EFFECT OF DEFICIT IRRIGATION ON THE PRODUCTIVITY AND CHARACTERISTICS OF TOMATO

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ABSTRACT

In order to assess the effect of water irrigation deficit during season on yield and mechanical damage of processing tomato, an open field experiment was carried out in two seasons 2010/2011 – 2011/2012. Four irrigation treatments were studied: (ET_1: 1 time potential crop evapotranspiration (ET_c), ET_2: 0.9 ET_c, ET_3: 0.8 ET_c and 0.7 ET_c, ET_4). The study investigated the yield and mechanical damage in packing cage under four levels of water requirements. Numerous mechanical impacts on fruit occurred with resulting mechanical damages of 15.9, 9.9, 7.1, and 9.5% for treatments ET_1, ET_2, ET_3, and ET_4, respectively. Total productions of tomato were 30.77, 29.50, 28.88 and 25.54 ton/fed, but net productions of tomato were 25.88, 26.58, 26.83 and 23.12 ton/fed for treatments ET_1, ET_2, ET_3 and ET_4, respectively. The bruised productions of tomatoes were 4.89, 2.92, 2.05 and 2.43 ton/fed for treatments ET_1, ET_2, ET_3 and ET_4, respectively. The net profit values for treatments ET_1, ET_2, ET_3 and ET_4 were 68990.7, 68841.5, 68644.2, and 59804.6 LE/fed, respectively. The amounts of water saved from ET_2 and ET_3 were 163.5 and 327 mm, respectively. The amount of water saved can be used to provide other areas to increase the production and thereby increase the water use efficiency.

Key words: Mechanical damage, physical properties, mechanical properties, yield, tomato, deficit irrigation.

INTRODUCTION

Water plays a crucial role in determining the yield of processing tomato but it is likely that a water scarcity period will have to be faced in the near future. Water shortage and the increasing competition for water resources between agriculture and other sectors compel the adoption of irrigation strategies in semi-arid Mediterranean regions, which may allow saving irrigation water and still maintain satisfactory levels of production (***Costa et al., 2007***).

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One of the means to improve water use efficiency (***Topcu et al., 2007***) is deficit irrigation. Deficit irrigation effects have been extensively studied on several crops including tomato. Tomatoes (*Lycopersicon esculentum Mill*.) are commercially important vegetable worldwide, with an annual production of more than 120 million tons in the world. Tomato is mainly cultivated in Egypt followed by China, United States, Turkey and India, where tomato production arrived in Egypt to 8.5 million tons (***FAO, 2010***). Packaging becomes very vital in the trading process for fruits. Packaging and its associated problems therefore affect the quality of fresh produce. During packaging, there is a static mechanical load in the lower fruit layers of tomato bulk due to filling tomatoes over each other, which leads to high mechanical load and damage of tomato fruit (mechanical damage). The major cause of mechanical damage (bruising) is impact. Impact sensitivity of fruits and vegetables is defined as having components, namely bruise threshold and bruise resistance (***Bajema and Hyde, 1998***). Bruising in fruits and vegetables occurs when the produce rubs against each other, packaging containers, parts of processing equipment and the tree (***Altisent, 1991***). The bruised tomato can be classified into two types after test, severe bruise damage with crack under the skin and medium-slight damage without crack (***Linden et al., 2006***). Evidence of severe problems of mechanical damage is increasing affecting the trade of these products. This is because there is great demand for high quality fruits and vegetables worldwide (***Altisent 1991***). The high level of mechanical damage and diseases (often encouraged by mechanical damage) are clear indications of the need to improve the techniques of packing of perishable items like tomatoes. One likely means of achieving this is to explore alternative packing cage. However, a thorough investigation of the existing packing cage (particularly the specific locations within the packaged fruits where damage is mostly concentrated) requires investigation. Understanding the behavior of the produce under static and dynamic loads provides useful information in reducing mechanical damage and enhancing quality of the fresh produce in packing cage, because damage to fresh produce due to mechanical forces is among the most important causes of losses of quality (***Batu, 1998; Dewulf et al., 1999***).

This study investigated the effects of physical, mechanical properties and mechanical damage on production of tomatoes under different water levels.

MATERIALS AND METHODS

1. Location and plant materials

The experiments were conducted in October 2010-2011 and 2011-2012 of the experimental farm of the Irrigation Unit, Agricultural Engineering Department, Faculty of Agriculture, Cairo University. Some chemical and physical characteristics of the experimental field soil are shown in tables (1) and (2). Also Table (3) shows some physical analyses of irrigation water used in the experiment. The soil and water samples were tested in Soil Science Department – Faculty of Agriculture – Cairo University.

Table (1): Some physical analyses of soil samples.

Soil depth (cm)	Texture	FC ($cm^3\ cm^{-3}$)	WP ($cm^3\ cm^{-3}$)	Bulk density ($g\ cm^{-3}$)	pH	EC_e ($dS\ m^{-1}$)
00 – 20	SCL	42.07	14.43	1.29	7.74	2.43
20 – 40	SCL	41.80	14.91	1.31	7.69	1.92
40 - 60	SCL	38.96	17.15	1.33	7.81	1.78

Table (2): Some chemical analyses of soil samples.

Depth, cm	pH	EC ds/m	$HCO3^-$ meq/l	CL^- meq/l	SO_4^{--} meq/l	Ca^{++} meq/l	K^+ meq/l	Mg^{++} meq/l	Na^+ meq/l
00 – 20	7.74	2.43	1.0	3.6	19.84	7.8	1.14	6.4	9.10
20 – 40	7.69	1.92	0.9	3.0	15.9	5.6	0.82	5.4	7.98
40 – 60	7.81	1.78	0.8	3.2	13.62	4.0	0.82	5.0	7.8

Table (3): Some chemical and physical analyses of water sample.

pH	7.20	Ca^{++}, meq/l	3.60	K^+, meq/l	0.18
EC, ds/m	0.83	Mg^{++}, meq/l	2.60	SAR	0.51
Cl^-, meq/l	1.00	Na^+, meq/l	0.90	T.S.S*	0.00
HCO^-_3, meq/l	5.00	SO^{--}_4, meq/l	1.28		

* T.S.S = Total Suspended Solids in irrigation water

The tomato (El-Odds E448) variety (*Lycopersicon esculentum*) was used in this study, which is planted at a spacing of 0.5 × 1.2 m within and between rows. The research focused on the tomato light red stage of maturity, which is at this stage more solid and convenient for storage and transportation (***Allende et al., 2004; Lien et al., 2009***).

The fruits in this experiment were hand harvested at the light red ripening stage according to US Department of Agriculture (USDA) standards (***USDA, 1991***). Extremely large or small tomatoes were excluded. After careful transportation to the laboratory, the tomatoes were inspected again to ensure that they were uniform, non-damaged and not attacked by worms. In addition, the measurements were conducted within 48 hours.

