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RESEARCH ARTICLE

A Study of the growth and yield of *Solanum lycopersicum* under greenhouses differentiated by the LDPE cover-film

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Previous studies have been conducted in order to figure out which type of polymer has the best chemical or mechanical properties such as resistance and durability. However, knowing which type of polymer is appropriate for agricultural use is fundamental and should not be neglected. For this purpose, a study of the impact of two low-density polyethylene (LDPE) greenhouse cover-films (monolayer and tri-layers) on the growth and yield of tomato (*Solanum lycopersicum*) species, has been carried out in the semi-arid region of Tiaret city in Algeria. The present study is directly related to the field of agro-ecology. It consists on comparing the influence of the microclimates such as temperature and relative humidity together with the luminous flow inside the two greenhouses, on the evolution and the final yield of two varieties of tomato. Statistical analysis was established to compare the evolution of tomato plants from the initial state to the final stage of development. It showed that there was indeed a difference in development between tomato plants. In addition, the production yield of both Marmande and ACE 55 VF varieties was 3.1 kg/m^2 and 2.9 kg/m^2 respectively for the monolayer film versus 2.3 kg/m^2 and 2.0 kg/m^2 for the tri-layers film. The results also indicated that even though the tri-layers film had superior life span and better resistance to the external factors than the monolayer film, the internal conditions of the greenhouse covered by the monolayer film were more suitable for tomato culture in the harsh environment of semi-arid areas.

Keywords: Polymer; Development; Monolayer; Tri-layers; Biometry; Production; Climate

Introduction

Conventional multilayer films of LDPE are the best solution for many applications such as plasticulture since they are cheap, easy to process, mechanically tough and bio-inert. They also, respond to the requirements of the plant by transmitting only 80% of the infrared and 80% of the global solar radiation (Langlais & Rychewaert, 2000). However, the degradation of the polyethylene exposed to different surrounding conditions is still not well understood because of its complex process, such as many degradation mechanisms perform together till the overall damage of the material (Dehbi & Mourad, 2016). The composition and the structure of these LDPE films need to be changed in order to fit the weather conditions that they're going to endure throughout usage (Dehbi et al., 2011). A greenhouse is a closed constitution that provides protection to plants and allows them to be grown in a controlled environment that includes both soil and micro-climate to which they are unsuited (Jones, 2007, Sani et al., 2013). Under protected conditions, the natural habitat is modified to suitable situations for ideal plant growth. This ultimately helps in the production of fruit quality appropriate for exports and domestic consumption (Singh & Sirohi, 2006). A good fruit crop cannot be expected if there has not been a reasonable vegetative growth.

Tomato constitutes one of the popular health foods and is ranked third with respect to the global crop production (Bhowmik et al., 2012, FAO, 2006). It’s one of the vegetable species that has the benefit to be grown beneath shield all year round. Also, its crops are widely cultivated in large kinds of surrounding conditions with various climatic states in the world, starting with some tropical climate areas to some degrees of the Arctic Circle (Golam et al., 2012).

Greenhouse tomatoes could also be more gainful than formal agronomic crops; however, it faces several abiotic stresses. Also, extreme temperatures may be a crucial drawback today (Golam et al., 2012). Tomato seedlings have many varieties that can be distinguished by their fruit quality, weight and yield as well as plant height and the number of fruits per plant (Naz et al., 2011). Plant growth and physiology are extremely influenced by the light spectrum of the growth environment. Also, temperature control and relative humidity reduction play a principal role in preserving greenhouse crop health (Jiao et al., 2007).

The purpose of the present study was to carry out two production systems, which were: a greenhouse covered by a monolayer LDPE film and a second greenhouse covered by a tri-layers LDPE film, for the cultivation of two tomato varieties (ACE 55 VF and Marmande). It was founded on the analysis of the development and the production of tomato plants, based on the effect of the two different greenhouse cover-films under the climatic conditions of a semi-arid area.

