Centre.

2.2. Facilites

The execution of this trial has been developed in two multispan greenhouses (greenhouses T3-1 and T3-3), with a total cultivated area of 500 m^2 each one **(Figure 2)**.

These greenhouses were equipped with air recirculators, an interior shading screen and an automated opening and closing system for side and roof windows.

The soil of these greenhouses has been an imported soil with three different layers: a heavy imported soil of 30 cm depth placed over the original soil of the Experimental Centre, covered with a layer of manure of 3 cm depth and with an upper sand layer of 10 cm depth used as a mulching.

The irrigation and fertilization of the tomato crop has been carried out using a drip irrigation system, with paired rows of dripper lines located at a distance of 1.5 m between pairs of lines and 0.3 m between two dropper-holder branches that were part of the same pair of lines, and with the emitters within the same dropper-holder branch located every 50 cm. The installation of drip irrigation has had self-compensating drippers with a unit flow of 3 litres hour^{-1} dripper^{-1}.

The fertigation system used during this trial has been controlled automatically with an irrigation unit provided with a programmer and four tanks of concentrated nutrient solution.

At the start of the trial, prior to transplanting the crops, the **Energy Glass Solar Panel System (described in Annex 1)** was installed on the Greenhouse T1 (T3-1) roof. This system comprises 36 Energy Glass Flexible photovoltaic panels, arranged in two rows of 18 panels each. Technicians from Proconsult, a local solar engineering company, conducted the installation on behalf of Energy Glass/Saxon Capital Group **(refer to Figures 3 and 4)**. The Energy Glass Panels installed on the greenhouse roof have been specifically designed for:

1). Passive electricity generation,

2). EMF & EMR resistant

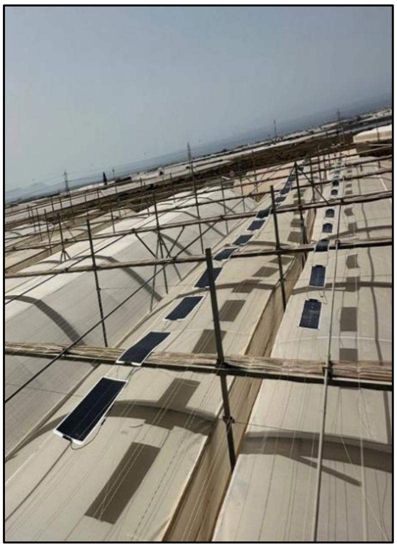
3). Bumble Bee and other pollinators friendly

4). Wind resistant

Three Inverters (**Fig. 7**), two storage batteries (**Fig. 8**) and an electrical control panel (**Fig. 5 and 6**), were, installed to make the greeenhosue self sufficent without the need of the electric grid.

The roof area of the greenhouse is 500 m2 (5,381.9 square feet). The Energy Glass photovoltaic panels installed have a total surface area of 20.6 m2 (222 square feet), covering only 4.12% of the total surface area.

Figure 2. General view of the greenhouse.



Figures 3 and 4. Two rows of Energy Glass Photovoltaic panels covering 4.12% of the total greenhouse roof area.

T0 (T3-3)

T1 (T3-1)

Figures 5 and 6. Electrical panels

Figures 7 and 8. Proconsult inverters and batteries

2.3. *Crop Management*

The field trial has been developed during a cherry tomato crop cycle (four months long). The tomato crop, evaluated variety “Genio”, has been transplanted the 3rd of August 2023 in the greenhouse, with more than 20 days old since its germination in the nursery and with three leaves completely developed **(Figure 9)**.

The plant density used has been 2 plants per m^2. During this trial the tomato crop have been guided using black polypropylene cords vertically tied to the wire structure of the greenhouse. The duration of the tomato cycle has been 115 days, and it has been removed 15th November 2023.

During this trial, the management strategy for all the evaluated treatments has been based on the contribution through the fertigation system of 100% of the crop evapotranspiration (ET_c) and a nutrient base solution to meet all the nutritional needed of the crop. The theorical ET_c of the crop have been estimated using the software PrHo and a historical climatic data serie.

The composition of the nutrient solution applied during the field trial is indicated in **Table 1.**

Table 1. Nutrient solution applied.

Parameter	**HCO_3^-**	**NH_4^+**	**K^+**	**NO_3^-**	**SO_4^-**	**Ca^{++}**	**Mg^{++}**	**$H_2PO_4^-$**	**Na^+**	**Cl^-**	**pH**	**CE (dS/m^{-1})**
(mmol l^{-1})	0.5	0.7	7.2	12.1	2.1	4.5	2.0	1.5	5.1	5.2	5.8	2.8

Figure 9. Tomato crop evolution.

2.4. *Experimental design*

Two experimental treatments have been evaluated during this trial, based on the use of photovoltaic panels, installed in the cover of the greenhouse:

- **T0 Treatment (connected to the grid):** It has been a control treatment, where there have **not been installed photovoltaic panels** (greenhouse T3-3). It is a traditional plastic tunnel of 500 square meters.
- **T1 treatment (Off Grid):** In this greenhouse the **Energy Glass photovoltaic panels have been installed** (greenhouse T3-1). It is a traditional plastic tunnel of 500 square meters.

Each experimental treatment has had three repetitions of 5 plants per repetition distributed randomly in the greenhouse. **Figure 10** schematically shows the distribution of the tomato plants inside the greenhouse.

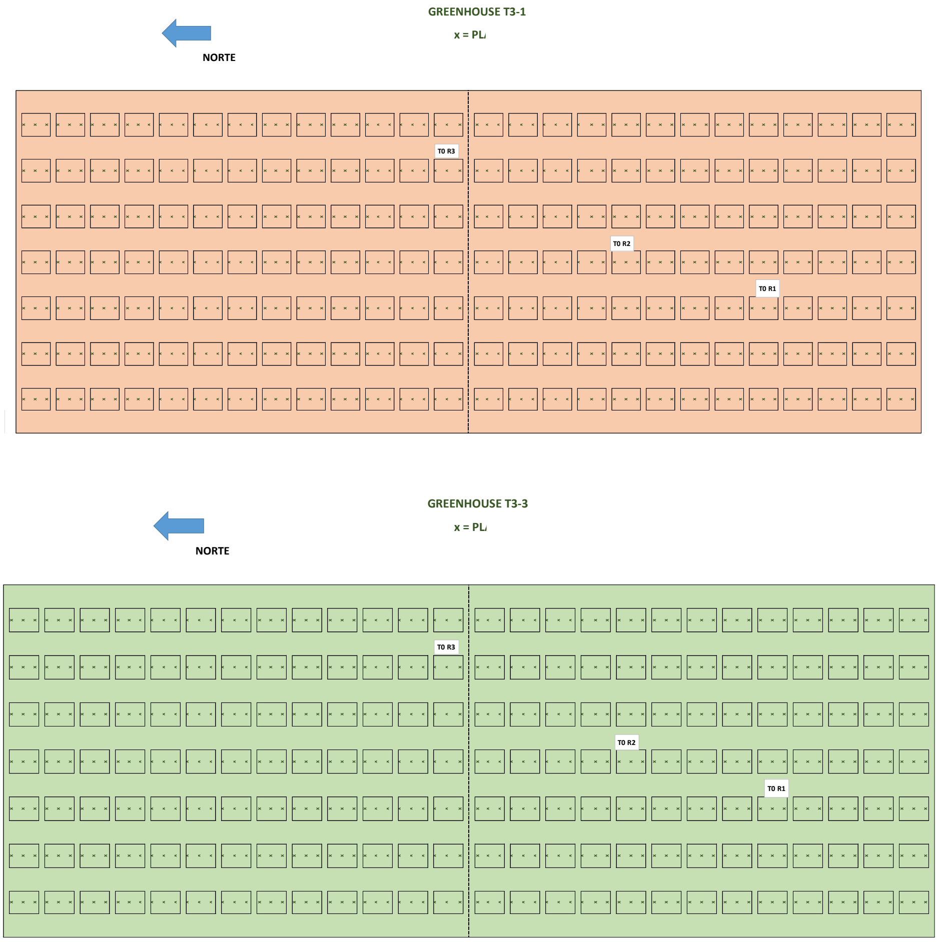


Figure 10. Distribution of plants inside the greenhouse.

2.5. *Characterised parameters*

1. <u>Climatic conditions:</u>

During all the field trial, the air temperature, and the air relative humidity inside each greenhouse, have been measured continuously using portable psychrometers (**Fig**. **11**). One psychrometer has been installed inside each greenhouse and another outside the greenhouses. These sensors have been programmed to measure data every 15 minutes.

Figure 11. Sensor to measure temperature and relative humidity of the air.

Also, three sensor of PAR radiation has been installed in this trial, one inside each greenhouse and another one outside the greenhouses to measure the incident PAR radiation using LI-COR Quantum Sensor LI-190 (Lincoln, NE 68504, USA) (**Figure 12**). These sensors have been installed in a horizontal position in the upper greenhouse area and have been programmed to make a data collection every minute, obtaining an average value every half an hour. The climatic data has been downloaded weekly and processed monthly.

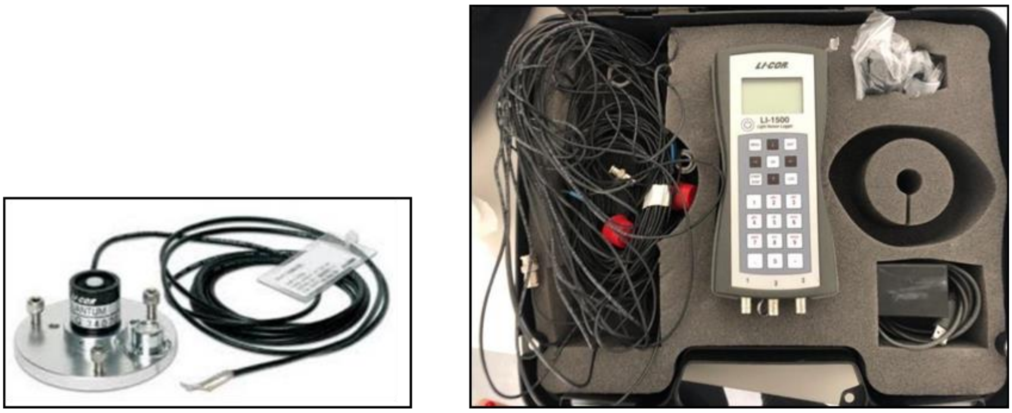


Figure 12. Logger and sensor used to measure the PAR radiation.

2. Crop growth:

Every two weeks and in five different moments of the vegetative growth phase of the tomato crop (19, 34, 48, 61 and 74 Days After Transplanting, DAT), six parameters have been measured and characterized: plant height, basal diameter of the main stem, number of developed leaves per plant, average distance between two consecutive leaves per plant, number of opened flowers per plant and number of developed fruits per plant, number of leaves expanded by plant and number of fruits by plant. This characterization has been developed in three repetitions per experimental treatment, and in five plants per repetition.

3. Yield:

The number and fresh weight of tomato fruits harvested have been measured in each episode of multiple harvests. There have been developed seven harvesting episodes of tomato fruits during this field trial. The harvested tomato fruits have been classified as commercial and non-commercial fruits.

