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# Agronomical and biological results of solar energy heating by the combination of the sunstock system with an outside captor on a muskmelon crop grown in polyethylene greenhouses.

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## Abstract

Six cultivars of muskmelon (Early Dew, "68-02", "Early Chaca", "Jivaro", "Super Sprint" and "Cantor") transplanted at two differents dates were cultivated under two PE greenhouses heated by solar energy recovery and compared to a control greenhouse.

The greenhouses were covered with a double shield of normal PE of 100 microns. The first greenhouse was considered as the control. The second one was equipped with a sunstock solar energy collector distribution system, consisting in a covering of 37% of the ground surface by flat black PVC tubes, used during the day as a solar energy captor for heating the water of a basin and during the night as a radiant mulch for heating the greenhouse by emission of radiation warmth.

The third greenhouse was equipped also with the same sunstock system, but connected with a supplementary outdoor collector by means of flat PE tubes corresponding to about 28% covering of the greenhouse, and resulting in a more important energy stock, available for heating during the night. Minimum air temperature was raised by about 1,5 and 2,5°C respectively in the second and the third greenhouse, while the minimum soil temperature was raised with about 1 and 2°C respectively. Evolution of the maximum temperatures was more irregular and was depending also from the incident energy.

Plant growth under the solar heated greenhouse was more accelerated, and resulted in an earlier fruitset, an earlier production and a higher total yield.


## 1. Introduction

Production of early muskmelons is very important for the Tunisian vegetable grower, because of the very high prices during the month April and the first two weeks of May. The earliest production is generally obtained in the southern regions (Gabes and Sfax) where nebulosity is much lower and global solar radiation higher. In other regions production is starting later and heating can be interesting to obtain an earlier production. Use of an air heater seems to be very expensive and very inefficient under PE greenhouse while solar heating seems to be more adapted and less expensive.

Preliminary experimental work indicates that a 60—70% soil covering gives the best results for heating, but this is rather expensive for the Tunisian grower. We tried to combine a cheap self made outdoor captor with a lower soil covering of the sunstock system.

## 2. Materials and Methods

Two greenhouses of the Filclair 7,5 m. type long 40 meter and covered with a double PE shield (2 × 100 µ) were equiped with sunstock radiant mulch film tubes and compared to a control greenhouse.

Each greenhouse was planted with eight lines of muskmelons and six of them were planted in coupled rows on a distance of 70 cm between the coupled lines and of 100 cm between the non coupled lines, bordered at each outside with a normal line. One heated greenhouse was equipped with a flexible radiant mulch laid out on the soil between the coupled rows. This mulch served as an inside solar energy captor during the day and as an energy distributor during the night. The other heated greenhouse was equipped with the same installation as the first one but was connected on a supplementary outdoor captor. The sunstock radiant mulch film tube consists in two 35 cm large sheets of flexible black PVC of 250 µ thick welded together by high frequency welding and divided in 5 pipes. Two mulch film tubes were located between each two coupled rows while at the outside of each borderline was laid out one mulch film tube. In this way we obtained a 37% covering of the soil surface. The water of an outdoor watertank of 12 $m^3$ circulated by an electrical pump of 400 Watt, programmed by a clock system and cut out from 8 a.m. to 9 a.m. and from 4.30 pm. to 2 am. Water circulated into the mulch film tubes under a pression of 10 cm water column resulting in a delivery rate of 6 $m^3$/hour.

The outside captor consisted in transparent low density plastic tubes of 15 cm diameter filled up at 8.00 a.m.

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and heated under small polyethylene tunnels. At 4.30 p.m. the heated water is released in the water tank.

The total capting surface was about 28% of the greenhouse surface. The capacity of the outside captor was about 9 $m^3$ so that the water tank contained only 3 $m^3$ during the day. Each greenhouse was divided in three blocks and each block was planted with six cultivars. ("Early Dew", "Jivaro", "68-02", "Super Sprint", "Early Chaca" and "Cantor" planted at 2 different dates (30 December and 26 January). The planting density was 1,7 plants/$m^2$ and the pruning system 203.

Each greenhouse received before planting 8 kg/$m^2$ well made stable manure and 220 units of $P_2O_5$. After planting a monthly fertilization of 40 units of N and 80 units of $K_2O$ was raked in and this during 5 months.

Irrigation was conducted with an Agrodrip system (2,6 liters/hour per dripper distanced at 0,33 m) in function of the ETP under greenhouse according to the formula of de Villale with the following cultural factors: growth 60%, flowering 65%, fructification and fruit development 80%, harvest 55%, end of harvest 40%.