Materials and Methods

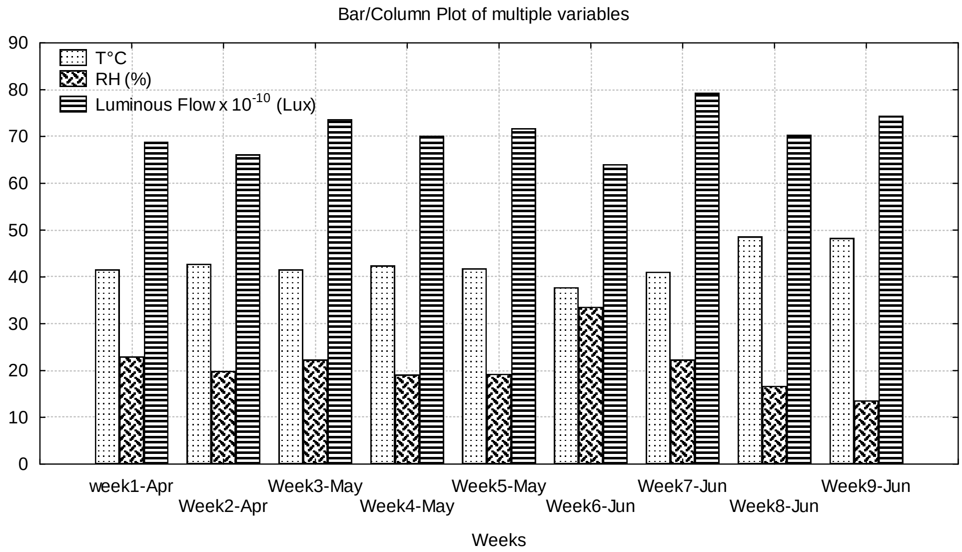
The experiment was carried out at the University of Ibn Khaldoun-Tiaret, Algeria. Two varieties of Tomato (Marmande and ACE 55 VF) were cultivated under two tunnel-type greenhouses located side by side and differentiated by the cover film (Monolayer and Tri-layers). Both films were made and provided by an Algerian company called Agrofilm-Setif. The monolayer film was transparent and had a density of 0.92 g/cm3 and a molecular weight average of 90 to 120 thousand ranges. The melt flow index (MFI) of the raw LDPE was 0.33 g/10 min and the MFI with stabilizer was 10 g/10 min. The tri-layers film was co-extruded and its original color was yellow. Also, it presented the following proportions in its layers ¼, ½ and ¼. The two LDPE films had the same thickness of 180 pm (Aouinet et al., 2019). Tomato plants were grown under the exact same conditions. The dimensions of each greenhouse were identical (width (w)=8 m; Length (l)=16 m; height (h)=3,5 m; surface (s)=128 m^2 and Volume (v)=306,5 m^2). Ten pots for each variety of tomato were installed, meaning twenty pots per greenhouse. The disposition of the pots was the same in both greenhouses (in the center) and the soil (400 g) used was a mixture of fine sand and agricultural soil (50/50) in each pot. Additionally, irrigation water proportions were exactly the same for each tomato plant.

This study was conducted from the germination stage to the advanced stage of development. Greenhouse cladding was done in early February and seeding was done at the end of the same month. Additionally, transplantation was made five weeks later and the harvest began at the end of June. During the period of the experiment, a Multimetrix (DL 53 Data logger) was used daily to determine the climatic parameters (air temperature and relative humidity) and a Light-meter (AMPROBE LM-120) was used to measure the luminous flow. Both sensors were put in the middle of the greenhouses (on top of the plants) during their use. Also, the two greenhouses were exposed to the exact same exterior conditions such as temperature, humidity, wind, and solar radiation.

The biometric parameters, such as the number of leaves and length of the stem, were measured weakly (one week after the transplantation). The height of each plant was measured in centimeter from the surface of the soil to the top of the stem, and the final yield of each variety of tomato under the corresponding greenhouse was calculated in kg/m2. The data of the mean values of growth and yield of tomato plants were statically studied and all data analysis were made using the Statistica software (version 8.0.360.0)

Results and Discussion

a)