The commercial tomato fruits have been classified in different commercial categories based on its equatorial diameter. This characterization has been developed in five tomato plants per repetition an in three repetitions per experimental treatment.

4. Pollinating activity

Every two weeks and in ten different moments (19, 25, 34, 48, 61, 74, 82, 89, 97 and 102 Days After Transplanting, DAT) the pollinating activity made by bumblebees have been measured counting the number of chopped flowers. This measurement has been developed in five tomato plants per repetition and in three repetitions per experimental treatment.

5. Population dynamic evaluation:

Every two weeks and in different moments (7, 14, 19, 34, 48, 56, 62, 76, 83, 89 and 96 DAT Days After Transplanting, DAT) the population dynamic evaluation of all the pests that appear naturally (*Tuta absoluta, Bemisia tabaci, Frankiniella occidentalis, Tetranychus urticae, Polyphagotarsonemus latus, Aculops lycopersic, Aphids spp.*...etc.) in the tomato crop have been measured by counts per plant. Five plants have been evaluated per treatment and repetition. In each plant has been count the total number of these pests. Said samplings have been carried out first thing in the day and by the same technical staff to avoid experimental errors.

6. Electromagnetic field measurements:

The electromagnetic field generated by the **Energy Glass electrical panels** installed by Proconsult (T3-1) and the traditional electrical panels installed in the greenhouse (T3-3) has been measured using an EMF detector (**Figure 13**), a portable device that measures electric field values (E) in V/m and magnetic field values (H) in milliGauss (mG) or microTesla (µT). The measurement has carried out by a Proconsult technician in the electrical panels located in both greenhouses (T3-1 and T3-3). The measurement has been done on 5 different parts of each electrical panel (top, bottom, right, left and centre).

Figure 13. Electrical and magnetic field detector (EMF)

2.6. Statistical treatment

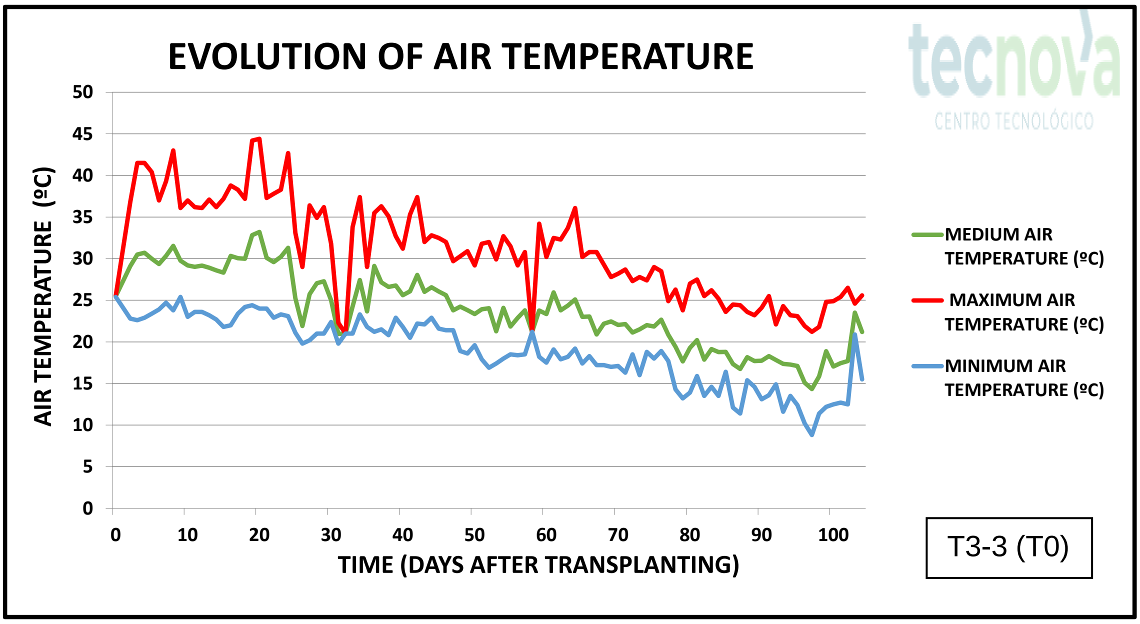
A statistical study of standard deviation and statistical error analysis has been carried out to determine if there have been statistically significant differences between the average values of the parameters characterized during this trial, with a confidence level of 95%. The programme Statgraphics Centurion XV software (Statpoint Technologies Inc., Warrenton, Virginia, USA) has been used to perform this statistical treatment.

3. RESULTS

3.1. Climatic conditions

In **Figures 14 to 19** are presented the daily data of medium, maximum, and minimum temperature and relative humidity of the air registered inside the T3-3 (T0) and T3-1 (T1) greenhouses and outside, respectively. The average air temperature that has been reached during this trial in the treatment T0 has been 23.8ºC and it has been included in a range that has oscillated between 8.8 and 44.4ºC, and in the treatment T1 has been 24.5ºC and it has been included in a range that has oscillated between 9.2 and 45.7ºC. The average relative humidity of the air reached during the trial in the treatment T0 has been 70.3% and it has oscillated in a range between 13.0% and 98.0% and in the treatment T1 it has been 69.1% and it has oscillated in a range between 21.0% and 100%.

The outside climatic conditions have been 22.4 ºC average of air temperature ranging from a minimum of 8.3ºC to a maximum of 38.2 ºC (**Figure 16**), and 65.3 % relative humidity ranging from a minimum of 3.9% to a maximum of 100% (**Figure 19**).


EVOLUTION OF AIR TEMPERATURE
AIR TEMPERATURE (ºC)
50
45
40
35
30
25
20
15
10
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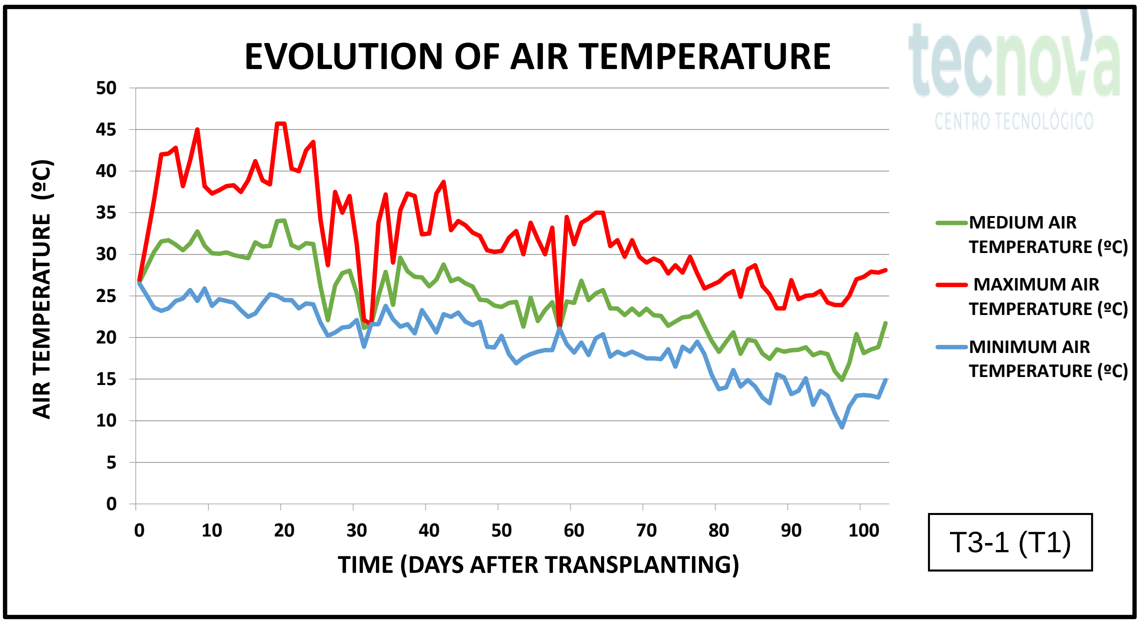
0
0
10
20
30
40
50
60
70
80
90
100
TIME (DAYS AFTER TRANSPLANTING)
tecnova CENTRO TECNOLÓGICO
MEDIUM AIR TEMPERATURE (ºC)
MAXIMUM AIR TEMPERATURE (ºC)
MINIMUM AIR TEMPERATURE (ºC)
T3-3 (T0)