The water used for irrigation had a low conductivity (1 350 micros = 0,65 gr/l). The influence of the solar heating systems on plant growth was evaluated by measuring plant height, stem diameter and the number and length of nodes, while the agronomical results were illustrated by comparing early yield, exportable yield, total yield and mean fruit weight. Early yield and exportable yield are defined as the production before 1st May and 1st June respectively.

It should be mentioned that 4 plants per genotype were measured per replicate, each elementary parcel was replicated three times, so that statistical analysis of significant differences could be carried out.

## 3. Results

### 3.1. Evolution of the water temperature in the storage tank.

It's obvious from figure 4 that the outdoor captor increases the water temperature in the tank with more than 2°C in comparison with the normal solar heated greenhouse in exception for week 4 and 11, while the pumps did not work.

In general maximum water temperature in the storage tank was higher when using an outdoor captor, while minimum temperature was quite similar.

The average daily temperature gain in the reservoir for the whole period was 6,1°C. for the one heated without outdoor captor and 8,8°C for the one with outdoor captor, corresponding to about 73 000 Kcal for the solar heated greenhouse without outdoor captor and to 106 000 Kcal with outdoor captor. Use of an outdoor captor by means of low density polyethylene tubes results in a higher efficiency of the heating system and can explain higher night temperatures, better development and increased earliness.

### 3.2. Influence of the solar systems on the bioclimate of the greenhouse

#### 3.2.1. Ambiant air temperature

Figure 1 shows that the average maximum air temperature was the highest under the heated greenhouse with outdoor captor, but the differences were more important during the early growing stage of the muskmelon crop. The small quantity of water available in the storage tank after filling up the outdoor captor limits the possibility of the cooling effect by reducing the energy uptake by the mulch tubes because of the higher temperature of the circulating water, resulting in a higher maximal air temperature. About 3 months after planting the differences became smaller on a developed muskmelon crop. This results don't correspond with those obtained in the Tunis region (13). The authors mentioned a cooling effect during the day. The sandy soil of the Sahel region has a low enthalpie and heat quickly reaching higher temperature levels than the heavy soils of the Tunis region and this can explain the different results. The global solar radiation in winter and spring is more important in the Sahel region and this can contribute also to obtain higher maximal temperatures. Table 1 shows weekly evolution of the absolute maximum temperature and indicates also the absence of the cooling effect of the solar heating systems in the Sahel region. Table 3, representing the numbers of hours per week with temperatures below 12°C and 14°C, shows important differences between the heated greenhouse and the cold greenhouses. The number of hours with air temperatures below 12°C is low in the heated greenhouses and never exceeds 13 hours/week for the greenhouse with an outdoor captor and 27 hours/week for the normal solar heated greenhouse. For the control greenhouse we noted up to 65,5 hours/week with temperatures inferior to 12°C. As daytime assimilation is found best after medium levelled night temperatures and lower after low and high night temperatures (7) it seems that the solar heated greenhouses present better conditions for plant development.

#### 3.2.2. Minimum soil temperature

Minimum soil temperature was measured at two levels: 10 cm and 20 cm. Figure 3 shows that during cold periods (week 1, 3, 4, 5, 9) the soil temperature of the control greenhouse evoluated between 14 and 15°C at 20 cm depth while in the heated greenhouse we observe soil temperatures for the same period between 14,5°C and 16 to 18°C at the corresponding depths. In general we observe the highest soil temperature under the greenhouse with the outdoor captor.

Differences between the normal solar heated greenhouse and the control greenhouse reach generally 1,5 to 2°C while we note about 2 to 3°C between the greenhouse with outdoor captor and the control. This is very important for plant development as soil temperature has an influence between 12 and 18°C on the root development and the root activity (8). Higher soil temperature within the zone 12 to 18°C results normally in a more important root system and root activity, stronger development and earliness.

### 3.3. Agronomical results

#### 3.3.1. Plant development

The variation of the plant structure was controled by measuring different plant parameters as plant height, stem diameter, number of nodes and length of nodes 90 days after planting.

It is evident from table 4 that the crop in the heated greenhouse was more developed but there were no significant differences in length of nodes and stem diameter. There was a very important difference in plant development between the early and the normal planting date (table 5). It seems that early planting is not very favourable for plant growth of the muskmelon crop, resulting in a smaller length of nodes and a lower development rate (80 cm height and 17 nodes against 160 cm of height and 24 nodes). As shown in table 6 the varieties "Jivaro" and "Early Chaka" are the most vigorous presenting significantly higher plants and thicker stem diameter. The tall development of the variety "Jivaro" results from a higher number of nodes while for the variety "Early Chaca" this results from longer nodes.