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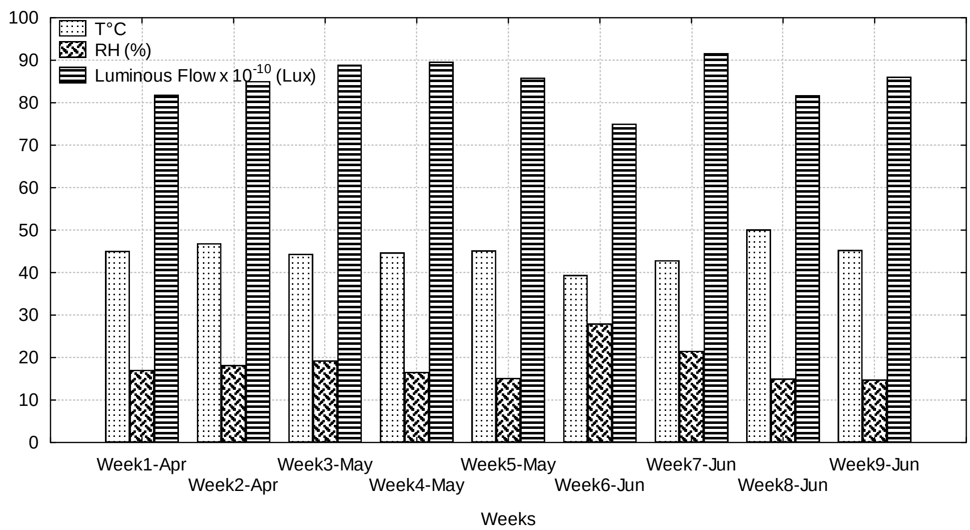


Figure 1. Comparison of variations in climate and luminous flow during the experimentation period for the tri-layers and monolayer greenhouses (a: Tri-layers; b: Monolayer).

A comparative study of the climatic variations and the luminous flow of the tri-layers and the monolayer greenhouses during the period of study was realized (Figure 1). The greenhouse covered by the monolayer film, absorbed more light thanks to the transparent color of this latter and therefore, was the clearest one. The difference in brightness within the two greenhouses was about 200 Lux. Also, the monolayer greenhouse was warmer than the tri-layers greenhouse and thus, the least humid. The difference in temperature between the two greenhouses was around 5°C.

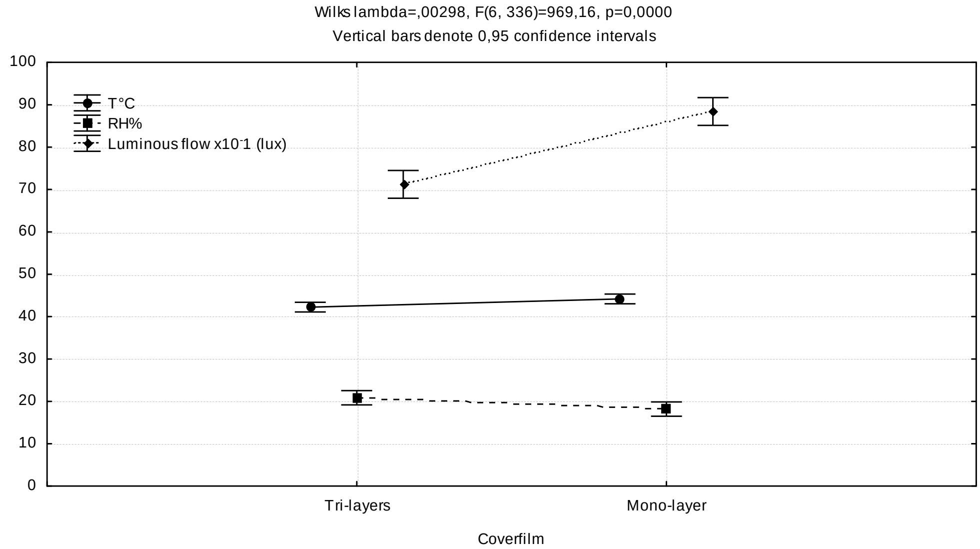


Figure 2. Analysis of variance ANOVA presenting the effect of the climatic parameters and the luminous flow on the type of the cover film (tri-layers and monolayer).

Figure 2 shows an ANOVA analysis of variance of the effect of the type of cover-film (monolayer and tri-layers), on the temperature, relative humidity and luminous flow inside the two greenhouses used in this study. It indicates a highly significant difference with a p-value (p=0,0000) lower than the confidence level (a=0.05). This only confirms the last results shown in Figure 1.