EVOLUTION OF AIR TEMPERATURE
AIR TEMPERATURE (ºC)
50
45
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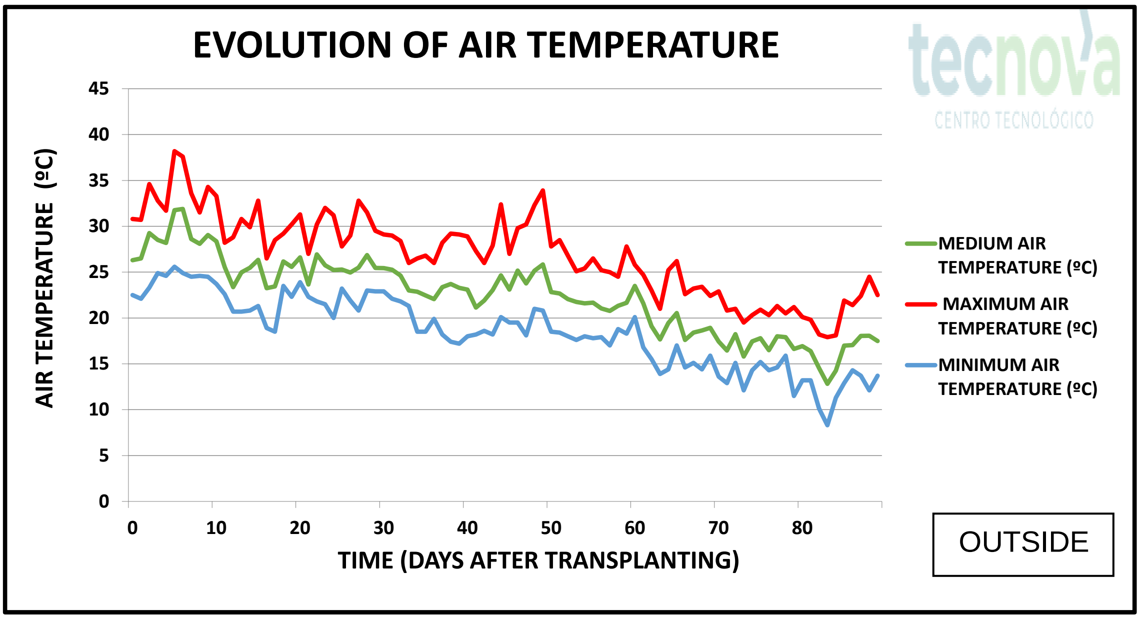
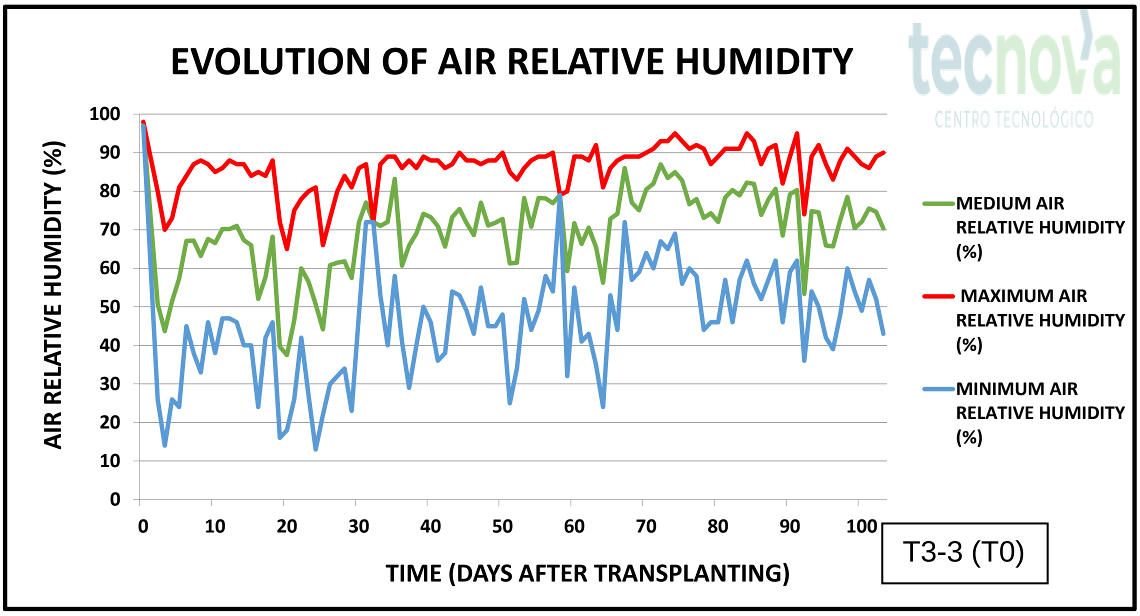
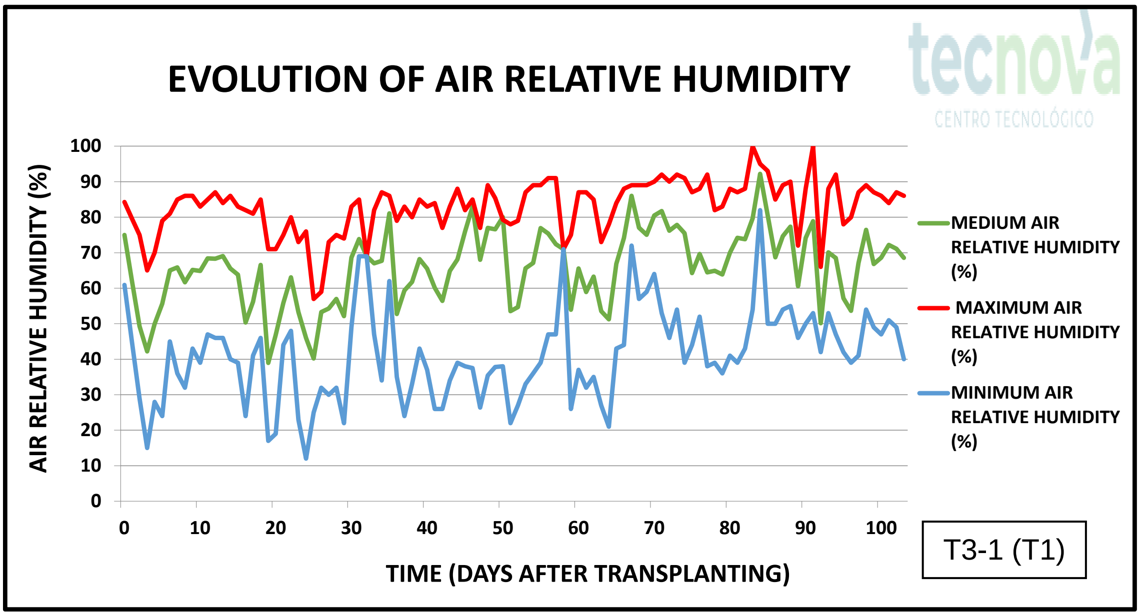
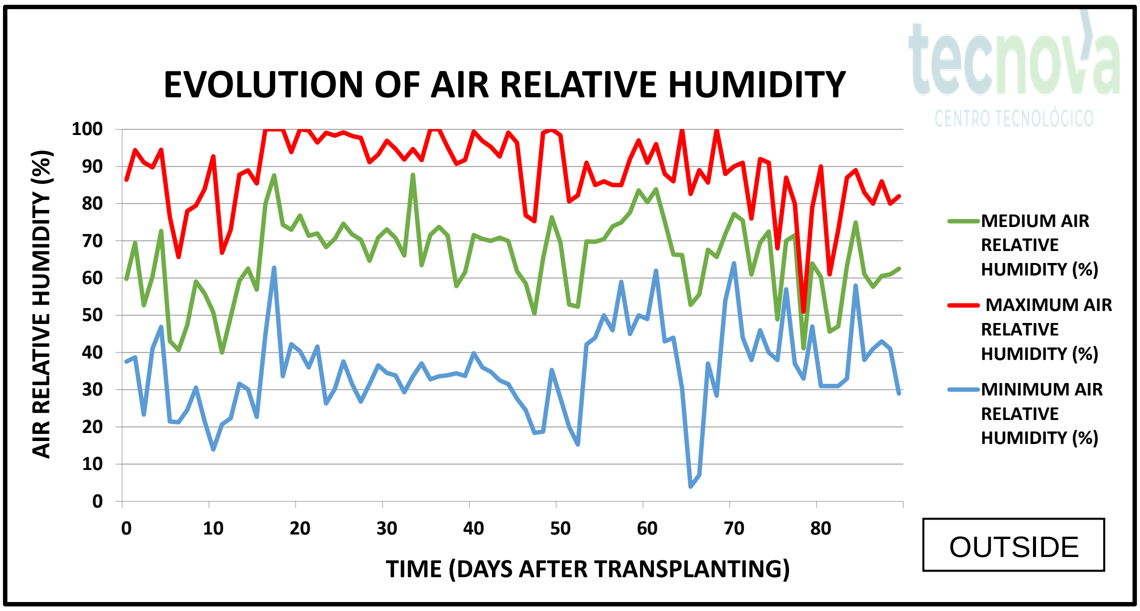
100
TIME (DAYS AFTER TRANSPLANTING)
tecnova CENTRO TECNOLÓGICO
MEDIUM AIR TEMPERATURE (ºC)
MAXIMUM AIR TEMPERATURE (ºC)
MINIMUM AIR TEMPERATURE (ºC)
T3-1 (T1)



Figures 14, 15 16. Evolution of the air temperature of T3-1, T3-3 and outside the greenhouse, respectively.







Figures 17, 18 and 19. Evolution of the air relative humidity of T3-1, T3-3 and outside the greenhouse, respectively.

Figure 20 shows the evolution of daily integral of PAR radiation (Photosynthetically Active Radiation) incident on the crop under each film plastic material evaluated and outside the greenhouses during all the trial. **Figure 21** shows the coefficient of transmissivity of each treatment. During the period that ranged between 0-103 DAT (Days After Transplanting), there has been installed one PAR radiation sensor per treatment (T0 and T1) and one sensor outside the greenhouse.

The average values of the daily integral of PAR radiation measured and estimated throughout the trial have been of 6.2 MJ m^{-2} day^{-1}; 6.3 MJ m^{-2} day^{-1} and 16.0 MJ m^{-2} day^{-1} for treatments T0, T1 and outside, respectively (**Figure 20**).

The average transmissibility coefficients measured and estimated during the trial have been 42.5 and 42.6% for the experimental treatments T0 and T1, respectively (**Figure 21**).

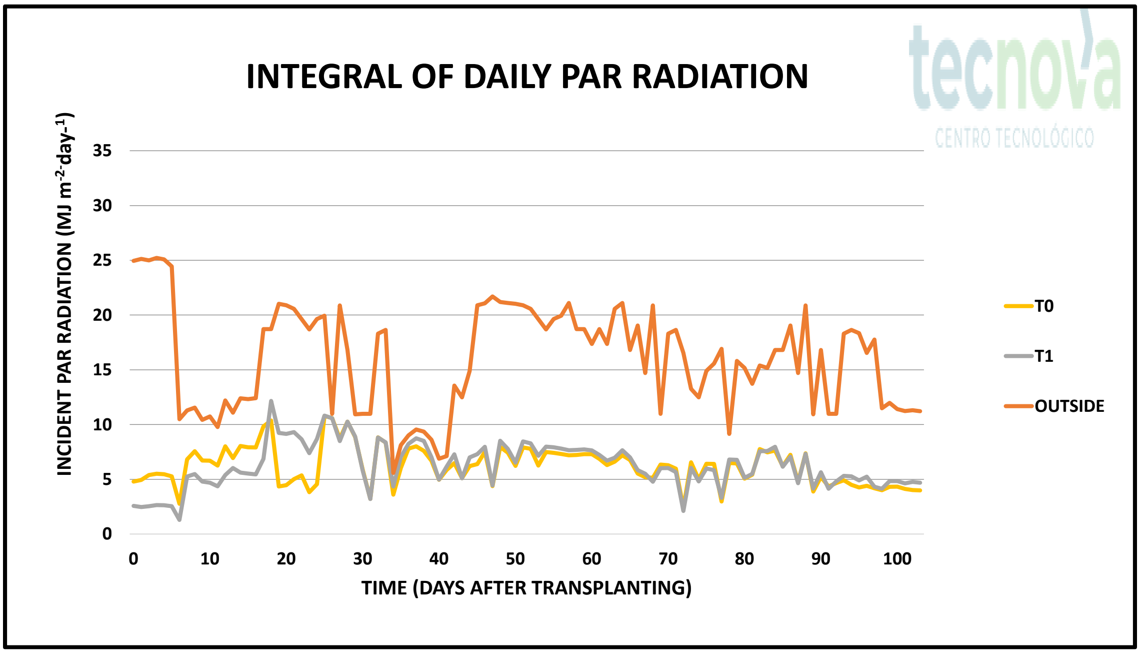


Figure 20. Evolution of the daily integral of PAR radiation.

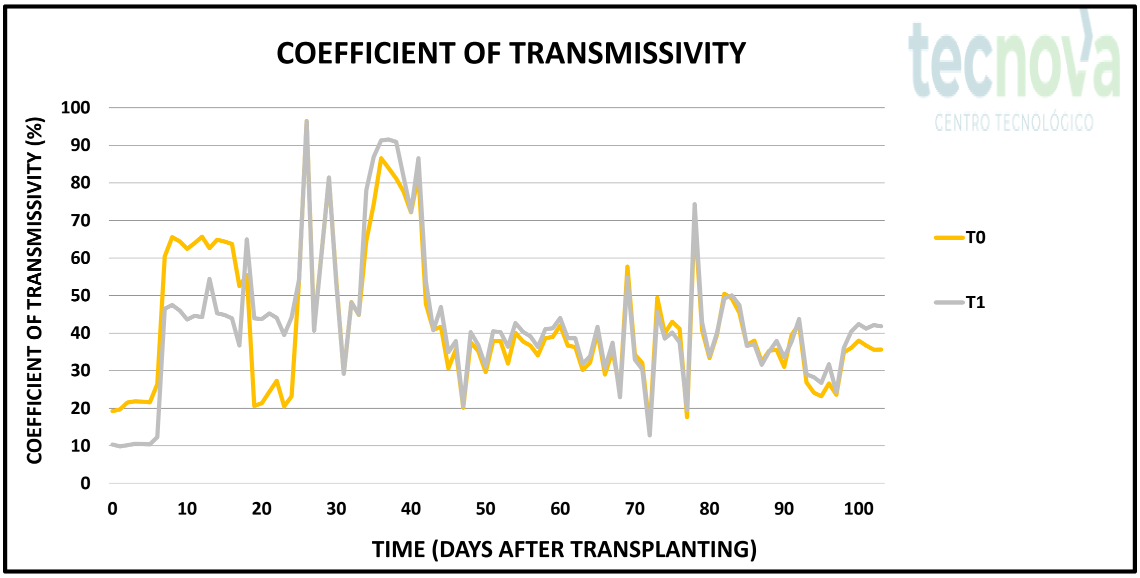


Figure 21. Evolution of the daily transmissibility coefficient.