#### 3.3.2. Production

The mean influence of the heating system is shown in table 4. Earliness is not significantly increased but this can be explained by the absence of honey bees during the first week of fructification. Exportable yield is highest in the normal solar heated greenhouse and is not influenced under the greenhouse with outdoor captor, while total yield is not different under the 3 greenhouses. Mean fruit weight is higher in the heated greenhouse and the highest mean fruit weight is observed under the greenhouse with outdoor captor.

Table 5 shows that early planting favoures early yield (997 g/m$^2$ against 509 g/m$^2$) and exportable yield (4,601 g/m$^2$ and 3,083 g/m$^2$) and differences in comparison with the late planting date are significant, but total yield is not higher and mean fruit weight is significantly lower (587 g against 633 g).

If exportable yield under the solar heated greenhouse with the outdoor captor is not different from the control, this seems to be explained by table 7 showing the interaction between planting date and heating system. For the early planting date exportable yield increases in function of the obtained minimum temperatures under the different greenhouses, and while the heating of the greenhouse by means of a supplementary outdoor captor results in more favourable temperatures this results in better fruitset and higher production. Late planting in combination with solar heating can result in high soil temperatures and this particularly under the greenhouse with the outdoor captor where the daily available water quantity was low. As higher soil temperatures can result in lower dry matter concentration in root and foliage (8) this can explain the lower plant activity during the last period of heating (April) and the lower exportable production.

As results from table 6 it's obvious that "Super Sprint" is the most early variety and there is no difference between the 5 others in early yield. Exportable yield is the highest for the variety "Super Sprint" (5 076 g/m$^2$), "Early Chaca" (4 375 g/m$^2$) and "Jivaro" (4 023 g/m$^2$) and the lowest for "Cantor" (2 743 g/m$^2$). Total yield is highest for "Jivaro" (8 962 g/m$^2$) and "Super Sprint" (8 590 g/m$^2$) and lowest for "Cantor", "Early Dew" and "Early Chaca" (6 700g/m$^2$). Mean fruit weight was higher for "Early Dew" (827 g) and for the Cantaloup types for "68-02" (666 g) and "Jivaro" (638 g) and a later ("Cantor") variety indicates that for the first planting date heating results in a more important early yield without differences in total yield (figure 5) for a late planting solar heating has an influence on precocity and total yield if used on a early variety ("Jivaro") but has a negative effect if used on a late variety ("Cantor"). It seems that in this case the higher soil temperature resulting normally from higher water temperature in the storage tank and in the mulch film tubes results in a lower productivity. The lowest production is obtained with the sunstock solar heating system coupled with the outdoor captor (figure 6).

## 4. Conclusion

Solar heating of greenhouses by means of a sunstock captor distributor system can be of great importance for improvement of bioclimate under greenhouses but needs a 70% covering of the soil. (12,14). Our results are not always very significant because of the low covering (37%) (11). In the Monastir region the global solar radiation is more important and the nebulosity is lower so that accumulation of calories in the water tank should be more important.

Use of the solar heating on a muskmelon crop can be interesting because resulting in more precocity and better prices. The best results were obtained by combination of an early planting date with an early variety and this under solar heated greenhouse with a supplementary outdoor captor. Use of solar heating on a late variety and a late planted crop results in crop diminution and is not envisagable. As energy losses by radiation are very important in Tunisia (10) it seems that the solar heating system has to be combined with systems reducing radiation losses during the night.