Another ANOVA analysis of variance was established in order to compare the mean values of stem length development of the two tomato varieties in both greenhouses (Figure 3). This shows a highly significant difference, with a P=0.00015 versus a confidence interval of 0.95. Consequently, it can be concluded that the Marmande S and ACE 55 VF have grown differently in the two different greenhouses during the study period.

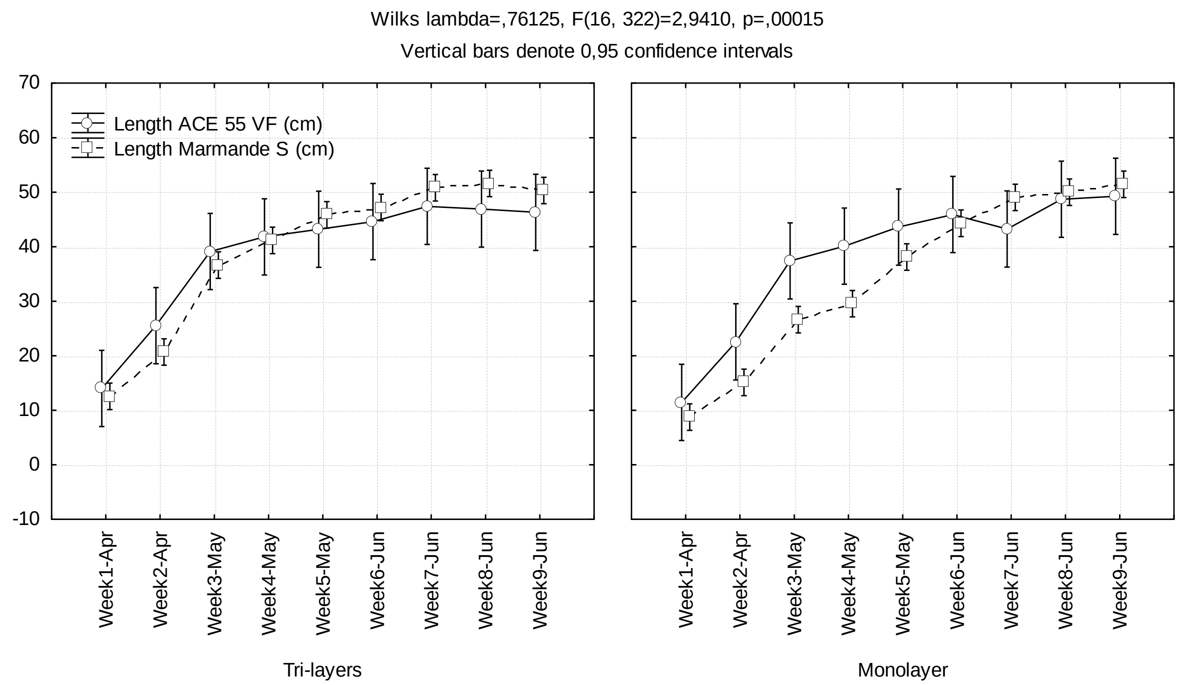


Figure 3. Analysis of variance showing the effect of the type of the cover film and date on stem length of two tomato varieties (ACE 55 VF and Marmande S).

According to Figure 3, both tomato varieties have shown two trends of evolution in the tri-layer greenhouse. A quick and progressive one from the first week to the third, and a slow one starting from the third week to the ninth with a slight favorable difference for the Marmande variety since it has reached 47 cm with a standard deviation of 17.1 during the eighth week in June. In the last week, tomato plants have experienced a regression in length for the Marmande variety reaching an average of 46.25 cm and a standard deviation of 17.4. However, the ACE 55 VF variety showed the same type of regression but with an average of 50.3 cm and a standard deviation of 6.42 during the last week. The temperature, relative humidity, and luminous flow were constant from the first week to the fifth, displaying about 42°C, 20% and 700 Lux, respectively. Nevertheless, during the sixth week, a singularity appeared characterized by a temperature drop with a value equal to 4.2°C (37.8°C). The light intensity also decreased to a value of 640 Lux and therefore, the humidity increased up to 33.6%. The maximum temperature reached was 48.6°C with 13.6% of relative humidity in June (Figure 1).