Figure 22 shows the daily data of medium, maximum, and minimum wind speed in metres per second (m/s) outside the greenhouses during all the trial, the average of wind speed has been 2.0 m/s ranging from a minimum of 0.0 to a maximum of 12.9 m/s.

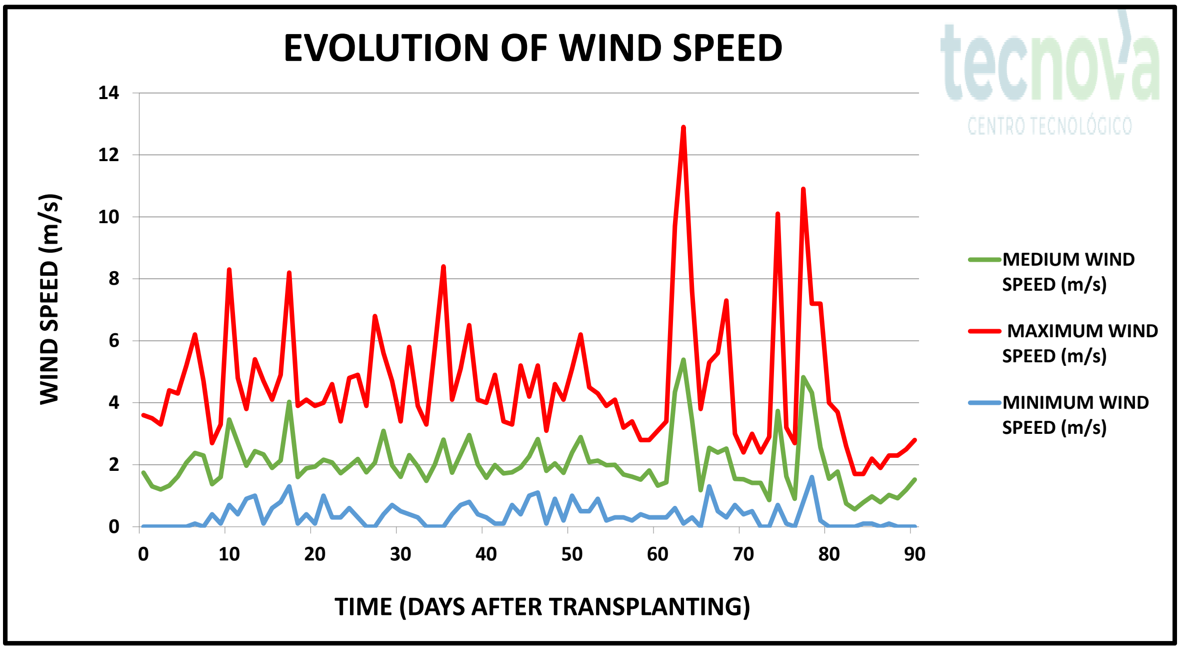


Figure 22. Evolution of wind speed.

3.2. Crop growth

The results obtained from the different growth parameters evaluated are within the range of normality and align with those previously obtained in other tests. These results indicate that the plants are normal and healthy.

- **<u>Evolution of crop height</u>**

Height is measured because it considerably influences the yield of the crop. Therefore, it is an essential parameter to measure during the trial, as it indicates the plant's health status Height is measured because it considerably influences the yield of the crop. Therefore, it is an essential parameter to measure during the trial, as it indicates the plant's health status.

For a cherry tomato plant, as in our case, to be considered healthy and for its yield to be within normal values, it must reach a height of between 200-300 cm in 3 months, which has been achieved during this trial

Table 2 and **Figure 23** show the results (average values and standard error for all the experimental treatments) of the evolution of the tomato crop height characterized during the vegetative growth phase at five different moments of the trial.

The height of the tomato crop has been increasing progressively during the vegetative growth phase in all the experimental treatments evaluated. Since the beginning of crop, the crop height has been higher in the treatment T0, finding statistically significant differences between treatments.

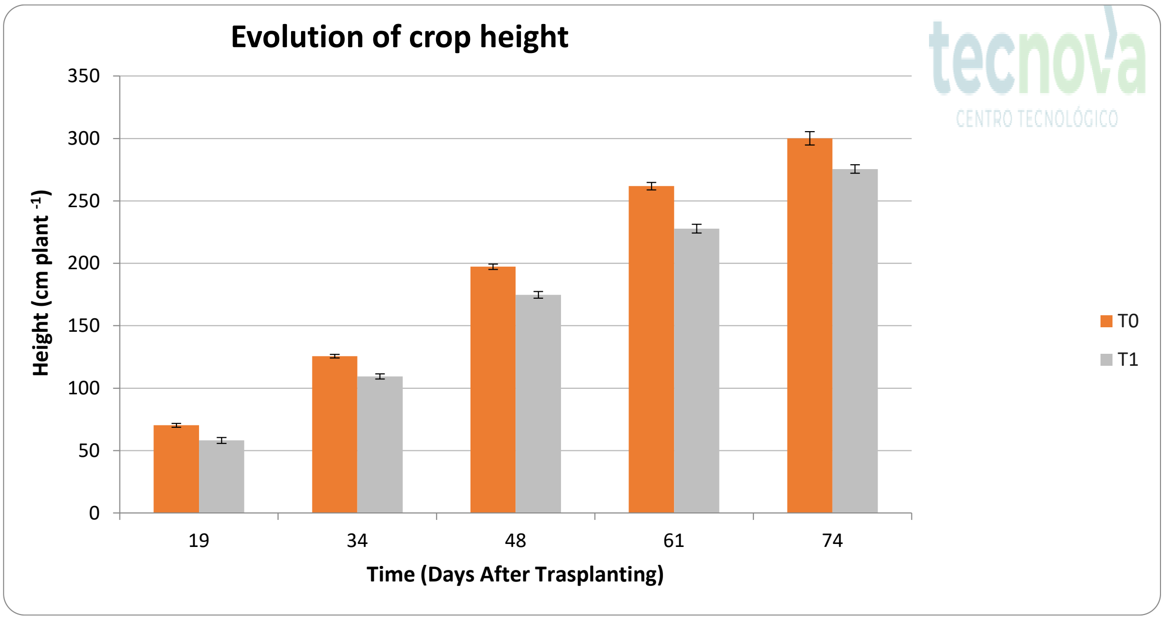


Figure 23. Evolution of crop height.

Table 2. Averages values and standard error of the evolution of crop height.

	EVOLUTION OF CROP HEIGHT (cm plant-1)									
	AVERAGE					STANDARD ERROR				
Treatment/DAT	19	34	48	61	74	19	34	48	61	74
T0	70.3 b	125.7 b	197.3 b	261.8 b	300.1 b	1.5	1.4	2.1	2.9	5.3
T1	58.2 a	109.5 a	174.8 a	227.8 a	275.5 a	2.4	2.0	2.7	3.4	3.4

*Different letters indicate statistically significant differences between treatments.

- **Evolution of basal diameter of main stem**

The basal diameter of the main stems is measured because it significantly influences the development of the roots and the yield of the crop. Therefore, it is an essential parameter to measure during the trial, as it indicates the health status of the plant. A better basal diameter leads to a more developed root system, which in turn enhances nutrient uptake from the soil and increases the yield.

For a cherry tomato plant, as in our case, to be considered healthy, it must reach a basal diameter of between 1-2 cm in 3 months. This has been achieved during this trial.

Table 3 and **Figure 24** show the results (average values and standard error for each experimental treatment) of the basal diameter of the main stem during the vegetative growth phase, at five different moments of the trial

The evolution of the basal diameter of the main stem of the tomato crop has been increasing progressively during the vegetative growth phase in all the experimental treatments evaluated, until reaching 1.5 cm. Significant differences have only been found between treatments at 19 DAT, where the treatment T0 showed higher basal diameter values. At 74 DAT the basal diameter of the main stem has been similar in both treatments.

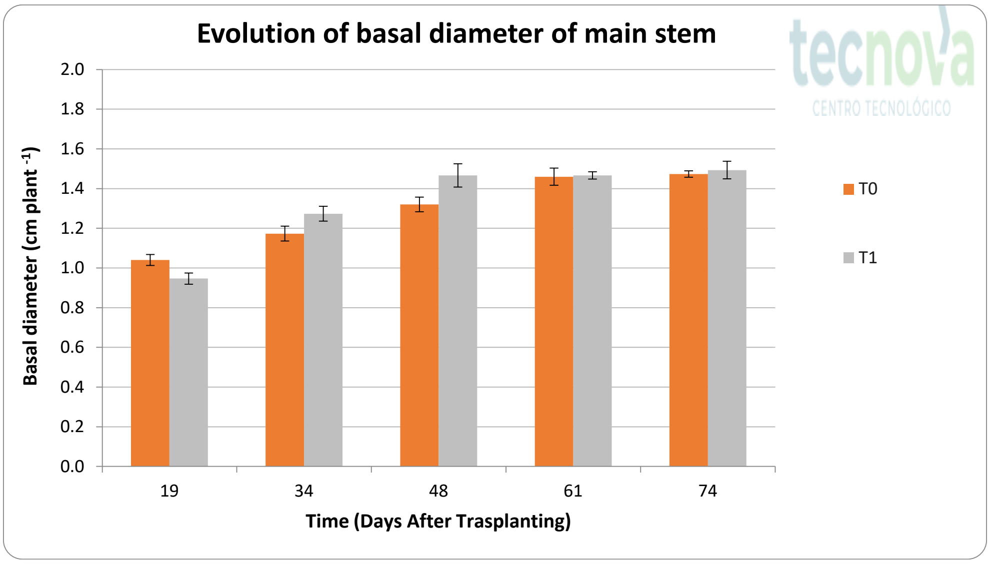


Figure 24. Evolution of the basal diameter of the main stem.

Table 3. Averages values and standard error of the basal diameter of the main stem.

	EVOLUTION OF BASAL DIAMETER OF THE CROP (cm plant-1)									
	AVERAGE					STANDARD ERROR				
Treatment/DAT	19	34	48	61	74	19	34	48	61	74
T0	1.0 b	1.2 a	1.3 a	1.5 a	1.5 a	0.0	0.0	0.0	0.0	0.0
T1	0.9 a	1.3 a	1.5 a	1.5 a	1.5 a	0.0	0.0	0.1	0.0	0.0

*Different letters indicate statistically significant differences between treatments.