*Figure 1:* Evolution of the maximum air temperature

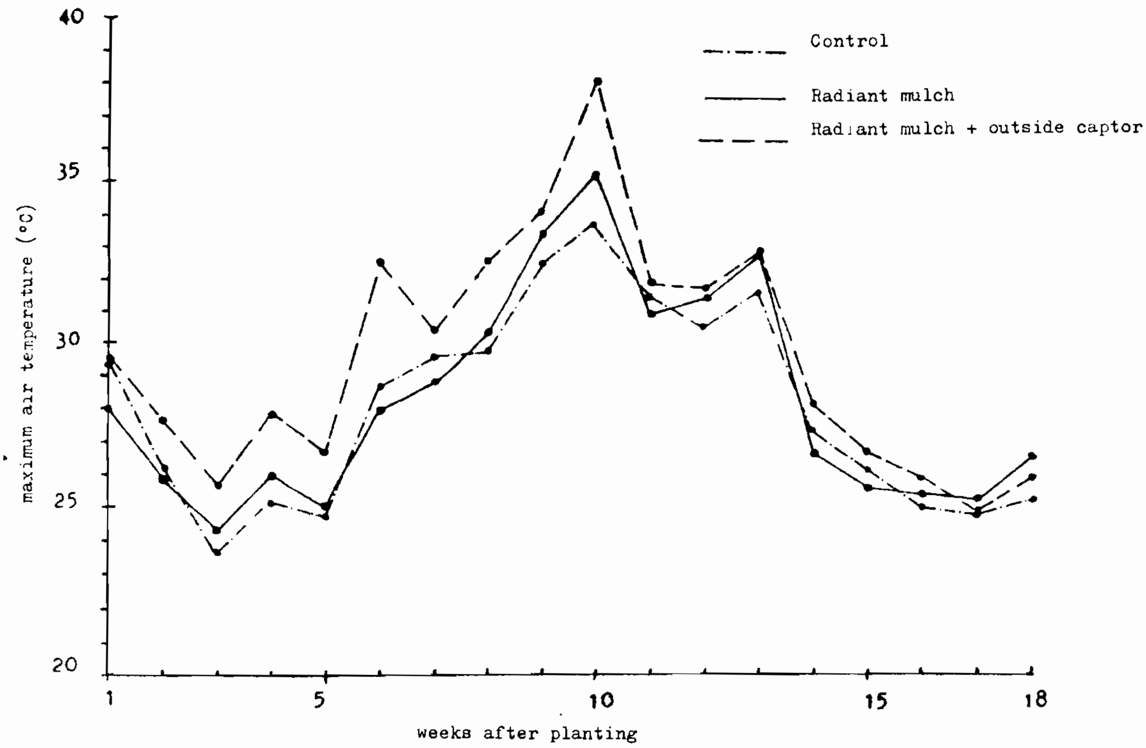


*Figure 2:* Evolution of minimum air temperature

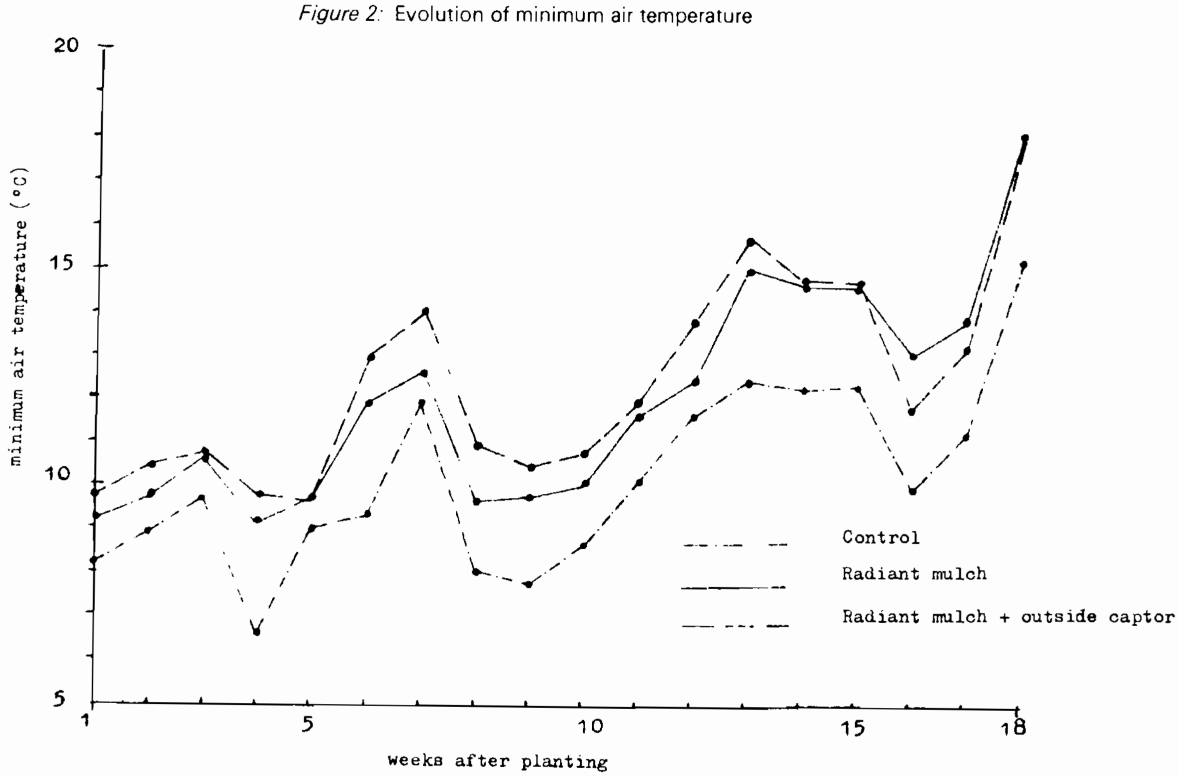