For the monolayer greenhouse, the evolution of tomato stem length was progressive. However, it was constant and weaker for the Marmande variety compared to the ACE 55 VF. This latter has known two different types of progression, a fast one from the first to the third week and a slow one from the third to the last week. Unlike the tri-layers greenhouse, there was no reduction in length for both tomato varieties. The maximum length reached for the two varieties was about 48.7 cm with a standard deviation of 4.3 for ACE 55 VF and 51.5 cm with a standard deviation of 3 for the Marmande (Figure 3).

The rate of stem elongation usually increases with temperature (Costa & Heuvelink, 2005). A good development of tomato plants has to be within an optimum range of daytime temperatures between 25-30°C, with a higher limit of 35 °C. If it goes on top of that, there will be some effects on germination, seedling, vegetative stage, flowering and fruit set (Zhang, 2010, Miller et al., 2001). In a past study, Wittwer and Honma (1979) found out that uneven growth, failures in fruit set and serious foliage diseases can be caused by temperature differences of 10 to 15 F° within the same greenhouse. Moreover, high-temperature stress can completely inhibit the function of the photosynthesis apparatus, knowing that it's one of the most heat-sensitive processes in plants (Camejo et al., 2005). This might explain the diminution of stem height during the last week when extreme temperatures were observed. Actually, the highest parts of tomato plants were completely dry and there was no recovery after that. Additionally, Costa and Heuvelink (2005) stated that high humidity improves stem elongation, though the effects are very small. Plant transpiration decreases when air humidity increases and the other way around too (Jones, 2007). The results show that the relative humidity has been very low and has never reached the optimum value of 50%. That's because of the high evapotranspiration of the plant caused by elevated temperatures. Furthermore, drought can be very harmful to the reproductive phase of plant growth. Jones (2007) also said that the optimum light intensity for plant growth is about 1400 Lumens, photoperiod 14h (1 Lux=lumens m^{-2}). Besides, they have considered that, even if tomato plants are known by their need to be grown under full sunlight, it happens that their best growth condition is when the plants are sheltered from extreme sunlight.