- **Evolution of the distance between internodes**

The distance between internodes is measured because it significantly influences productivity. Shorter internodes indicate greater productivity of the plant, as this suggests that a higher number of fruit-bearing branches will be produced, leading to a greater yield. Conversely, longer internodes will suggest lower productivity, with fewer branches formed and, consequently, fewer fruits and reduced yield.

For a cherry tomato plant, as in our case, to be considered healthy, it must reach an internode distance of between 6-9 cm in 3 months. This has been achieved during this trial.

Table 4 and **Figure 25** show the results (average values and standard error for each experimental treatment) of the evolution of the estimated average distance between two consecutive leaves per plant (distance between internodes) at five different moments of the trial.

The evolution of the distance between internodes in the tomato crop has been increasing progressively during the vegetative growth phase in all the experimental treatments evaluated. Statistically significant differences have been found during all the trial, and the distance between consecutive internodes has always been higher in the treatment T0.

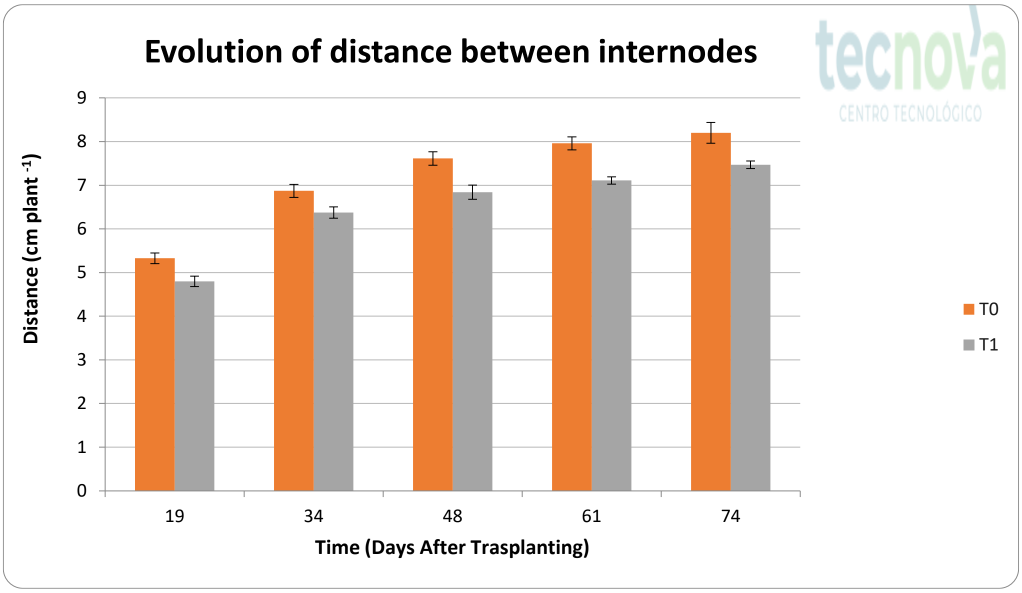


Figure 25. Evolution of the distance between internodes

Table 4. Averages values and standard error of the distance between internodes

	EVOLUTION OF THE DISTANCE BETWEEN INTERNODES (cm plant-1)									
	AVERAGE					STANDARD ERROR				
Treatment/DAT	19	34	48	61	74	19	34	48	61	74
T0	5.3 b	6.9 b	7.6 b	8.0 b	8.2 b	0.1	0.1	0.2	0.1	0.2
T1	4.8 a	6.4 a	6.8 a	7.1 a	7.2 a	0.1	0.1	0.2	0.1	0.1

*Different letters indicate statistically significant differences between treatments.

- **Evolution of the number of developed leaves**

The number of leaves is measured because it significantly influences the process of photosynthesis, and consequently, the plant's yield. The greater the number of leaves, the higher the photosynthetic activity, which results in better crop health and a greater yield.

For a cherry tomato plant, as in our case, to be considered healthy, it must have between 30-40 leaves in 3 months. This has been achieved during this trial.

Table 5 and **Figure 26** showed the results (average values and standard error for each experimental treatment) of the number of developed leaves per plant during the vegetative growth phase at five different moments of the trial.

The evolution of the number of developed leaves by the crop has been increasing progressively during the vegetative growth phase in all the experimental treatments evaluated. However there has not been found statistically significant differences between the treatments.

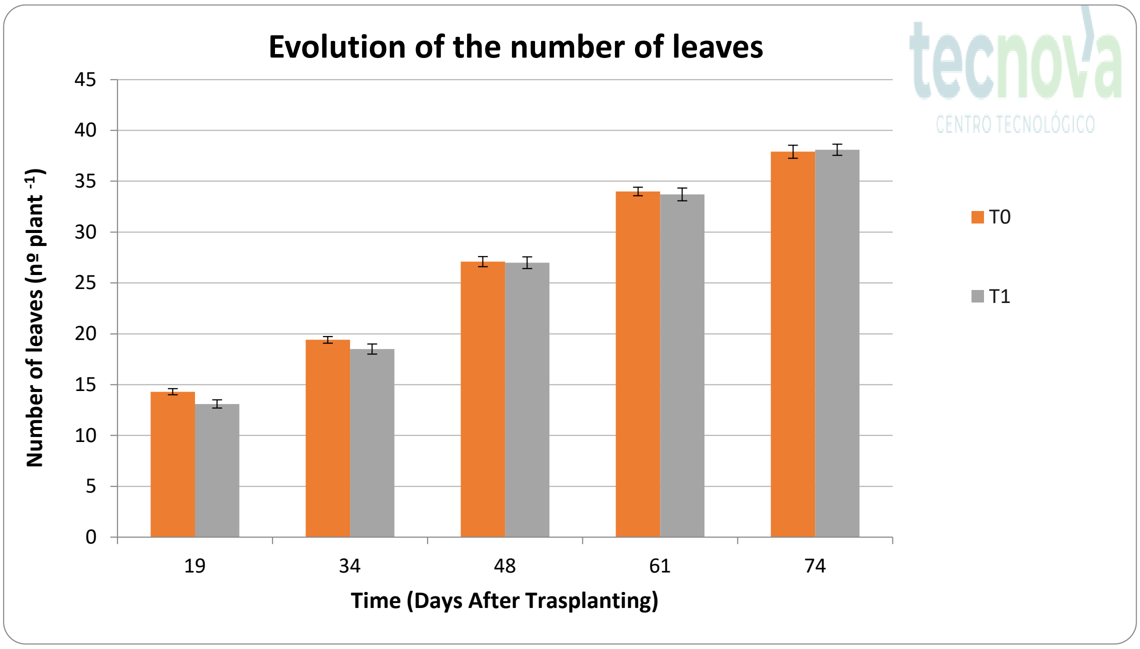


Figure 26. Evolution of the number of developed leaves.

Table 5. Averages values and standard error of the number of developed leaves.

	EVOLUTION OF LEAVES OF THE CROP (nº leaves plant-1)									
	AVERAGE					STANDARD ERROR				
Treatment/DAT	19	34	48	61	74	19	34	48	61	74
T0	14.3 a	19.4 a	27.1 a	34.0 a	37.9 a	0.3	0.3	0.5	0.4	0.6
T1	13.1 a	18.5 a	27.0 a	33.7 a	38.1 a	0.4	0.5	0.6	0.6	0.5

*Different letters indicate statistically significant differences between treatments.

- **<u>Evolution of the number of opened flowers</u>**

The number of flowers is measured because it significantly influences the process of photosynthesis, the development of fruits, and consequently, the plant's yield. Each flower has the potential to become a fruit through the process of pollination, typically by bumblebees.

For a cherry tomato plant, as in our case, to be considered healthy, it should have between 5-10 flowers per measurement and per plant. <u>This standard has been achieved during this trial.</u>

Table 6 and **Figure 27** showed the results (average values and standard error for each experimental treatment) of the number of opened flowers per plant during the vegetative growth phase at five different moments of the trial.

Statistically significant differences between treatments have been found at 34 DAT, when the number of opened flowers has been higher in treatment T1. Significant differences have also been found at 74 DAT, but in this case the number of opened flowers has been higher in treatment T0.

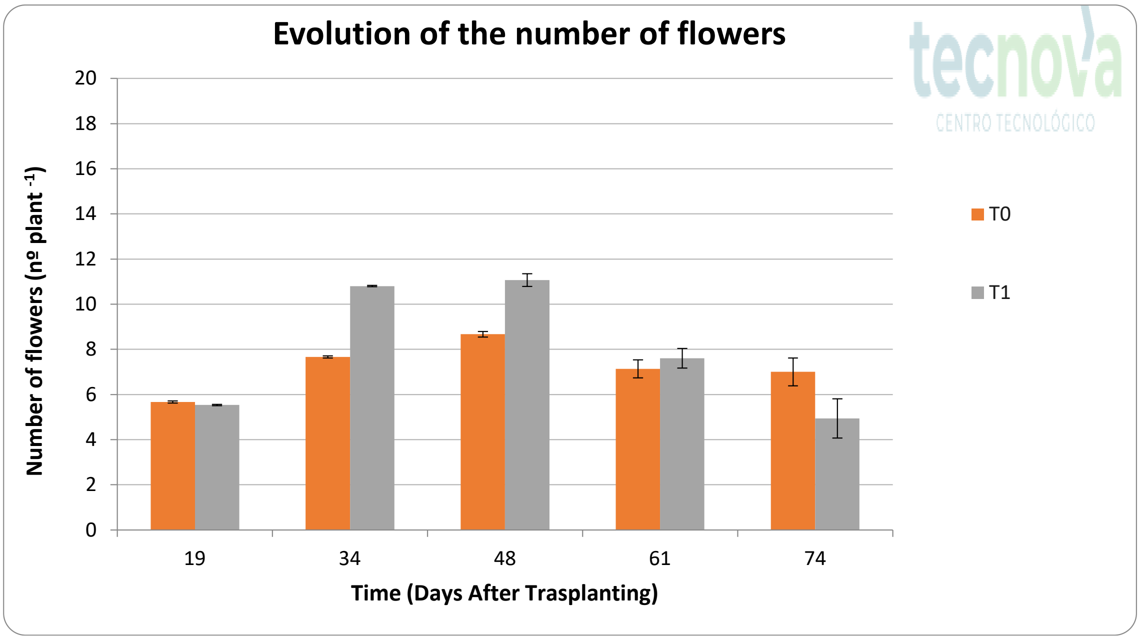


Figure 27. Evolution of the number of opened flowers.

Table 6. Averages values and standard error of the number of opened flowers.

	EVOLUTION OF NUMBER OF FLOWERS (number flower plant-1)									
	AVERAGE					STANDARD ERROR				
Treatment/DAT	19	34	48	61	74	19	34	48	61	74
T0	5.7 a	7.7 a	8.7 a	7.1 a	7.0 b	0.4	0.4	0.7	0.8	0.7
T1	5.5 a	10.8 b	11.1 a	7.6 a	4.9 a	0.5	0.8	1.0	0.7	0.5

*Different letters indicate statistically significant differences between treatments.