2. Experimental design and treatments

The tomatoes were arranged in a completely randomized experiment design with three replicates. Four irrigation treatments were applied (ET_1: 1 time potential crop evapotranspiration (ET_c), ET_2: 0.9 ET_c, ET_3: 0.8 ET_c and 0.7 ET_c, ET_4). Fertilizers consisted of 84 kg/fed actual N (as ammonium sulphate), 95.8 kg/fed K_2O, 300.3 kg/fed P_2O_5, and 399 kg/fed El-Mowfer-Bio (as a different source of phosphorus). Plants were transplanted in a single plot. The Plot consists of 5 rows (20 x 6 m). Irrigation water was delivered via a trickle system. The emitters used in the trickle irrigation system were with flow rate of 4 L/min/0.5 m, the emitters were spaced at 50 cm with polyethylene tubes (16 mm in external diameter with 20 m in length).

3. Measurements

3.1. Determination of crop irrigation water requirement

The FAO Penman–Monteith method (***Allen et al., 1998***) was used to calculate the reference evapotranspiration ET_o in the CROPWAT Program. Crop water requirements (ET_c) over the growing season were determined from ET_o according to the following equation using crop coefficient K_c:

$$ET_c = K_c ET_o \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where ET_c is the crop water requirement, K_c is the crop coefficient and ET_o is the reference evapotranspiration. Since there was no rainfall during the experimental period, net irrigation requirement was taken to be equal to ET_c.

The total amounts of irrigation water applied (from transplantation to harvest) in the irrigation levels in this study were 1635 mm in ET_1, 1471 mm in ET_2, 1308 mm in ET_3 and 1144 mm in ET_4. The water requirement was determined for different months based on crop growth stages and climatic data.

3.2. Water use efficiencies

Water use efficiency (kg/m^3) was calculated as the ratio between total fresh yield at harvest (kg/fed) and total water used (m^3/fed). Water use efficiency was also calculated from marketable total yield (kg/fed) and total water use (m^3/fed) (***Lovelli et al., 2007***).

3.3. Energy consumption of operating pump (E_{cp})

The energy consumption of operating pump (E_{cp}) was calculated from equation (3) according to ***Ghonimy,* (2003)**.

$$E_{Cp} = \frac{3.6 M_p \times SAW}{Q_p} \qquad \text{........................(2)}$$

Where;

E_{cp} = Energy consumption of operating pump, MJ/fed;

M_p = Motor power = 3 , kW;

SAW = Seasonal amount of applied water, m^3/fed;

Q_p = Pump flow rate = 15 , m^3/h.

3.4. Some physical parameters measurements

The tomato fruits were harvested during harvesting stages and divided into four groups (treatments) after being labeled. Ten tomatoes were taken from each group and the following measurements were determined for each fruit; the tomato size, in terms of the three principal axial dimensions (figure 1), that is (in mm), the longitudinal height L_c (the height between the upper contact point and lower contact point uncompressed), the maximum transverse diameter L_{max}, and minimum transverse diameter L_{min}. All dimensions of tomatoes were measured by Vernier calliper to an accuracy of 0.01 mm. The mass of tomato was determined using a digital balance with an accuracy of 0.01 g. Tomato volumes were measured by the water displacement method. Tomatoes were weighed in air and allowed to float in water. Fruits were lowered with a needle into a beaker containing water and the mass of fruit in the water was recorded.

$$\text{Volume (cm}^3\text{)} = \frac{\text{Displaced water (g)}}{\text{Water specific mass (g/cm}^3\text{)}} \qquad \text{............ (3)}$$

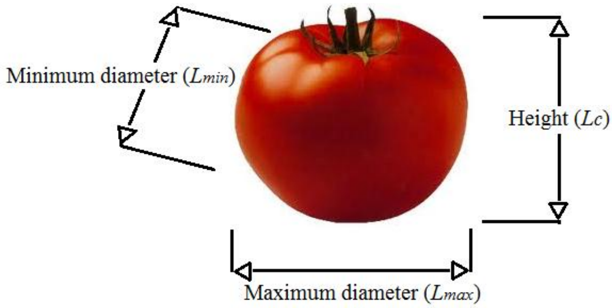


Figure (1): Three principal axial dimensions of tomato.

The solid density or true density is defined as the ratio of mass of the sample to its true volume (***Mohsenin, 1986; Joshi et al., 1993***)

$$\rho_s = \frac{M}{V_c} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

Where; ρ_s is the solid density (g/cm^3) and V_c is the volume of cage that contains the samples (cm^3).

3.5. Mechanical parameters measurements

3.5.1. Coefficient of static friction

Coefficient of static friction is the ratio of force required to start sliding the sample over a surface divided by the normal force, i.e. the weight of the object (***Bahnasawy, 2007***). The static coefficient of friction of tomato against different materials, namely cartoon, plastic, glass, metal and wood was determined.

A device was locally designed and fabricated to measure the static friction force between feed material and the friction surface (according to ***Ibrahim 2008***).

The static coefficient of friction was calculated as follows:

$$\mu = \frac{F_T - F_E}{W} \ldots\ldots\ldots\ldots\ldots\ldots \text{(5)}$$

Where;

μ = Coefficient of static friction

F_T = Force required to start motion of filled wooden frame (N).

F_E = Force required to start motion of empty wooden frame (N).

W = Weight of the object (N).

3.5.2. Mechanical damage evaluation

Mechanical damage appears due to impacts and compressions on product during harvesting, transport, and manipulation processes. Damages can appear at the moment at which the impact or compression takes place, or later, during storage. These damages have a direct effect on loss of quality and reduce sale prices. External quality is considered of paramount importance in the marketing and sale of fruits.

Force-Deformation curve (F-D) is shown in Figure (2). AB is the loading stage while BC is the unloading stage. The loop area, ABC, is defined as the plastic strain energy. The deformation, D_p, of tomato corresponding to point C is the plastic deformation; D_e is elastic deformation of tomato. In this study, the mechanical damage of bruised tomato was defined by the following equation;

$$R_c = \frac{D_p}{D_p + D_e} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

The mechanical damage (R_c, mm) is a measure of the damping characteristics of the fruit. The slope of line AB is loading slope, which is a ratio of force to distance within the region of fruit's elastic deformation. The abscissa of point B is the deformation ($D = D_e + D_p$) of tomato under the corresponding compressibility, while the y-axis of point B is the peak force F_{max} (N) the tomato received.