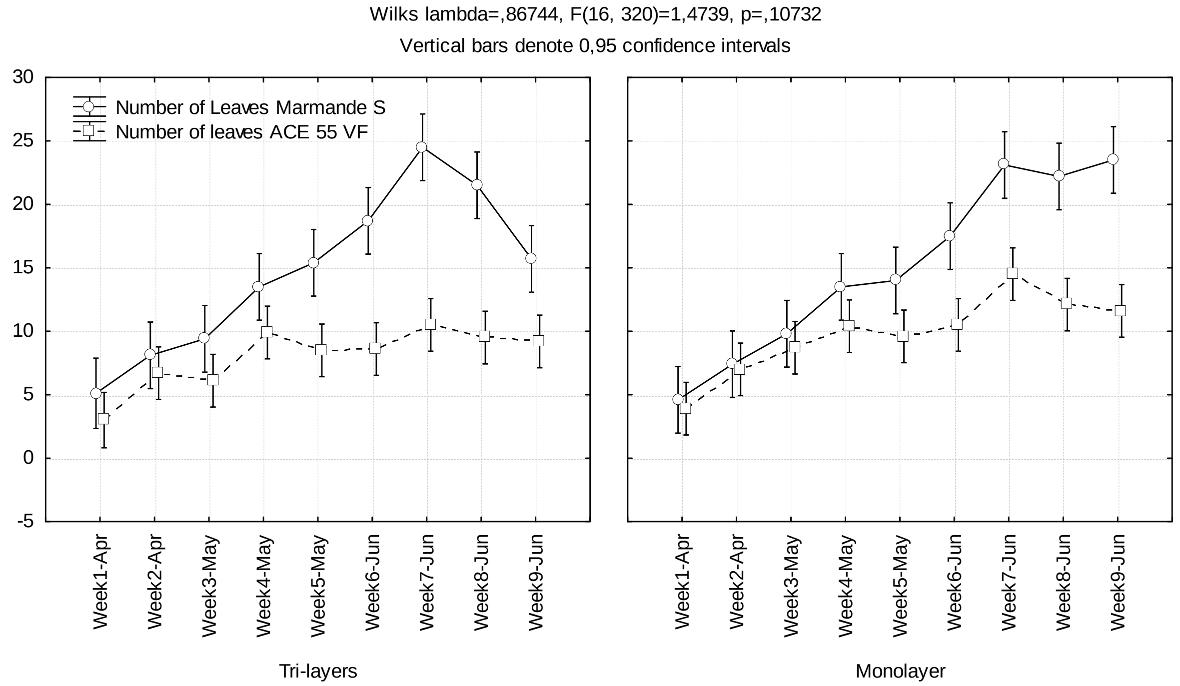


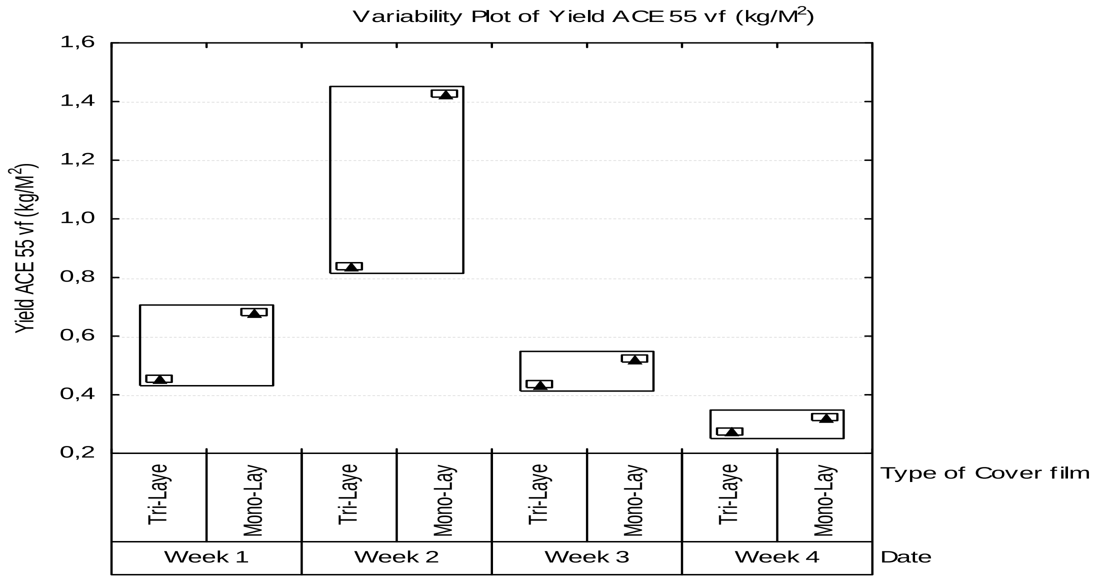
Figure 4. Analysis of variance showing the effect of the type of the cover film and date on the number of leaves of two tomato varieties (ACE 55 VF and Marmande S).

The analysis of variance ANOVA established to show the impact of the cover film on the growth of tomato leaves (Figure 4), showed a non-significant difference with a P=0.10 which was higher than the confidence interval a=0.05. It also indicates an accelerated evolution for the Marmande variety at the tri-layers greenhouse, from the first week to the seventh reaching an average of 24 leaves with a standard deviation of 9.3 out of ten pots. The number of leaves relapses after that, reaching 16 leaves with a standard deviation of 6.7 during the last week. The only reasonable explanation for that, is the increase of the temperature above the threshold of 35°C (Figure 1). High temperatures can affect the photosynthetic process increasing leaf temperatures (Lloyd & Farquhar, 2008). It can be thirty degrees above air temperature within the greenhouse. Also, the soil was almost constantly dry and it couldn't hold the amount of irrigation water given to it each day even after the quantity was doubled. Snyder and Richard (1992) stated that plants wilt at the top of the soil whenever there is a water deficiency on it. This process allows them to reduce water loss. Also, there will be no recovery for plants that reach the continuous wilting point because their tissues will be completely damaged. The evolution of the number of leaves for the ACE 55 VF variety was low and more or less constant, not exceeding 10.5 leaves. In addition, there has been too much leaf rolling during extreme periods of heat. This process is explained through the work of other researchers like Fernandez and Castrillo (1999) and Saglam et al. (2008), who stated that in order to avoid dangerous periods, plants tend to change their physiological process and organ position by leaf rolling. Old dry leaves were continuously removed from tomato plants; this also explains the diminution of the number of leaves in the results. Also, Amati et al. (2002) said that old, yellow or sick leaves should be removed from tomato plants in order to control the development and spreading diseases.