- <u>**Evolution of the number of fruits on development**</u>

The number of fruits is measured to calculate the yield produced by the crop, which is directly influenced by the parameters indicated above.

For a cherry tomato plant, as in our case, to be considered healthy, it should have between 90-100 fruits per plant in 3 months. This standard has been achieved during this trial

Table 7 and **Figure 28** showed the results (average values and standard error for each experimental treatment) of the number of fruits on development per plant during the vegetative growth phase at five different moments of the trial.

There has not been found statistically significant differences between the treatments, and the number of tomato fruits on development has been increasing progressively during the vegetative growth phase in all the experimental treatments evaluated. At 74 DAT the number of fruits on development has been higher in the treatment T0.

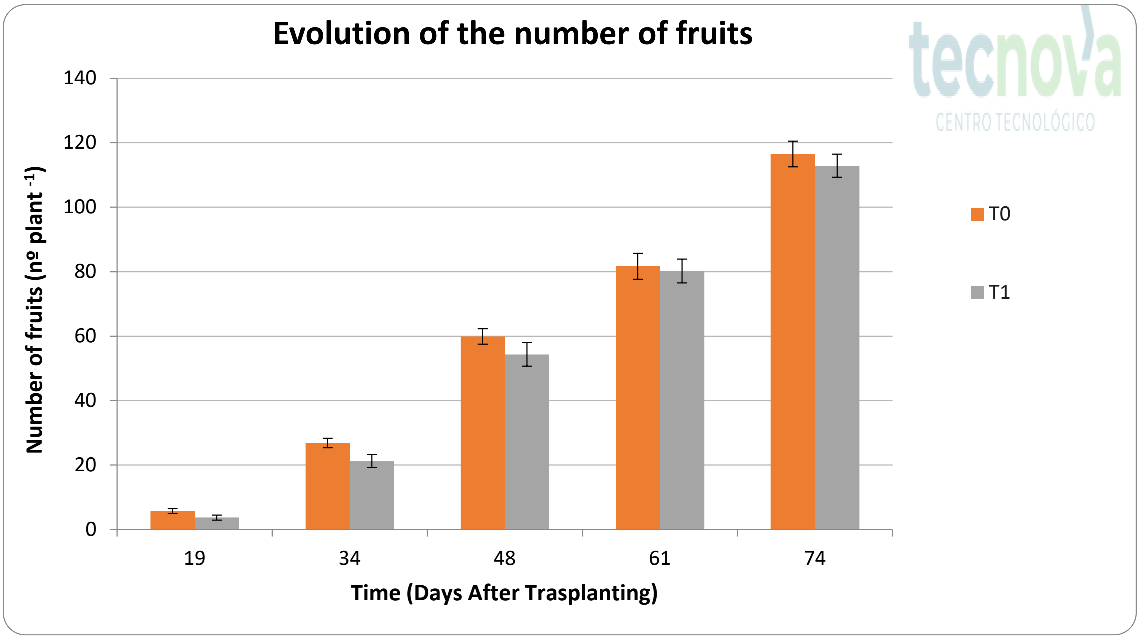


Figure 28. Evolution of the number of fruits on development.

Table 7. Averages values and standard error of the number of fruits on development.

	EVOLUTION OF NUMBER OF FRUITS (number fruits plant-1)									
	AVERAGE					STANDARD ERROR				
Treatment/DAT	19	34	48	61	74	19	34	48	61	74
T0	5.7 a	26.9 a	59.9 a	81.7 a	116.5 a	0.8	1.5	2.4	4.0	4.0
T1	3.7 a	21.3 a	54.3 a	80.2 a	112.9 a	0.8	2.0	3.6	3.7	3.6

*Different letters indicate statistically significant differences between treatments.

3.3. Yield

The yield measured at each DAT (Days After Transplanting) is the cumulative yield. For example, at 75 DAT, the values obtained in the table are the sum of the yields achieved at 56 DAT and 75 DAT (cumulative yield). Therefore, at the end of the test (103 DAT), it will be the sum of all the yields recorded on the preceding days.

In each episode of multiple fruit harvests, commercial fruits have been classified into categories based on their equatorial diameter, distinguishing between the following commercial categories: category 1 (equatorial diameter greater than 30 mm), category 2 (equatorial diameter between 20-30 mm), and category 3 (equatorial diameter less than 20 mm). Fruits smaller than 20 mm are considered non-commercial.

The normal values of accumulated commercial yield for a cherry tomato crop over three months range from 2.5 to 4 kg per m². **The values reached during this trial fall within this range, with (T1) producing 2.9 kg per m², and (T0) 2.8 kg per m².**

Figures 29 and **30** show the results of the accumulated yield evolution (expressed as average values of fresh weight of harvested fruits in each episode of fruit harvesting and in each evaluated experimental treatment) of commercial and total (commercial fruits + non-commercial fruits) fruit yield harvested during the trial. The commercial fruits are those suitable for sale and are usually classified in categories according to their size, and the non-commercial fruits are those that have suffered damage and are not suitable for marketing.

Tables 8, 9, 10 and **11** show the results of the average values and standard error of the fresh weight of harvested fruits in each experimental treatment and each episode of fruit harvesting.

In the same way, **figures 31** and **32** show the results of the accumulated number of fruits produced (expressed as average values of the number of fruits harvested in each episode of multiple harvests of fruit and in each experimental treatment evaluated) of commercial and total fruits (commercial fruits + non-commercial fruits) during the trial. **Tables 12, 13, 14** and **15** show the average values and the standard error of the number of fruits (commercial and total fruits) harvested in each experimental treatment and in each episode of multiple fruit harvests made during the trial.

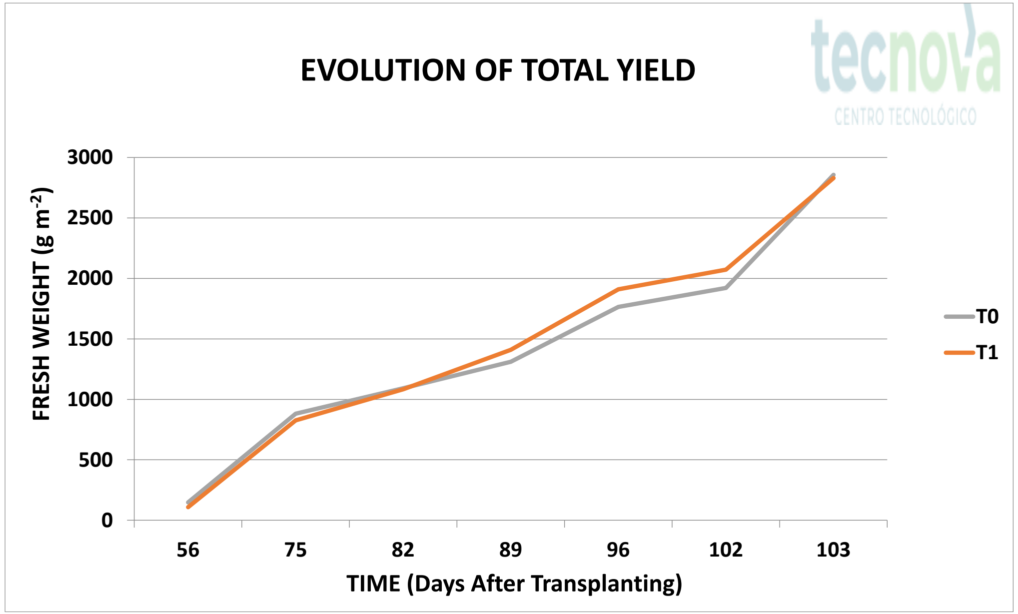
Statistically significant differences have been found in the fresh weight of total fruits (commercial + non-commercial) and commercial fruits between treatments only at 56 and 102 DAT (Days After Transplanting), being higher the values of commercial and total fresh weight at 56 DAT in the treatment T0 and at 102 DAT in the treatment T1.

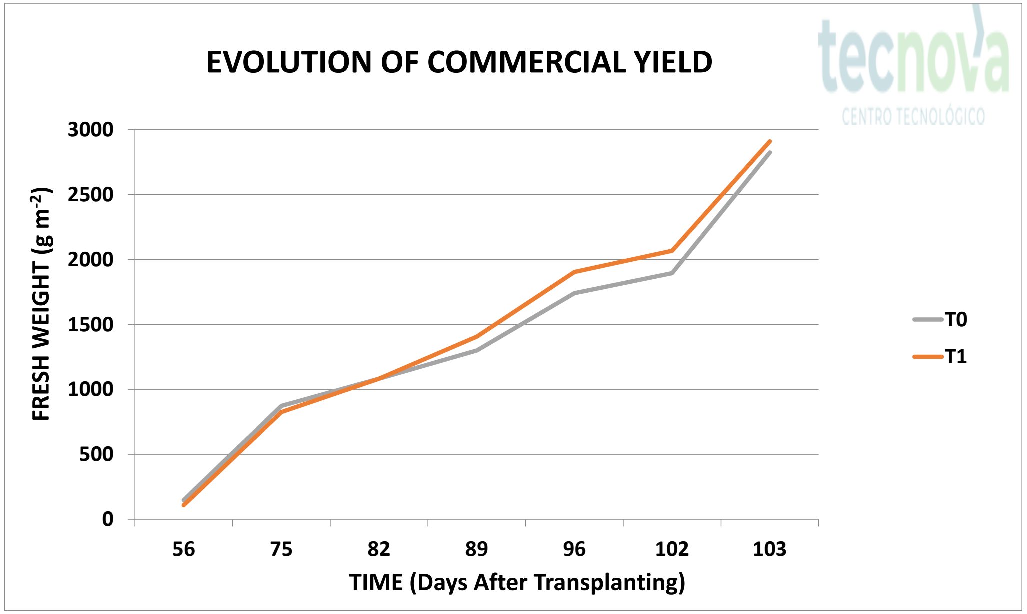
T1 Produce Samples 102 DAT

In other episodes of multiple fruit harvests made during the trial, since 89 DAT the total and commercial fresh weight have been higher in the treatment T1 with respect to the treatment T0 (**Tables 8** and **10**), although without statistically significant differences.

Statistically significant differences have been found in the number of commercial and total fruits (commercial + non-commercial) between treatments only in the first harvest, 56 DAT (Days After Transplanting), being higher the values of commercial and total number of fruits in the treatment T0.

In other episodes of multiple fruit harvests there has not been found statistically significant differences between the treatments, although the total and commercial number of fruits at the end of the trial have been slightly higher in the treatment T0 with respect to the treatment T1 (**Tables 12** and **14**).





Figures 29 and 30. Evolution of accumulated fresh weight of total and commercial fruits of the tomato crop.

Tables 8 and 9. Evolution of accumulated fresh weight of total fruits (average and standard error) of the tomato crop.