Different compressibilities cause varying degrees of mechanical damage to tomato. Thus, under the condition of certain compressibility, the degree of mechanical damage to tomato can be evaluated by determining the volume of bruise of tomato in this research. The compressibility (e) was defined (***Gonzalez et al., 1998***) by:

$$e = \frac{L_c - L}{L_c} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where, L_c represents the compression diameter and L is the diameter of the tomato during compression. The compressibilities used in this study were 0, 5, 10, 15, and 20%. The bruise of tomato (the deformation after unload) at a compressibility of 0% means that the tomato is intact without any degree of mechanical damage.

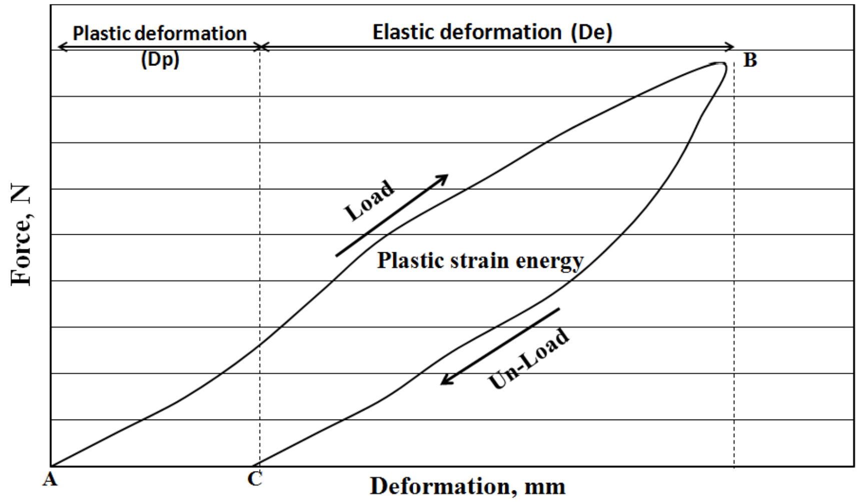


Figure (2): Force-Deformation curve (F-D) (*Zhiguo et al., 2010*).

RESULTS AND DISCUSSION

1. Irrigation water deficit

The deficit irrigation during season is considered as an alternative approach to achieve adequate fruit yield and save irrigation water. The total amount of irrigation water applied in the experiment was 6865.6, 6179.0, 5492.5 and 4805.9 m^3/fed.

2. Tomato production

The irrigation up to 100 % ET_c gave highest total yields (30.77 t/fed) than that obtained under very stressful condition (70 % ET_c). The crop suffered by water shortage in other treatments. The total productions of tomato under different water levels were 30.77, 29.5, 28.88 and 25.54 t/fed. This result is due to the amount of water added to the first treatment (ET_1) is larger than the amount of water added to the other treatments.

3. Energy consumption

Energy consumption was determined for each treatment in (MJ/fed). Figure (3) shows that the maximum energy consumption (4943.2 MJ/fed) was found with ET_1 while the minimum energy consumption (3460.3 MJ/fed) was found with ET_4 treatment.

Energy consumption cost was determined in (LE/fed) through the determination of production of tomato. The maximum cost of energy consumption (590.4 LE/fed) was found with ET_1, while the minimum cost (413.3 LE/fed) was found with ET_4 treatment (figure 4).

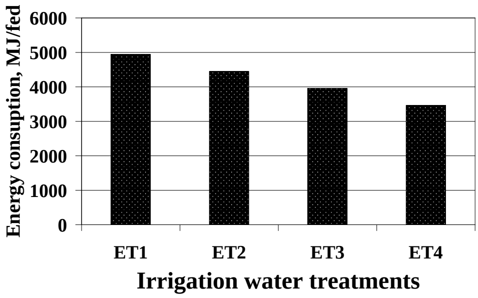


Figure (3): Energy consumption under different water treatments.

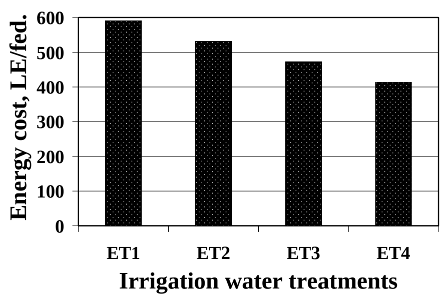


Figure (4): Energy cost under different water treatments.

4. Tomato fruit characteristics

4.1. Physical characteristics of tomato fruits

Table (4) shows the average values of fruit mass, fruit volume, bulk density, fruit length, fruit diameter and fruit thickness. Minimum values of the mass, length, width, thickness, and volume were 88.9 g, 44.6 mm, 54 mm, 51.9 mm, and 87.5cm^3 found with ET_4, while the minimum value of solid density (0.969 g/cm^3) was found with ET_3. The maximum values of the mass, length, width, thickness, and volume were 116.7 g, 50.7 mm, 62.1, 59.9 mm, and 118 cm^3, found with ET_1 but the maximum value of solid density (1.028 g/cm^3) was found with ET_2.

Table (4): Some average physical properties of tomatoes for different treatments.

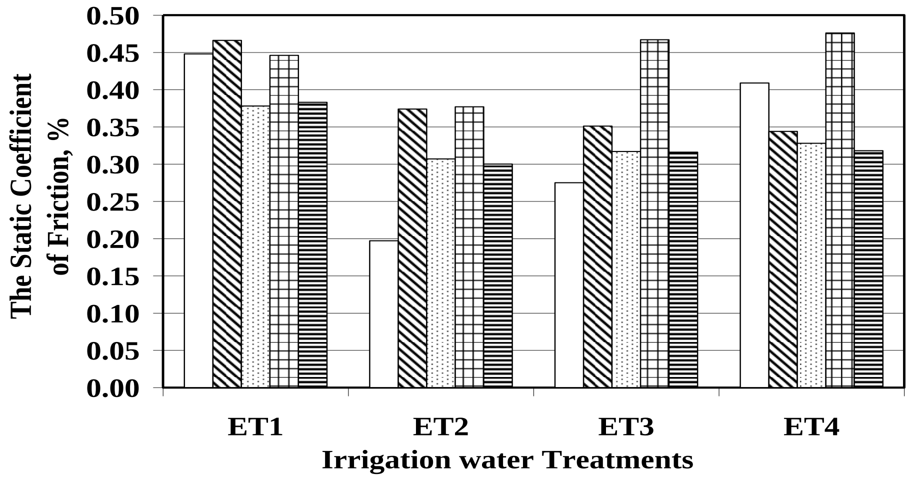
Treatments	Mass (g)	Length (mm)	Width (mm)	Thickness (mm)	Volume (cm^3)	Solid Density (g/cm^3)
ET_1	116.7	50.7	62.1	59.9	118	0.989
ET_2	101.3	47.3	59.7	58.7	99.5	1.028
ET_3	93.0	47.1	57.9	55.9	96.0	0.969
ET_4	88.9	44.6	54.0	51.9	87.5	1.015

The results show that the mass of tomatoes decreased by decreasing crop water requirements. Same results trend was found for the length, width, thickness and volume. The reason for these results is due to water stress decreasing the above-mentioned measurements.