Regarding the greenhouse covered with the monolayer film, we've noticed the same type of evolution of the number of leaves for the Marmande variety as that of the tri-layers film greenhouse (until the seventh week reaching 23 leaves with a standard deviation of 5.6). Then, the number of leaves remains by any means constant. The evolution was identical from the first to the fourth week for both varieties. The ACE 55 VF variety was always the one with fewer leaves. It has reached 14.5 leaves with a standard deviation of 4.4 in the seventh week after which, it decreased to 11.6 leaves with a standard deviation of 4.8 during the last week of the experiment (Figure 4).

Light intercept is an important plant productivity issue. Also, the interceptions of the solar radiations, as well as the photoassimilate production, are reduced whenever there's a leaf space diminution (Denise et al., 2018). This corresponds to our results regarding the ACE 55 VF tomato variety that showed a higher number of leaves inside the monolayer greenhouse compared to that of the tri-layers greenhouse. The Marmande variety didn't show the same effect. Also, the Tomato leaf area increases with humidity, although the effect could be very small (Costa & Heuvelink, 2005). Furthermore, leaf area could be reduced up to fifteen precent because of calcium deficiencies caused by extreme humidity (Holder & Cockshull, 1990). As it's been said before, because of the extreme heat, Relative humidity has never reached the optimum level (50%) for plant growth (Bakker, 1985). Actually, the highest values recorded in the tri-layers and monolayer greenhouses were 33% and 21% respectively. The only logical justification of the non-significant difference of the development of the two varieties of tomato under both greenhouses is the rapid loss of a number of leaves of the ACE 55 VF variety after 7 weeks of the experiment study, and some explanations were given in the preceding paragraphs. During the month of June, there has been a quick and progressive degradation of the monolayer film. Indeed, its mechanical properties have considerably decreased which led to its rupture that made the greenhouse completely bare at the end of the month. The tri-layers film has not undergone such rapid degradation and remained fully functional. This explains why the results of tomato plant development (stem growth and the number of leaves) have not been mentioned after that. Khan and Hamid (1995) believed in a study that LDPE films behaved otherwise during a period of time when they have faced many offensive surroundings such as mechanical stress and severe climate parameters owing to UV radiations, high temperatures, pollution, and wind pressure. They've also reported that the metal frame of the greenhouse includes a prejudicial impact on the plastic film because of corrosion and the retention of heat.

a)



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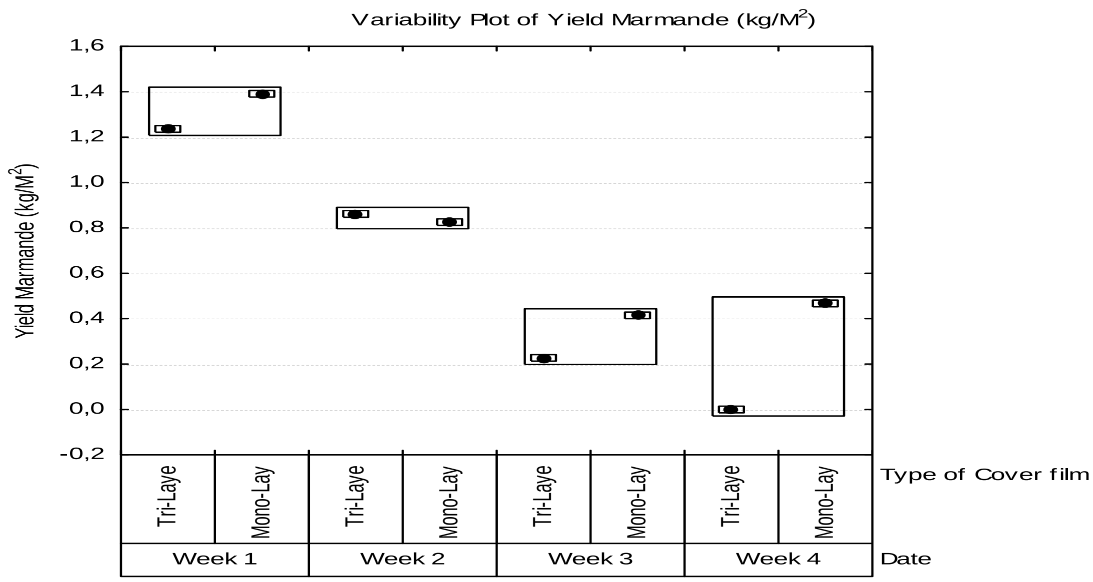