	Average values of the evolution of total yield (g/m^2)						
Treatment	**56**	**75**	**82**	**89**	**96**	**102**	**103**
T0	147.6 b	881.6 a	1091.4 a	1311.1 a	1764.6 a	1920.8 a	2856.3 a
T1	108.0 a	826.0 a	1083.9 a	1409.8 a	1910.0 a	2072.8 b	2828.9 a

	Standard error of the evolution of total yield						
Treatment	**56**	**75**	**82**	**89**	**96**	**102**	**103**
T0	4.7	56.6	53.1	29.6	24.0	6.0	114.7
T1	6.6	105.9	123.6	107.6	66.9	45.6	164.4

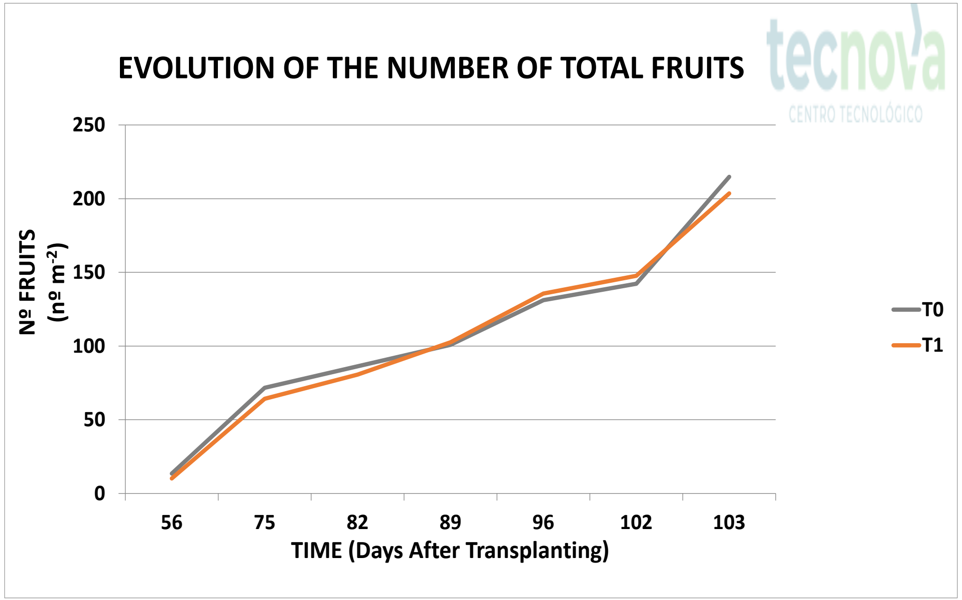
**Different letters indicate statistically significant differences between treatments.*

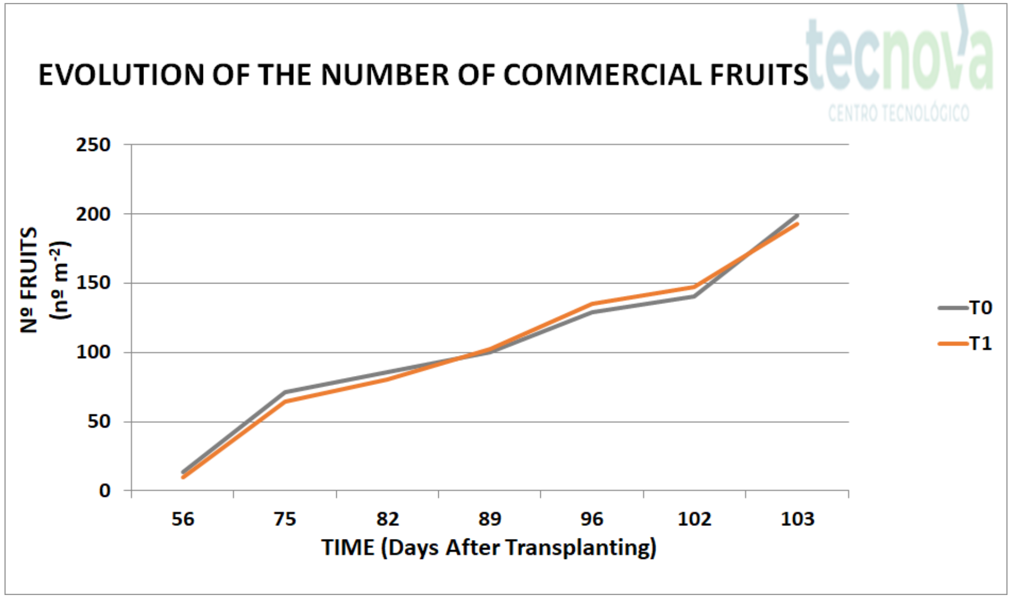
Tables 10 and 11. Evolution of accumulated fresh weight of commercial fruits (average and standard error) of the tomato crop

	Average values of the evolution of commercial yield (g/m^2)						
Treatment	**56**	**75**	**82**	**89**	**96**	**102**	**103**
T0	147.6 b	873.6 a	1082.0 a	1300.1 a	1740.8 a	1894.4 a	2824.6 a
T1	108.0 a	826.0 a	1082.4 a	1406.9 a	1904.3 a	2067.1 b	2910.2 a

	Standard error of the evolution of commercial yield						
Treatment	**56**	**75**	**82**	**89**	**96**	**102**	**103**
T0	4.7	62.2	59.5	36.5	31.0	16.2	106.7
T1	6.6	105.9	122.7	108.2	69.7	48.8	168.1

**Different letters indicate statistically significant differences between treatments.*





Figures 31 and 32. Evolution of total and commercial accumulated number of fruits of the tomato crop.

Tables 12 and 13. Evolution of accumulated total number of fruits (average and standard error) of the tomato crop.

	Average values of the evolution of the number of total fruits (No. m^2)						
Treatment	56	75	82	89	96	102	103
T0	13.4 b	71.7 a	86.2 a	100.8 a	131.1 a	142.3 a	214.9 a
T1	10.1 a	64.2 a	80.7 a	102.6 a	135.7 a	147.7 a	203.6 a

	Standard error of the evolution of total number of fruits						
Treatment	56	75	82	89	96	102	103
T0	0.8	2.7	2.9	2.8	5.2	5.4	9.6
T1	0.5	6.6	7.6	6.0	3.1	2.4	5.2

**Different letters indicate statistically significant differences between treatments.*

Tables 14 and 15. Evolution of accumulated number of commercial fruits (average and standard error) of the tomato crop

	Average values of the evolution of the number of commercial fruits (No. m^2)						
Treatment	56	75	82	89	96	102	103
T0	13.4 b	71.1 a	85.6 a	100.0 a	129.4 a	140.4 a	199.1 a
T1	10.1 a	64.2 a	80.6 a	102.3 a	135.2 a	147.2 a	193.0 a

	Standard error of the evolution of commercial number of fruits						
Treatment	56	75	82	89	96	102	103
T0	0.8	3.1	3.1	2.5	4.5	4.4	7.8
T1	0.5	6.6	7.5	6.0	3.3	2.7	5.2

**Different letters indicate statistically significant differences between treatments.*

3.4. Pollinating activity.

At the beginning of the trial, one hive of bumblebees was empty, so we replaced it with another, and there have been no problems with the pollination activity since then.

<u>The pollinating activity carried out by the bumblebees has not been adversely affected by the presence of photovoltaic panels. In fact, it has been even better in the greenhouse with the panels (treatment T1) in recent weeks.</u>

During this trial, in ten moments (19, 25, 34, 48, 61, 74, 82, 89, 97 and 102 DAT), the pollinating activity made by bumblebees has been measured counting the number of chopped flowers. This measurement has been developed in five tomato plants per repetition and in three repetitions per experimental treatment. **Figure 33** and **Tables 15 and 16** show the results of the pollinating activity.

The pollinating activity has been higher in the treatment T0 at the beginning of the crop, finding statistically significant differences between treatments at 19 and 25 DAT. However, since 48 DAT, the pollinating activity was higher in treatment T1, showing significant differences at 82 and 89 days after transplanting.

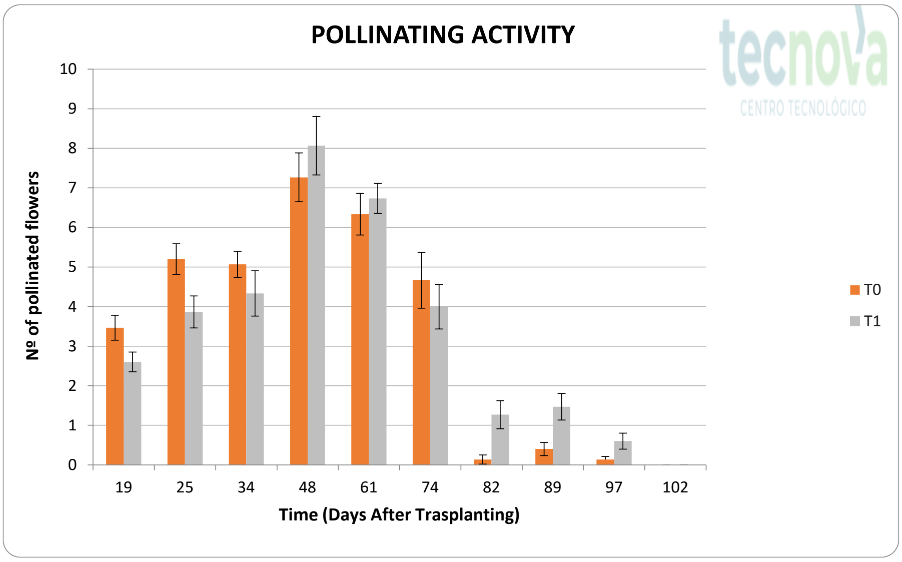


Figure 33. Pollinating activity.

Tables 15 and 16. Average and standard error values of the pollinating activity.

**Different letters indicate statistically significant differences between treatments.*

	AVERAGE									
Treatment/DAT	19	25	34	48	61	74	82	89	97	102
T0	3.5 a	5.2 b	5.1 a	7.3 a	6.3 a	4.7 a	0.1 a	0.4 a	0.1 a	0.0 a
T1	2.6 a	3.9 a	4.3 a	8.1 a	6.7a	4.0 a	1.3 b	1.5 b	0.6 a	0.0 a

	STANDARD ERROR OF POLLINATING ACTIVITY									
Treatment/DAT	19	25	34	48	61	74	82	89	97	102
T0	0.3	0.4	0.3	0.6	0.5	0.7	0.1	0.2	0.1	0.0
T1	0.3	0.4	0.6	0.7	0.4	0.6	0.4	0.3	0.2	0.0

3.5. Population dynamic evaluation of pests

During the trial, foliar treatments were applied to the crop, as indicated in Table 19. These treatments were carried out due to the appearance of pests in DAT 56, continuing until the end of the trial, a result of the increase in temperatures, which is normal for the period during which the field trial was conducted. Before the appearance of pests, preventive foliar treatments were also applied. These treatments do not affect the crop's development or yield.

During this trial, in ten different moments (7,14, 19, 34, 48, 56, 62, 76, 83, 89 and 96 DAT), the population dynamic evaluation of pests has been measured. This measurement has been developed in five tomato plants per repetition and in three repetitions per experimental treatment. **Tables 17 and 18** show the results of the population dynamic.