4.2. Mechanical characteristics of tomato fruits

4.2.1. Coefficient static of friction

The static coefficient of friction of tomato varied on five different surfaces with different treatments. Figure (5) shows the static coefficient of friction of tomato on carton surface, the minimum static coefficient of friction ranged from 0.179 to 0.214 % with a mean value of 0.197 % ± 0.02 for treatment ET_2, while the maximum static coefficient of friction ranged from 0.407 to 0.488 % with a mean value of 0.448 % ± 0.06 for treatment ET_1. The static coefficient of friction of tomato in treatment ET_1 was higher than that in treatment ET_2 by 127.5 %. For plastic surface, the minimum static coefficient of friction ranged from 0.325 to 0.377 % with a mean value of 0.351 % ± 0.05 for treatment ET_3, while the maximum static coefficient of friction ranged from 0.365 to 0.567 % with a mean value of 0.466 % ± 0.08 for treatment ET_1. The static coefficient of friction of tomato in treatment ET_1 was higher than that in treatment ET_3 by 32.8 %. For metal surface, the minimum static coefficient of friction ranged from 0.292 to 0.322 % with a mean value of 0.307 % ± 0.04 for treatment ET_2, while the maximum static coefficient of friction ranged from 0.366 to 0.390 % with a mean value of 0.378 % ± 0.03 for treatment ET_1. The static coefficient of friction of tomato in treatment ET_1 was higher than that in treatment ET_2 by 23.2 %. For wood surface, the minimum static coefficient of friction was ranged from 0.371 to 0.383 % with mean value of 0.377 % ± 0.06 for treatment ET_2, while the maximum static coefficient of friction ranged from 0.471 to 0.482 % with a mean value of 0.476 % ± 0.05 for treatment ET_4. The static coefficient of friction of tomato in treatment ET_4 was higher than that in treatment ET_2 by 26.3 %. For glass surface, the minimum static coefficient of friction ranged from 0.273 to 0.326 % with a mean value of 0.300 % ± 0.03 for treatment ET_2, while the maximum static coefficient of friction ranged from 0.368 to 0.397 % with a mean value of 0.383 % ± 0.04 for treatment ET_1. The static coefficient of friction of tomato in treatment ET_1 was higher than that in treatment ET_2 by 27.6%.



□ Carton	0.448	0.197	0.275	0.409
▧ Plastic	0.466	0.374	0.351	0.344
▒ Metal	0.378	0.307	0.317	0.328
⊞ Wood	0.446	0.377	0.467	0.476
▤ Glass	0.383	0.3	0.316	0.318

Figure (5): The mean static coefficient of friction of tomato on carton, plastic, metal, wood and glass surfaces.

4.2.2. Mechanical damage evaluation

1. Force-Compressibility-Mechanical damage relationship

The data extracted from the force-deformation curve and from the fruit physical parameters measurement led to an appropriate evaluation of the degree of mechanical damage to tomato. Figure (6) shows the relationship between different compressibilities (e) and percentage of mechanical damage (R_c). Peak force (F_{max}) and mechanical damage (R_c) increased with the lifting of applied compressibility in all treatments. This is consistent with the findings of other researchers (***Linden et al., 2006***).

The results showed that ET_1 was the most affected treatment by mechanical damage where mechanical damage was 37.4 % at compressibility 20 % and load (peak force F_{max}) 18 N, while R_c arrived to 28.6, 28.3, and 27.1% with ET_2, ET_3, and ET_4, respectively at the same F_{max} 18 N (figure 6). This result due to the tomato in ET_1 treatment received more water than other treatments and thus leads to tomatoes were more weakness than other tomato in treatments ET_2, ET_3, and ET_4.

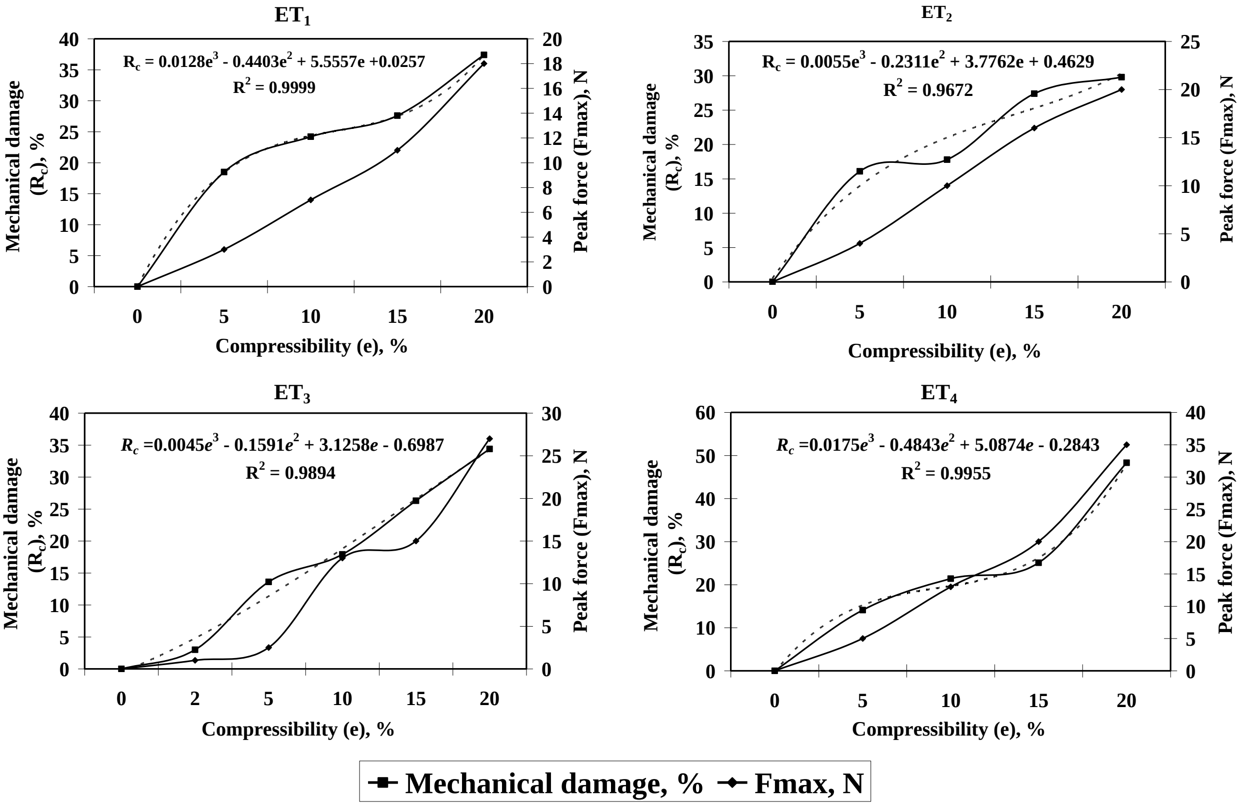
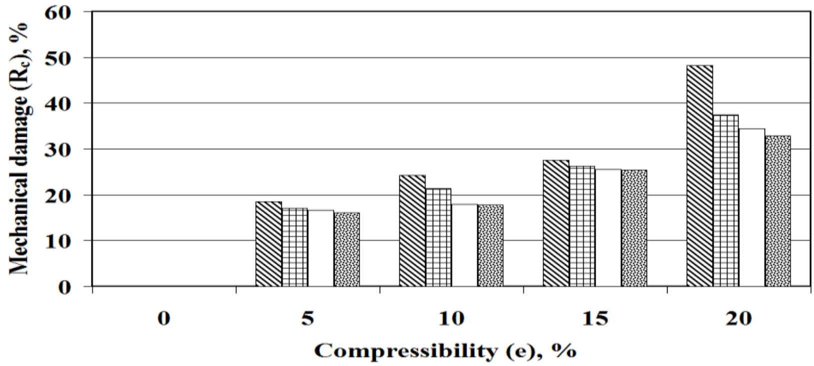