Figure 5. Analysis of variability plot showing the effect of the tri-layer and monolayer films on the yield of two tomato varieties (a: ACE 55 VF; b: Marmande).

Figure 5 shows that tomato plants gave a better yield in the monolayer greenhouse with a total yield from both varieties considered 6 kg/m^2 (3.1 Kg/m^2 for the Marmande variety and 2.9 Kg/m^2 for the ACE 55 VF variety). The harvest period was about one month (July). The tri-layers greenhouse gave a total yield of 4.3 Kg/m^2 (2.3 Kg/m2 for the Marmande variety and 2 Kg/m^2 for the ACE 55 VF variety). The maximum harvest for the Marmande variety was during the first week of July, with a value of 1.4 kg/m^2 for the monolayer greenhouse and also 1.4 kg/m^2 for the tri-layers greenhouse. For the ACE 55 variety VF, the highest harvest was during

the second week with a value of 1.4 kg/m^2 for the monolayer greenhouse and 0.8 kg/m^2 for the tri-layers greenhouse. Heat stress has become a huge problem to plant yield all over the world because of the poor quality of the resulting fruits (Hall, 2001). Elevated temperatures can decrease pollen quality, increase floral anomaly and thus lower the fruit number (Dorais et al., 2001). Snyder and Richard (1992) reported that pollination needs an optimum temperature within the range of 70 to 82°F (22 to 28°C). When relative humidity is very low or less than 60%, the stigma of tomato plants can completely dry out and because of that, pollen grains won't be able to stick to it. Yield decreases considerably after short periods of water deficiency. Morgan (2003) stated that the good success of any tomato growing process is related to the comprehension of the plant physiology, starting from the seeding to the final phase of development (harvest). He additionally stated that, there has been fruit yields higher than 50 kg m^{-2}, at the time that general fruit yields have been very low, in the 10-to 20 kg m^{-2} ranges. The yield obtained from both greenhouses was even lower than that. It's certainly related to continuous exposure to extreme temperatures.
The mechanical behaviour, UV-visible spectroscopy and the tensile tests of the LDPE films (mono and tri-layers) such as yield strength, elasticity, lifespan, resistance, and strength were considered in a previous study (in the same area). For that, samples from both polymers were taken and studied each month of the experimental. According to Dehbi et al. (2016) and Aouinet et al. (2018), the elastic modulus increase with time, which caused a degradation of the flexibility. Also, the tri-layers films presented a higher level of ductility and fracture stress. The authors have concluded that after long exposure of the films to the surrounding conditions, the quality of both films was deteriorated (mainly because of sunlight radiations). They have revealed that the degradation was mostly due to the aging process, UV radiations and also intense temperatures. The tri-layers cover film showed up to be much more stable with 10 months' tolerance to exposure without 50% of its properties degrading, while the maximum lifespan of the monolayer film was for five months (which was our case too with the same LDPE films). This is why they have concluded that tri-layers film is more recommended than the monolayer film as greenhouse cover.

Conclusion

In this work, alternatives to increase the yield of tomato production in semi-arid s areas are proposed. Although multilayer films have been a great finding for greenhouse, the use of monolayer and multilayer LPDE presented differences concerning the effect on the yield and tomato production. In spite of the fact that the tri-layers film is resistant and its lifespan is very impertinent compared to the monolayer film, this study has shown that the yield of tomato production in the greenhouse covered by the monolayer film is better than the one in the greenhouse covered by the tri-layers film. Following our contribution, it can be said that the monolayer film is adequate for tomato production in Northern Algeria. In the upcoming researches, the monolayer cover-film life durability must be taken into consideration and should be improved in the future.

Conflict of Interest

The authors state that there is no conflict of interest and have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript.

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