*Figure 3:* Evolution of minimum soil temperature

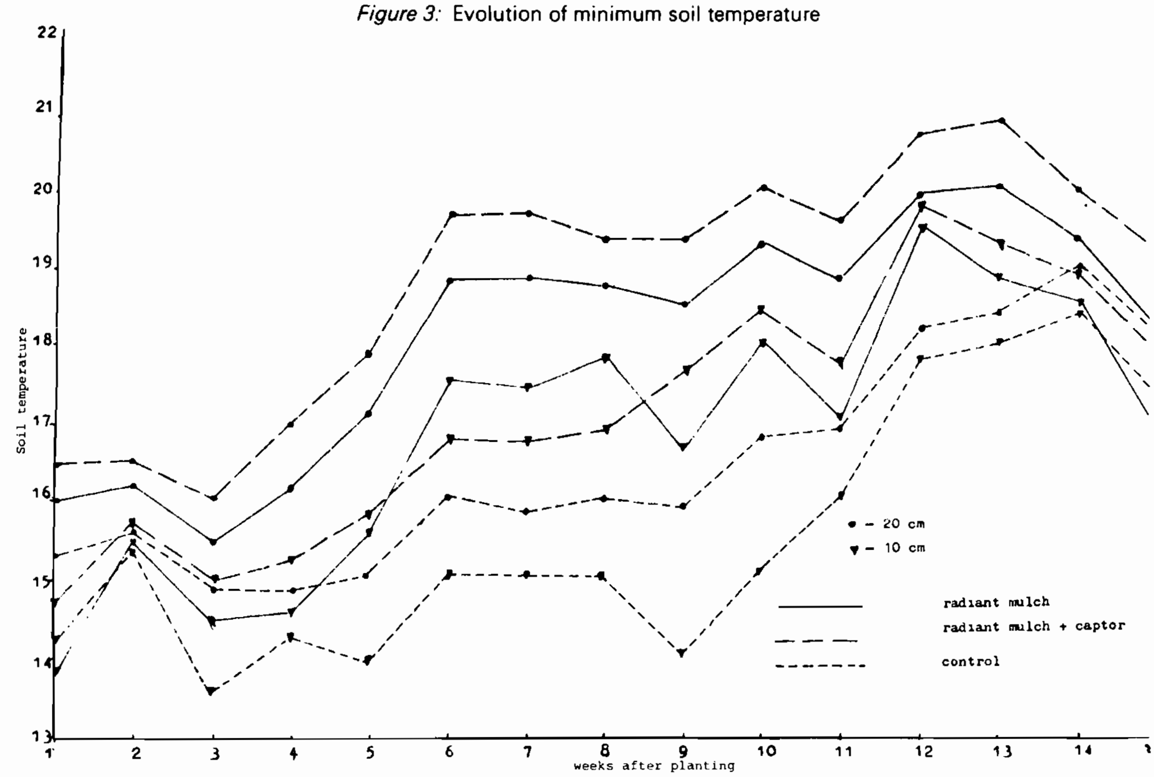


*Figure 4:* Evolution of mean minimum and maximum temperature of the water in the storage tank