Figure (6): The mechanical damage percent (R_c) at different loads (F_{max}) and compressibility (e) under different water treatments.

2. Effect of deficit irrigation on mechanical damage of tomato

From figure (7), it is clear that decreasing the water applied decreased the mechanical damage. The data indicated that the bruise volume increased with the increase of compressibility for all treatments. Also it is clear that at the same value of compressibility, decreasing the amount of applied water decreased the mechanical damage to tomato fruit.

No significant difference existed in mechanical damage between the third and fourth treatments (ET_3 and ET_4) and the difference increased at a compressibility percent of 20%. For ET_1, the mechanical damage gradually increased up to 15 % compressibility but at 20 % compressibility the mechanical damage increased largely (figure 7). This is a result of increased water content in the fruit, leading to the collapse of the fruit quickly when they arrive to a specific compressibility.



ET1	0	18.5	24.2	27.6	48.3
ET2	0	17.1	21.4	26.3	37.4
ET3	0	16.6	17.9	25.5	34.4
ET4	0	16.1	17.8	25.4	32.8

Figure (7): Effect of deficit irrigation on mechanical damage of tomato under different compressibilities.

5. Relationships between deficit irrigation, fruit production and mechanical damage

The compression on the tomato fruits causes bruises and thus leads to damage the fruit, but the volume of this damage varies depends on its position in the packing cage. The more compression leads to increased bruising affecting the fruit (***Zhiguo et al., 2010***). Moreover, increasing the depth of the fruit in the packing cage means more influential weight (compression) and thus leads to increase the volume of damage that occurs.

In this study, the effect of depth of tomato in the packing cage on the volume of the bruise was investigated and thus the mechanical damage percent that occurs. Dimensions of packing cage of tomatoes popular in Egypt according to farms are 55 × 40 × 30 cm for length, width and depth, respectively. Moreover the number of tomato fruits in the packing cage, the number of layers of tomatoes, and the weight of the packing cage can be determined by the three dimensions of the fruit that has been studied in the physical properties for each treatment (Table 5).

Table (5): Number and weight of tomato layers in packing cage.

Item	Water levels			
	ET_1	ET_2	ET_3	ET_4
Number of tomato layers	6	6	6	7
Number of tomatoes in the packing cage	370	413	447	542
Mass of tomatoes in packing cage, kg	43.2	41.8	41.6	48.2

Figure (8) shows that the maximum compressibility in treatments ET_1, ET_2, ET_3, and ET_4 was 10.6, 7.1, 6.8, and 5.4% at the last layer in packing cage, respectively, as a result of the weights of tomato layers on top of each other and according to the data extracted from force-compressibility-mechanical damage relationship. The results show that the deformation in each tomato layer increased with the increase in the depth of layer in packing cage in all treatments which increases volume of bruise according to position of tomato layer in packing cage. Maximum deformation (5.38 mm) was found with ET_1, while the minimum deformation (2.39 mm) was found with ET_4 in the last tomato layer (figure 8).

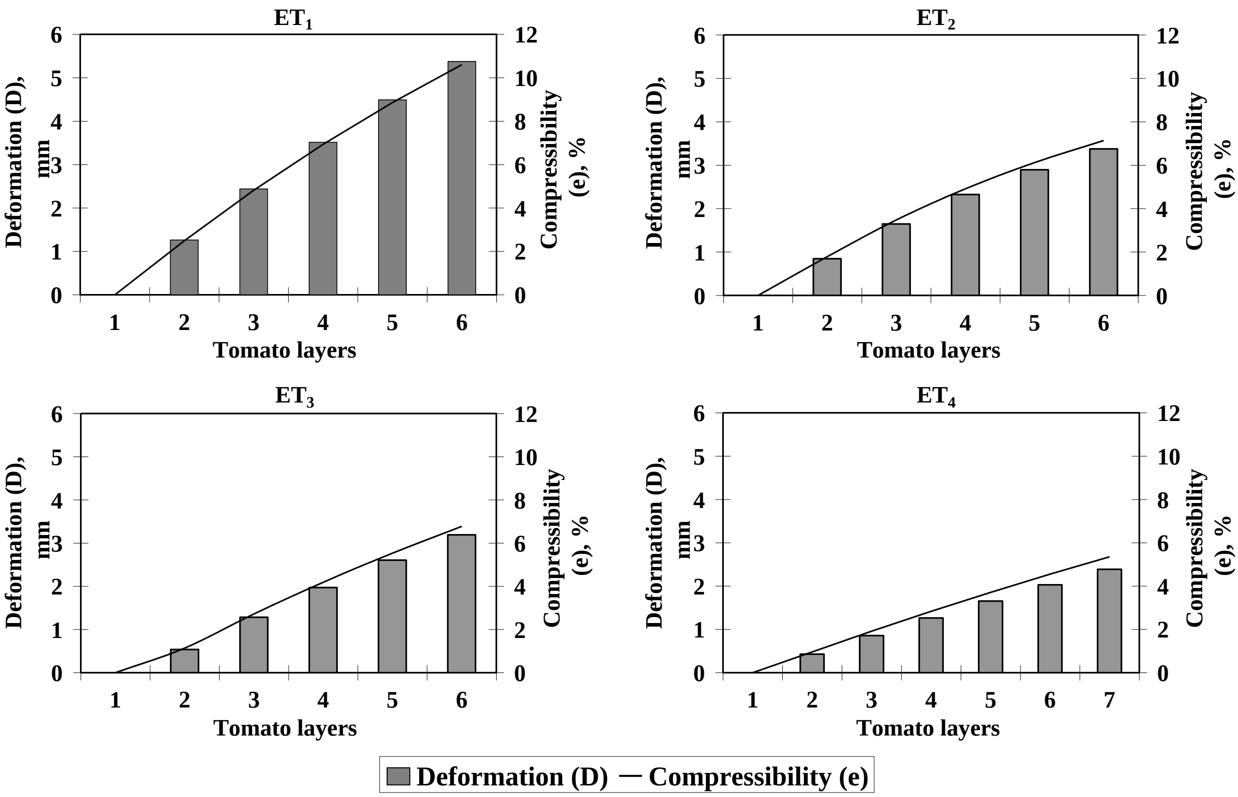


Figure (8): Compressibility-Deformation relationship for each tomato layer in packing cage under different water treatments.