The population dynamic of *Bemisia tabaci* has been higher in the treatment T0 and the population dynamic of *Tetranychus urticae* and *Aculops lycopersic* has been higher in the treatment T1, although not reaching relevant values. To reduce the population of the different pests in the crop, several foliar treatments have been applied to the plants as is described in **Table 19.**

Tables 17 and 18. Average value of the number of individuals per plant (treatment T0 and treatment T1)

Treatment T0							
DAT/PEST	*Tuta absoluta*	*Bemisia tabaci*	*Frankiniella occidentalis*	*Tetranychus urticae*	*Polyphagotarsonemus latus*	*Aculops lycopersic*	*Aphids spp*
7	*0*	*0*	*0*	*0*	*0*	*0*	*0*
14	*0*	*0*	*0*	*0*	*0*	*0*	*0*
19	*0*	*0*	*0*	*0*	*0*	*0*	*0*
34	*0*	*0*	*0*	*0*	*0*	*0*	*0*
48	*0*	*15*	*0*	*15*	*0*	*0*	*0*
56	*0*	*10*	*0*	*25*	*0*	*0*	*0*
62	*0*	*5*	*0*	*11*	*0*	*26*	*0*
76	*0*	*2*	*0*	*70*	*0*	*60*	*0*
83	*0*	*5*	*0*	*11*	*0*	*26*	*0*
89	*0*	*5*	*0*	*11*	*0*	*26*	*0*
96	*0*	*5*	*0*	*11*	*0*	*26*	*0*

Treatment T1							
DAT/PEST	*Tuta absoluta*	*Bemisia tabaci*	*Frankiniella occidentalis*	*Tetranychus urticae*	*Polyphagotarsonemus latus*	*Aculops lycopersic*	*Aphids spp*
7	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0
56	0	8	0	0	0	0	0
62	0	8	0	14	0	20	0
76	0	4	0	125	0	100	0
83	0	5	0	14	0	20	0
89	0	5	0	14	0	24	0
96	0	5	0	14	0	24	0

Table 19. Foliar treatments applied during the crop.

Week	Product	Active matter	Dose
31	AGRIMEC	abamectina	100 cc/hl
31	ALTACOR	Rynaxypyr	10 gr/hl
34	TUREX	bacillus thuringiensis var.kurstaki	2 gr/l
34	SPINTOR	Spinosad	25 cc/hl
34	MOVENTO	spirotetramat	60 cc/hl
34	ALTACOR	Rynaxypyr	10 gr/hl
34	TUREX	bacillus thuringiensis var.kurstaki	2 gr/l
34	MOVENTO	spirotetramat	60 cc/hl
34	ALTACOR	Rynaxypyr	10 gr/hl
40	SIVANTO	Flupiradifurona	60 ml/hl
40	ACRAMITE	bifenazato	25 cc/hl
40	BELTHIRUL	bacillus thuringiensis var.kurstaki	1 gr/l
42	MOVENTO	spirotetramat	60 ml/hl
42	OBERON	spiromesifen	50 ml/hl
42	TUREX	bacillus thuringiensis var.kurstaki	2 gr/l
43	LUNA	Fluopyran	40 ml/hl
43	MOVENTO	spirotetramat	60 ml/hl
43	OBERON	spiromesifen	50 ml/hl
43	BELTHIRUL	bacillus thuringiensis var.kurstaki	2 gr/l
44	BELTHIRUL	bacillus thuringiensis var.kurstaki	2 gr/l
44	MOVENTO	spirotetramat	60 ml/hl
44	SIVANTO	Flupiradifurona	60 ml/hl

3.6. Electromagnetic field measurements

The bottom of the traditional electrical panels exhibited the highest measurements of electric (E) and magnetic (H) fields, with recorded values of E=95V/m and H=10.92 μT. In contrast, the **Energy Glass electrical panels** installed by Proconsult **showed significantly lower values,** with E=24V/m and H=2.89 μT, as documented in Table 20. The E and H field values at the bottom of the traditional electrical panels installed in greenhouse T3-3 (treatment T0) were more than three times higher than those measured for the Energy Glass units installed in greenhouse T3-1 (treatment T1).

Table 20. Electric (E) and magnetic (H) field values recorded in electrical panels.

Energy Glass Panels and Electric Box	Traditional Electric Box Connect to the Electric Grid

	Electric and magnetic field values in the panels			
	T3-1		T3-3	
	E (V/m)	H (μT)	E (V/m)	H (μT)
Bottom	24	2.89	95	10.92
Top	17	0	31	0
Right	17	0	65	0
Left	10.2	0	77	0
Center	48	0.08	56	0

4. CONCLUSIONS

In conclusion, the scientific test to evaluate the agronomic effects of Energy Glass Solar photovoltaic panels during tomato cultivation in a greenhouse was comprehensive and meticulous. The primary aim was to assess how these panels influenced the crop's growth, development, and pollination variables while providing the necessary energy for the greenhouse's operations. Notably, the study did not seek to enhance crop yield or fruit characteristics, ensuring that T1 and T0 greenhouses had normal functioning, remained unaltered, and received the same standardized growing treatment. This approach maintained the integrity of the test, preventing the introduction of extraneous variables that could distort the results.

Upon thorough analysis of the data collected, it is evident that the Energy Glass Solar panels, as detailed in Annex 1 of this document and supplied by Saxon Capital, have successfully met the objective. The test validates that these panels, occupying less than 5% of the greenhouse's roof area, minimized shadow zones and allowed optimal natural light penetration. Moreover, it was established that the electromagnetic fields generated by the Energy Glass Solar system were lower than those from the control greenhouse's standard electrical grid. This finding is significant, as it demonstrates that the Energy Glass Solar panels do not adversely affect the pollinating activity of bumblebees or the natural growth of plants.

The key data from the test, can be summarized as follows:

- **Climatic Conditions:** The trial spanned an autumn-winter tomato cropping cycle in southeastern Spain. T0 and T1 treatments experienced similar temperature and humidity ranges, reflecting the region's typical climate.
- **Photosynthetically Active Radiation (PAR):** The daily integral PAR radiation levels observed align with the standard values for the period, indicating that the panels did not hinder light availability crucial for plant growth.
- **Transmissivity Coefficients:** These remained consistent across treatments, further affirming the panels' efficiency in allowing light transmission.

- **Wind Resistance:** Despite strong winds, especially during the CIARAN storm in late October and early November, the Energy Glass panels remained effective and resilient, ensuring an uninterrupted energy supply.
- **Plant Growth Metrics:** Parameters such as plant height, basal diameter, internode distance, and leaf count showed that the photovoltaic panels did not negatively impact plant growth, with all measurements falling within the normal ranges for a three-month tomato crop.
- **Flowering and Fruiting Patterns:** The number of flowers and fruits developed across treatments did not significantly differ, indicating that the panels did not adversely affect these critical stages of crop development.
- **Crop Productivity:** The fresh weight of the fruits and the number of harvestable fruits were comparable between treatments, reinforcing the conclusion that the photovoltaic panels had no detrimental effect on crop yield, nor its quality as commercial standard produce grew in similar amounts and inside the average production per square meters in a test of these characteristics. (The normal values of accumulated fresh weight achieved in three months range from 2.5 kg to 4 kg per m^2)
- **Pollination Efficiency:** Contrary to concerns, the pollination activity was more effective in the greenhouse with the Energy Glass panels post 48 DAT, showcasing that these panels do not impair but may enhance the pollination process.
- **Electromagnetic Field Levels**: **The Energy Glass panels produced lower electromagnetic fields than traditional electric panels connected to the grid, alleviating concerns about potential negative effects on plant growth or pollinator activity.**

  In some specific areas of the electrical control box where measurements were taken, the EMF emissions difference between T1 (Energy Glass power greenhouse) was three to seven times lower than those measured in T0 (electric box connected to the grid)

The Energy Glass Solar panels have demonstrated and validated their efficacy in maintaining optimal greenhouse conditions without compromising plant growth, development, or pollination processes. The panels not only provided sufficient energy for greenhouse operations but did so in a manner that was harmonious with the natural growth cycles of the tomato crop. This alignment of renewable energy technology with agricultural best practices offers a promising avenue for sustainable and efficient farming practices.

5. CONTACT IN TECNOVA

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lrodriguez@fundaciontecnova.com / slopez@fundaciontecnova.com

6. ANNEX

ANNEX I

EnergyGlass™

Tecnova Foundation
Sede Tecnova.
Parque Tecnológico de Almería,
Avda. de la Innovación,23, El Alquián,
04131 Almería, Spain

Performance Data

The intent of this specification is to clearly define the EnergyGlass greenhouse solar panel system installed and working at Tecnova Foundation, relative to the cherry tomato crop grow project and validation.

Product description:

EnergyGlass, electro-magnetic frequency & radiation, ("EMF/EMR") resistant, electrical generating, solar panel system.

Panel make up:

(2) @ 0.070'' nano interlayer panes x (1) @ 0.0312'' EMF, EMR interlayer x (3) @ 0.015'' bond films x (1) module @ 0.125", and (1) junction box; (Total Nominal Thickness: (0.16''), imperial system or (4 mm), metric system.

Product Characteristics:

This product is; 1), passive electricity generation, 2). EMF & EMR resistant, 3). Bee and other pollinators friendly, 4). Wind resistant; 5). Economical.

Product use:

Residential & Commercial greenhouses, grow houses, and other locations which require passive electrical generation.

EnergyGlass Solar Panel Composition of product named herein:

[Nano Interlayer x Bonding Film x Module x Bonding Film x EMF/EMR Interlayer x Bonding Film x Nano Interlayer]

1. **TNT: [0.16"].**
2. **Glass type: [N/A]**
3. **Nano Interlayer color: [clear]**

4. **Module color: [Black].**
5. **EMF/EMR color: [whitish hue]**
6. **Bonding Film: [SAF proprietary]**
7. **Bonding Film color: [clear]**

Nano Interlayer Performance Data:

1. **Tensile Strength: 10,400 psi [ASTM D-638]**
2. **Tensile Modulus : 351,000 psi [ASTM D-638]**
3. **Flexural Strength: 14,200 psi [ASTM D-790].**
4. **Flexural Modulus: 351,000 psi [ASTM D-790].**

Quality and Testing Assurance Standards:

1. **Miami Dade County Quality Assurance Manual.**
2. **Underwriters Laboratories.**
3. **International Electrotechnical Commission, (IEC)**
4. **Underwriters Laboratories, (Follow Up Service).**
5. **International Code Council, (ICC).**

Qualification Standard which may apply:

1). American Society for Testing and Material Standards.

Storage:

1. **Stored goods pursuant to fabricated guidelines and warranty.**
2. **Stored goods in a well-ventilated shaded area under roof and out of weather.**

Warranty:

1. **Specified duration and term: (25) years.**

1. **Cleaners, Primers and sealers: Neutral non-aggressive see manufacturer recommendations for each application.**

References:

[ASTM International] American Society for Testing and Materials

Applicable ASTM Standards: [C 1036], [C 1048], [C 1172], [C 1349], [C 1376], [C 1464], [E 1300]

[GANA] Glazing Association of North America; [Full manual inclusive of table IV & 01-0300].

[ANSI] American National Standards Institute; [ANSI Z97.1 – 2004].

[ASCE] American Society of Civil Engineering; [ASCE 7-98].

[CPSC] Consumer Product Safety Standard; [16 CFR 1201].

[UL] Underwriters Laboratories

[NFPA] National Fire Protection Association; [NFPA 257].