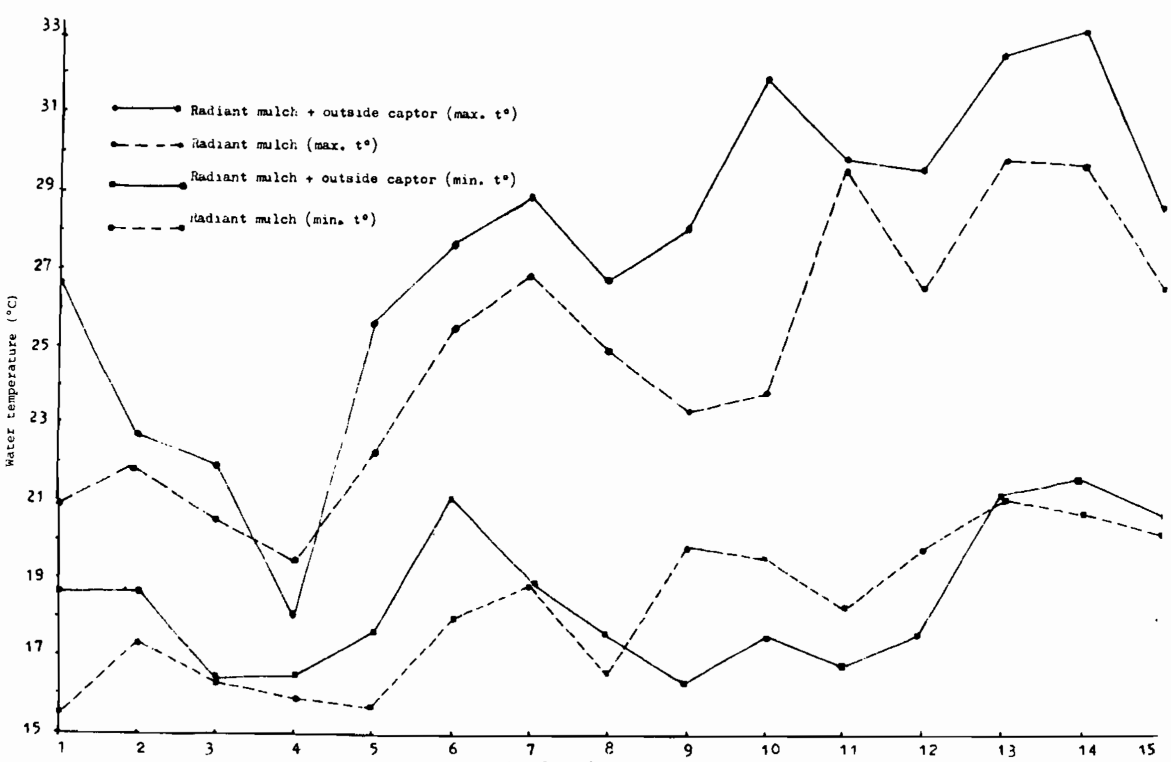

*Figure 5:* Cumulated production of 2 muskmelon cultivars for early plantation

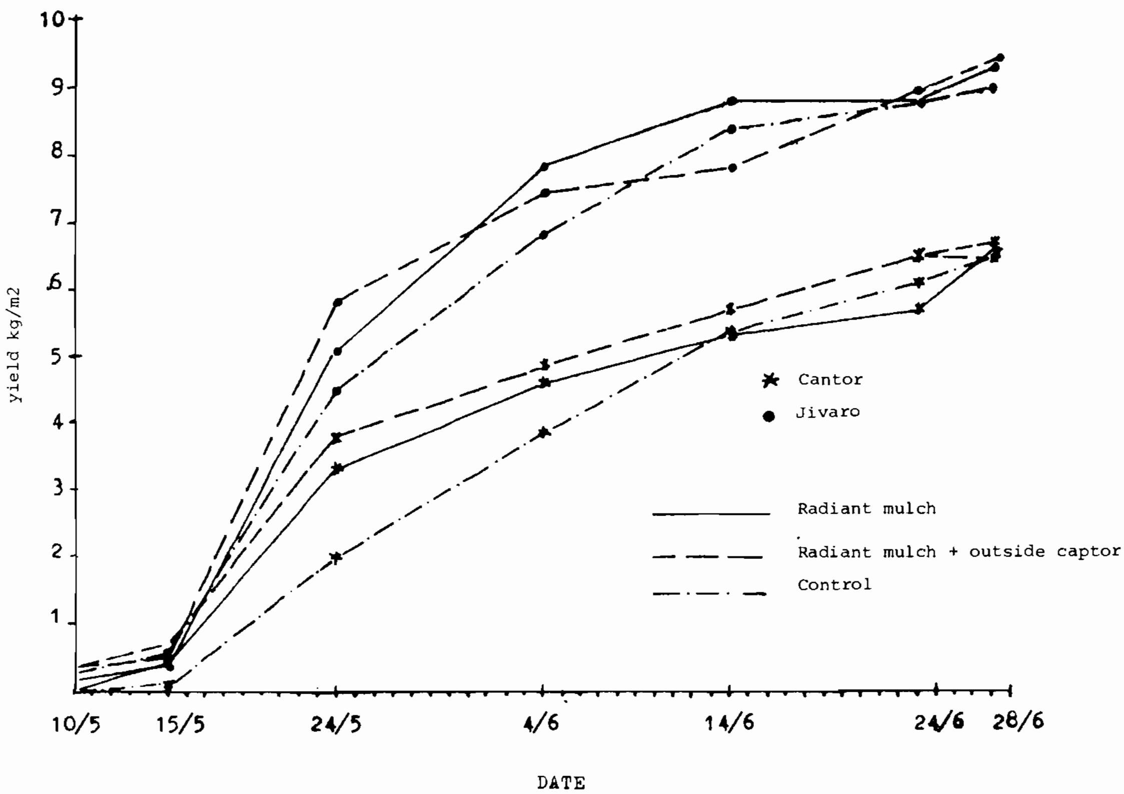


*Figure 6:* Cumulated production of 2 muskmelon cultivars for late plantation

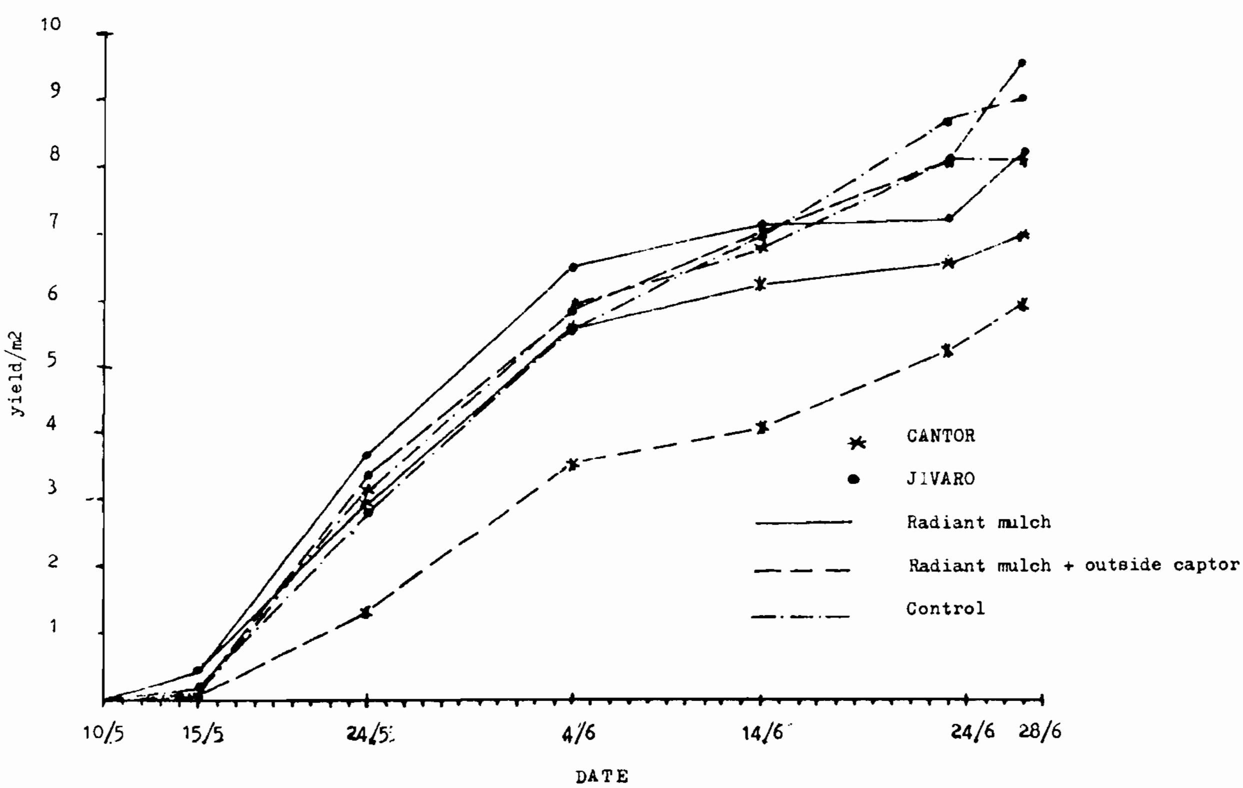

*TABLE I*

**Weekly evolution of the absolute maximum air temperature**

| Week number after planting | Control greenhouse | Outside captor | Inside + outside captor |
|---|---|---|---|
| 1 | 30 | 37,7 | 40 |
| 2 | 34,2 | 37,7 | 38 |
| 3 | 31,5 | 42,5 | 38 |
| 4 | 33 | 35,5 | 35,8 |
| 5 | 29,9 | 30 | 32 |
| 6 | 26 | 28 | 30 |
| 7 | 26 | 26,5 | 28 |
| 8 | 28 | 27,8 | 28 |
| 9 | 31,3 | 29,8 | 31 |
| 10 | 28,2 | 29,9 | 30,2 |
| 11 | 38,6 | 41 | 41 |
| 12 | 30,6 | 33,3 | 33,8 |

*TABLE 2*

**Weekly evolution of the absolute minimum air temperature**

| Week number after planting | Control greenhouse | Outside captor | Inside + outside captor |
|---|---|---|---|
| 1 | 7 | 8 | 9 |
| 2 | 6,5 | 8 | 9,2 |
| 3 | 8,2 | 9 | 10,9 |
| 4 | 9,5 | 12,2 | 13 |
| 5 | 10,9 | 13,2 | 13,9 |
| 6 | 11,5 | 13,9 | 14 |
| 7 | 8 | 12 | 10,9 |
| 8 | 7,9 | 11 | 10 |
| 9 | 11,9 | 15 | 15,1 |
| 10 | 11,3 | 12,9 | 12,8 |
| 11 | 13,1 | 15,2 | 15,2 |
| 12 | 9,6 | 11,9 | 12,2 |