The mechanical damage (R_c) in each tomato layer in the packing cage under deficit irrigation water is illustrated in figure (9). The mechanical damage (R_c) increased with increasing the layer depth in all treatments. Figure (9) shows that the maximum mechanical damage in treatments

ET_1, ET_2, ET_3, and ET_4 was 24.7, 17.6, 14.6 and 15.8% at the last layer in the packing cage, respectively.

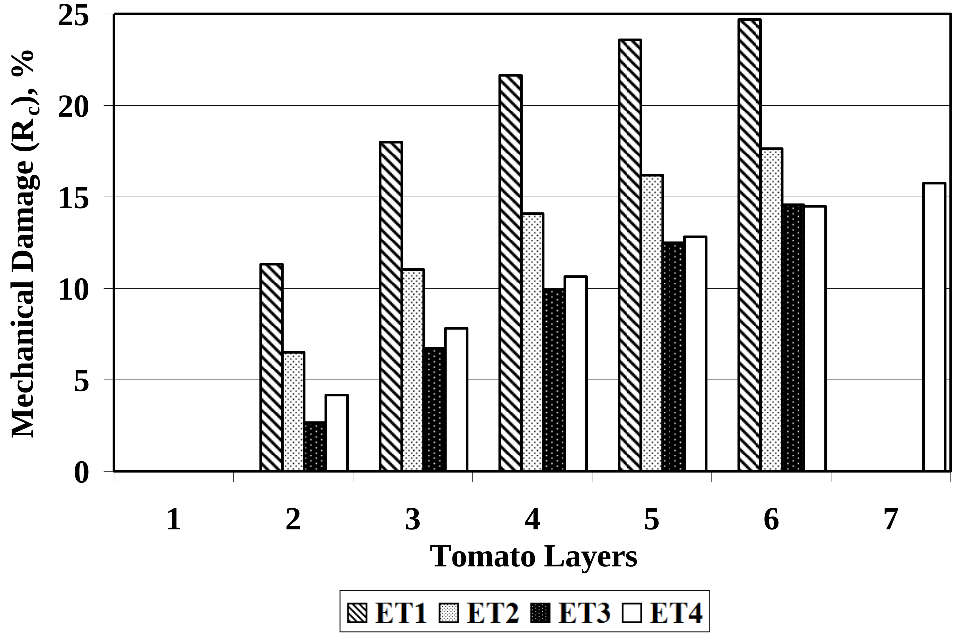


Figure (9): The mechanical damage (R_c) in each tomato layer in the packing cage under different water treatments.

The total mechanical damage of tomatoes in the packing cage under different water levels is illustrated in figure (10). It is clear that the total mechanical damage for tomato for the entire the packing cage decreased with decreasing the amount of water applied except in ET_4 where the total mechanical damage increased again due to increasing the number of tomato layers (7 layers) than previous first treatments (6 layers). Figure (10) shows the mechanical damage of the entire packing cage for treatments ET_1, ET_2, ET_3, and ET_4 were 15.9, 9.9, 7.1, and 9.5%, respectively.

As mentioned in part 2, treatment ET_1 has higher total production than other treatments. On the other hand, the total production for each treatment was included two parts, one was not affected by bruises as a result of loads in packing cage and the other was affected by bruises which affect the price value. Figure (11) shows that the net production was 25.88, 26.58, 26.83, and 23.12 ton/fed for treatments ET_1, ET_2, ET_3, and ET_4, respectively. The bruised productions were 4.89, 2.92, 2.05, and 2.43 ton/fed for treatments ET_1, ET_2, ET_3, and ET_4, respectively.

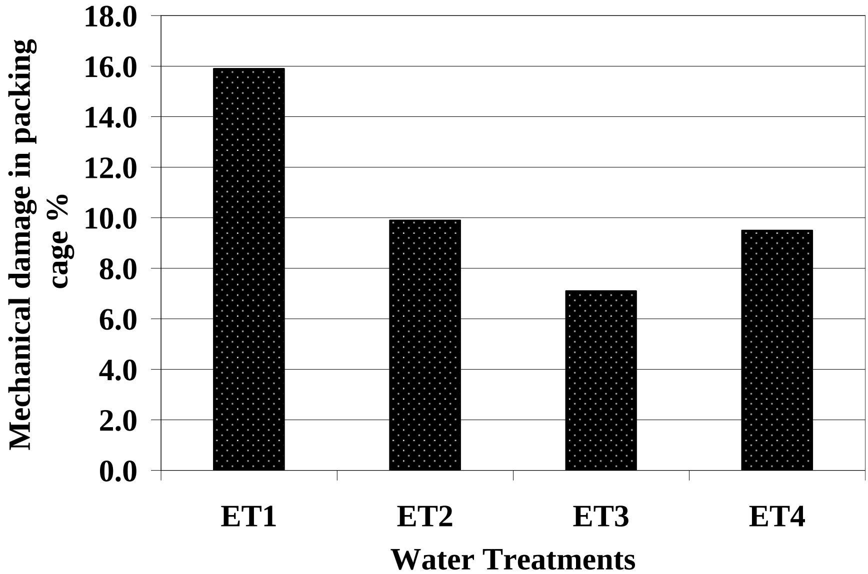


Figure (10): Total mechanical damage in entire packing cage under different water treatments.