*TABLE 3*

**Evolution of the number of hours per week with temperatures below the 12 °C and 14 °C level**

| Week number after planting | Control greenhouse | | Inside captor | | Inside + outside captor | |
|---|---|---|---|---|---|---|
| | 12 °C | 14 °C | 12 °C | 14 °C | 12 °C | 14 °C |
| 1 | 65,5 | | 20 | | 10 | |
| 2 | 42 | | 19,5 | | 8,5 | |
| 3 | 32 | | 27 | | 4 | |
| 4 | 14,5 | 27 | 0 | 15 | 0 | 8,5 |
| 5 | 9,5 | 36,5 | 0 | 4 | 0 | 1,5 |
| 6 | 4,5 | 44,5 | 0 | 1 | 0 | 0 |
| 7 | 39,5 | 71,5 | 0 | 35 | 13 | 41 |
| 8 | 28 | 53,5 | 5 | 14,5 | 7 | 35,5 |
| 9 | 1 | 6 | 0 | 0 | 0 | 0 |
| 10 | 4 | 11 | 0 | 3 | 0 | 5 |
| 11 | 0 | 64 | 0 | 0 | 0 | 0 |
| Total | 240,5 | 314 | 71,5 | 72,5 | 34,5 | 91,5 |

*TABLE 4*

**Influence of the heating system on plant development and production**

| Greenhouse | Plant development 90 days after planting | | | | Production | | | |
|---|---|---|---|---|---|---|---|---|
| | Plant height in cm | Stem diameter in mm | Number of nodes | Length of nodes | Early yield in g/m² | Exportable yield in g/m² | Total yield in g/m² | Mean fruit weight in g |
| Control | 110.4 b | 8.3 a | 19.0 b | 5.5 a | 721 a | 3,515 b | 7,515 a | 585 b |
| Indoor captor | 128.0 a | 8.2 a | 20.6 ab | 6.4 a | 735 a | 4,373 a | 7,780 a | 606 ab |
| Indoor + outdoor captor | 120.6 ab | 8.4 a | 22.0 a | 5.3 a | 802 a | 3,638 b | 7,589 a | 638 a |
| lsd 5% | 18.1 | 0.8 | 1.9 | 1.5 | 328 | 659 | 544 | 30 |

*TABLE 5*

**Influence of planting date on plant development and production**

| Planting date | Plant development 90 days after planting | | | | Production | | | |
|---|---|---|---|---|---|---|---|---|
| | Plant height in cm | Stem diameter in mm | Number of nodes | Length of nodes | Early yield in g/m² | Exportable yield in g/m² | Total yield in g/m² | Mean fruit weight in g |
| December 30th | 80.2 b | 8.0 b | 16.8 b | 4.7 b | 987 a | 4.601 a | 7,793 a | 587 b |
| January 26th | 159.1 a | 8.8 a | 24.3 a | 6.9 a | 538 b | 3.083 b | 7,463 a | 833 a |
| lsd 5% | 15.3 | 0.6 | 1.6 | 1.2 | 268 | 538 | 4444 | 25 |

*TABLE 6*

**Plant development and production of the different varieties**

| Variety | Plant development 90 days after planting | | | | Production | | | |
|---|---|---|---|---|---|---|---|---|
| | Plant heigth in cm | Stem diameter in mm | Number of nodes | Length of nodes | Early yield in g/m² | Exportable yield in g/m² | Total yield in g/m² | Mean fruit weight in g |
| Early Dew | 113.2 | 8.3 | 19.3 | 6.7 | 279 | 3,460 | 6,711 | 827 |
| Jivaro | 145.1 | 9.1 | 24.3 | 5.8 | 352 | 4,203 | 8,962 | 638 |
| 68.02 | 108.9 | 8.0 | 19.6 | 5.2 | 326 | 3,196 | 7,983 | 666 |
| Supersprint | 107.9 | 7.4 | 20.1 | 5.3 | 1 211 | 5,076 | 8,580 | 575 |
| Early Chaca | 136.9 | 8.7 | 20.5 | 6.4 | 232 | 4,375 | 6,789 | 446 |
| Cantor | 105.9 | 8.2 | 19.6 | 5.3 | 296 | 6,743 | 6,733 | 509 |
| lsd 5% | 26.5 | 1.1 | 2.7 | 2.1 | 484 | 932 | 763 | 30 |

*TABLE 7*

**Interaction planting date x heating system on the exportable yield**

| Heating system | Planting date | |
|---|---|---|
| | December 30th | January 26th |
| Control | 3,839 | 3,191 |
| Indoor captor | 4,842 | 3,903 |
| Indoor + outdoor captor | 5,122 | 2,155 |

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