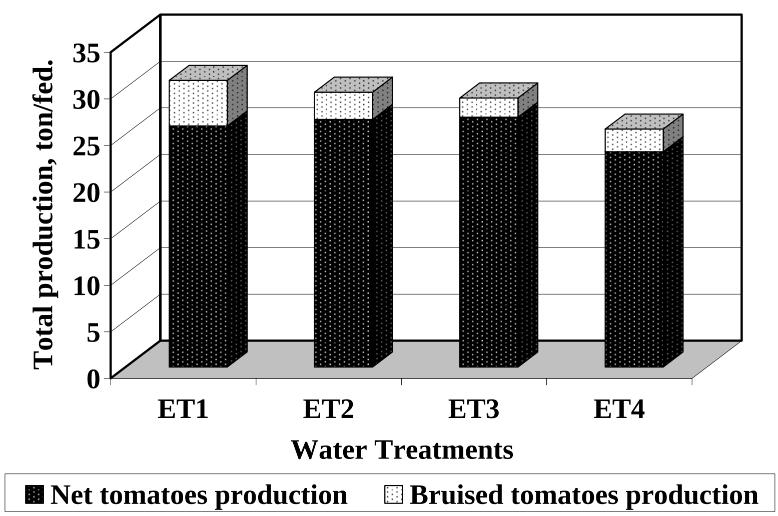


Figure (11): Total, net, and bruised tomatoes production under different water treatments.

6. Effect of deficit irrigation on Water Use Efficiency (WUE)

WUEs are given in table (6). WUE_y is computed on total fresh yield basis, while WUE_m is computed on total marketable yield basis. WUE_y and WUE_m increased with water shortage, but decreased again in ET_4 in case of WUE_m. The results suggest that the crop does not benefits from the water when the water is supplied to fulfill total crop requirements (ET_1). It is possible to save water improving its use efficiency in processing tomato to achieve adequate fruit yield.

Table (6): Total yield (WUE_y) and marketable yield (WUE_m) for the irrigation treatments.

Irrigation treatments	WUE_y (kg/m^3)	WUE_m (kg/m^3)
ET_1	4.48	3.77
ET_2	4.77	4.30
ET_3	5.26	4.88
ET_4	5.31	4.81

7. Benefit analysis

In order to determine the net profit, the value of benefit has to be subtracted from the energy consumed cost. It was found that the net profit values for the treatments ET_1, ET_2, ET_3, and ET_4 were 68990.7, 68841.5, 68644.2, and 59804,6 LE/fed, respectively (figure 12). There is no significant effect between treatments ET_1, ET_2, and ET_3 in price value.

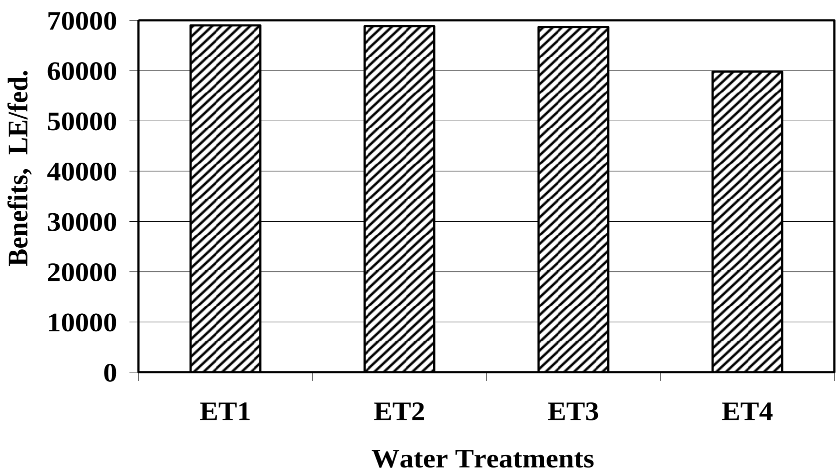


Figure (12): Net benefit of tomatoes production under different water treatments.

The influence of the physical and mechanical properties on tomato fruits under deficit irrigation water led to no significant differences in production when reducing the amount of water applied per feddan by 10, and 20%. The amount of water saved from ET_2 (163.5 mm) or ET_3 (327 mm) can be used to provide other areas to increase the production and *WUE*.

CONCLUSION

The objective of this work is to study the effect of mechanical damage on production of tomato under four levels of water requirement (70, 80, 90 and 100% from ET_c). By investigating some physical and mechanical properties and force – deformation curve of tomato. The following conclusion can be made:

- The total amounts of irrigation water applied were 1635, 1471, 1308, and 1144 mm for ET_1, ET_2, ET_3 and ET_4, respectively.
- The maximum energy consumed (4943.2 MJ/fed) was found with ET_1 with cost 590.4 LE/fed while the minimum energy consumed (3460.3 MJ/fed) was found with ET_4 treatment with cost 413.3 LE/fed.
- The results showed that mass, length, width, thickness and volume of tomatoes decreased by decreasing crop water requirements.
- The minimum and maximum value of solid density of tomato was 0.969 and 1.028 g/cm^3 for treatments ET_3 and ET_2, respectively.
- At load (force) 18 N, the mechanical damage was 37.4, 28.6, 28.3, and 27.1% with ET_1, ET_2, ET_3, and ET_4, respectively.
- The mechanical damage of the entire packing cage for treatments ET_1, ET_2, ET_3, and ET_4 were 15.9, 9.9, 7.1, and 9.5%, respectively.
- Total production of tomato was 30.77, 29.50, 28.88, and 25.54 ton/fed for treatments ET_1, ET_2, ET_3, and ET_4, respectively.
- Net production of tomatoes were 25.88, 26.58, 26.83, and 23.12 ton/fed for treatments ET_1, ET_2, ET_3, and ET_4, respectively, while the bruised production of tomatoes were 4.89, 2.92, 2.05, and 2.43 ton/fed for treatments ET_1, ET_2, ET_3, and ET_4, respectively.

- The net profit values for treatments ET_1, ET_2, ET_3, and ET_4 were 68990.7, 68841.5, 68644.2, and 59804.6 LE/fed respectively. There is no significant effect between treatments ET_1, ET_2, and ET_3.
- The amount of water saved from ET_2 and ET_3 were 163.5 and 327 mm, respectively. The amount of water saved can be used to provide other areas to increase the production and thereby increase the *WUE*.

REFERENCES

Allen, R.G.; L.S. Pereira; D. Raes and M. Smith, 1998. Crop evapotranspiration. Guidelines for computing crop water requirements. FAO I. and Drain. Paper No. 56, FAO, Rome, Italy, 300.

Allende, A.; M. Desmet and E. Vanstreels. 2004. Micromechanical and geometrical properties of tomato skin related to differences in puncture injury susceptibility. Postharvest Biol. Technol. 34: 131-141.

Altisent, M. R. 1991. Damage mechanisms in the handling of fruits: Progress in agricultural physics and engineering. John Matthew (Ed.), Commonwealth Ag. Bur. (CAB) I. Willingford, UK: 231-255.

Bahnasawy, A. H. 2007. Some physical and mechanical properties of garlic. Int. J. Food Eng. 3: 1–18.

Bajema, R. H. and G. M. Hyde. 1998. Instrumented pendulum for impact characterization of whole fruit and vegetable specimen. Transactions of the ASAE 41: 1399-405.

Batu, A. 1998. Some factors affecting on determination and measurement of tomato firmness. Tropical J. of Ag. and Forestry, 22: 411-418.

Costa, J. M.; M.F. Ortuno and M. M. Chaves. 2007. Deficit irrigation as a strategy to save water: physiology and potential application to horticulture. Journal of Integrative Plant Biology 49: 1421–1434.

Dewulf, W.; P. Jancsok; B. Nicolai; D. D. Roeck and D. Briassoulis. 1999. Determining the firmness of a pear using finite element modal analysis. J. of Ag. Eng. Res., 74 (3): 217-224.

FAO 2010. Food and Agriculture Organization of the United Nations. http://www.faostat.fao.org. 16Aug. 2012.

Ghonimy, M. I. 2003. Analytical approach to energy balance in seed-bed preparation for corn crop. Misr J. Ag. Eng., 20 (1): 1-17.

Gonzalez J.J.; K.L. Mccarthy and M. J. Mccarthy. 1998. MRI method to evaluate internal structural changes of tomato during compression. J. Texture Stud. 29: 537-551.

Ibrahim, M. M. 2008. Determination of dynamic coefficient of friction for some materials for feed pellet under different values of pressure and temperature. Misr J. Ag. Eng., 25(4):1389-1409.

Joshi, D.C.; S.K. Das and R.K. Mukherjee. 1993. Physical properties of pumpkin seeds. Agric. Eng. 54: 219–229.

Lien, C. C.; C.Y. Ay and C. H. Ting. 2009. Non-destructive impact test for assessment of tomato maturity. J. Food Eng. 91(3): 402-407.

Linden, V. V.; N. Scheerlinck and M. Desmet. 2006. Factors that affect tomato bruise development as a result of mechanical impact. Postharvest Biol. Technol. 42: 260-270.

Lovelli, S.; M. Perniola; A. Ferrara and T. Di Tommaso. 2007. Yield response factor to water (Ky) and water use efficiency of Carthamus tinctorius L. and Solanum melongena L. Agric. Water Manage. 92, 73–80.

Mohsenin, N. N. 1986. Physical properties of plant and animal materials. Structure, physical characteristics and mechanical properties. 2nd updated and revised ed. Gordon and Breach Sc. Pub. Inc. N. Y.

Topcu, S.; C. Kirda; Y. Dasgan; H. Kaman; M. Cetin; A. Yazici and M.A. Bacon, 2007. Yield response and N-fertilizer recovery of tomato grown under deficit irrigation. Europ. J. of Agron. 26: 64 – 70.

USDA 1991. United States Standards for Grades of Fresh Tomatoes. http://www.ams.usda.gov/standards/tomatfrh.pdf. 3 Jul. 2012.

Zhiguo L.; L. Pingping and L. Jizhan. 2010. Effect of tomato internal structure on its mechanical properties and degree of mechanical damage. African J. of Biotec. Vol. 9(12): 1816-1826.

الملخص العربي

تأثير النقص المائي على إنتاجية وخواص الطماطم

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يهدف هذا البحث إلى دراسة تأثير نسبة التلف الميكانيكي الناتج من انضغاط الطماطم داخل صندوق التعبئة على صافي إنتاجية الطماطم وذلك تحت مستويات ري مختلفة. ولتحقيق هذا الهدف تم إجراء تجارب حلقية في حقل وحدة الري بقسم الهندسة الزراعية بكلية الزراعة جامعة القاهرة خلال موسمي ٢٠١٠ و ٢٠١١. تم زراعة الطماطم (*Lycopersicon esculentum*) صنف (El-Odds E448) تحت أربع مستويات مائية وهي ET_1 وتمثل ١٠٠% من الاحتياجات المائية المطلوبة للطماطم وET_2 تمثل ٩٠% وET_3 تمثل ٨٠% وET_4 تمثل ٧٠%.

و قد بينت الدراسة ما يلى:

– كمية المياه الموسمية المضافة للمعاملات ET_1 و ET_2 وET_3 وET_4 كانت ١٦٣٥مم، ١٤٧١مم، ١٣٠٨ مم و ١١٤٤ مم على التوالي.

– أقصى طاقة مستهلكة كانت للمعاملة ET_1 بقيمة ٤٩٤٣.٢ ميجا جول/فدان بتكلفة ٥٩٠.٤ جنيه/فدان بينما أقل طاقة مستهلكة كانت للمعاملة ET_4 بقيمة ٣٤٦٠.٣ ميجا جول/فدان بتكلفة ٤١٣.٣ جنيه/فدان.

– نقص كتلة وطول وعرض وسمك وحجم ثمار الطماطم بنقص كمية المياه المضافة.

– أقصى كثافة حقيقية لثمار الطماطم كانت ١.٠٢٨ جرام/سم^3 للمعاملة ET_2 بينما أقل قيمة كانت 0.969 جرام/سم^3 للمعاملة ET_3.

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- عند قوة تحميل ١٨ نيوتن كان التلف الميكانيكي لثمار الطماطم ٣٧.٤ - ٢٨.٦ - ٢٨.٣ - ٢٧.١ % للمعاملات ET_1 - ET_2 - ET_3 - ET_4 على التوالي.
- مجموع التلف الميكانيكي في صندوق التعبئة للمعاملات ET_1 - ET_2 - ET_3 - ET_4 كانت ١٥.٩ – ٩.٩ – ٧.١ – ٩.٥ % على التوالي
- إنتاج محصول الطماطم للمعاملات ET_1 - ET_2 - ET_3 - ET_4 كانت ٣٠.٧٧ - ٢٩.٥ – ٢٥.٨٨ – ٢٥.٥٤ طن/فدان على التوالي.
- صافي إنتاج محصول الطماطم غير المتأثر بالكدمات للمعاملات ET_1 - ET_2 - ET_3 - ET_4 كانت ٢٥.٨٨ – ٢٦.٥٨ – ٢٦.٨٣ – ٢٣.١٢ طن/فدان على التوالي.
- إنتاج محصول الطماطم المتأثر بالكدمات للمعاملات ET_1 - ET_2 - ET_3 - ET_4 كانت ٤.٨٩ – ٢.٩٢ – ٢.٠٥ – ٢.٤٣ طن/فدان على التوالي.
- صافي ربح المحصول للمعاملات ET_1 - ET_2 - ET_3 - ET_4 كانت ٦٨٩٩٠.٧ – ٦٨٨٤١ – ٦٨٦٤٤.٢ – ٥٩٨٠٤.٦ جنيه/فدان.
- يتضح من صافي ربح المحصول انه لا توجد فروق معنوية بين الثلاث معاملات الأولى ET_1, ET_2 ET_3, ولكن يمكن الاستفادة من كمية المياه والتي تقدر ٢٠% في ري مساحات أخري وبالتالي زيادة وحدة الناتج من وحدة المياه.