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Interaction effects of water salinity and hydroponic growth medium on eggplant yield, water-use efficiency, and evapotranspiration

Farnoosh Mahjoor [a], Ali Asghar Ghaemi [a,*], Mohammad Hossein Golabi [b]

[a] Water Engineering Department, College of Agriculture, Shiraz University, 7144165186 Shiraz, Islamic Republic of Iran
[b] College of Natural and Applied Sciences, University of Guam, Mangilao, GU 96923, USA

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ABSTRACT

Eggplant (*Solanum melongena* L.) is a plant native to tropical regions of Southeast Asia. The water crisis and drought on the one hand and eggplant greenhouse crop development as one of the most popular fruit vegetables for people on the other hand, led to the need for more research on the use of saline water and water stress to optimize salinity level and their impact on eggplant evapotranspiration and encounter better yield and crop quality. The objective of the present study was to investigate the interactions of water salinity and hydroponic growth medium on qualitative and quantitative properties of eggplant and its water-use efficiency. The study used the factorial experiment based on completely randomized design with three replications of four levels of water salinity (electrical conductivity of 0.8 (control), 2.5, 5, and 7 dS m^{-1}) and three growth media (cocopeat, perlite, and a 50–50 mixture of the two by volume). Total yield, yield components, evapotranspiration, and water-use efficiency were determined during two growing periods, one each in 2012 and 2013. All of these indices decreased significantly as water salinity increased. Water with of 0.8 dS m^{-1} produced an average eggplant yield of 2510 g per plant in 2012 and 2600 g in 2013. The highest yield was observed in cocopeat. Water with 7 dS m^{-1} reduced yield to 906 g per plant in 2012 and to 960 g in 2013. Lowest yield was observed in perlite. The highest evapotranspiration values occurred in cocopeat at the lowest salinity in both years. Cocopeat and the cocopeat–perlite mixture were equally good substrates. The mixture significantly improved the quantitative and qualitative properties of eggplant yield.

1. Introduction

In 2009, the global production of eggplant was 35.3 million tons from 9.1 million hectares of agricultural land in the world. About 93% of this production took place in Asia, and only 7% was in Africa, America, and Europe (Food and Agriculture Organization of the United Nations, 2010). Greenhouse production of eggplant has been increasing year after year as a result of the development of agricultural technology. It is now in fourth place, after tomato, pepper and cucumber (Boyaci, 2007). Eggplant is usually considered moderately sensitive to salinity (Maas, 1984), although (Bresler, McNeal, & Carter, 1982) categorized it as sensitive to salinity. This difference can be attributed to plant variety and experimental conditions. Hydroponic cultivation is now common in horticultural eggplant production. Greenhouse and/or hydroponic cultivation are one of the most efficient ways to achieve maximum yield in minimum time with excellent quality. Because of the present difficulties in soil cultivation of horticultural crops as a result of nematodes, salinity, and environmental pollution, mineral and organic cultivation beds such as perlite and cocopeat have received much attention. In addition, higher water and nutrition requirements in soil systems have lead to an increase in soilless culture with horticultural crops in recent decades (Ramezanian, Tavallali, & Sadeghi Ghotbabadi, 2001). Choosing a suitable growth medium is of prime importance in soilless culture. Recently, cocopeat has been used most commonly in the horticulture industry in Europe, Australia, and America recently. Perlite is alumina silicate of volcanic origin, has low cation exchange capacity, and is also used for this purpose. These media increase drainage and improve aeration. For successful crop production in cultivation without soil in greenhouses, adequate nutrients in beds at each stage of plant growth must be assured. Both media provide good porosity, ensuring air and gas exchanges for plant roots, as well as

* Corresponding author.
E-mail addresses: ghaemi@shirazu.ac.ir, ghaemiali@yahoo.com (A.A. Ghaemi).

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water and nutrient holding capacity. Perlite is also rich in minerals such as iron, sodium, calcium, and other trace elements. Another issue in greenhouses is the estimation of actual crop evapotranspiration (ET_c) (Olympious, 1995). Some researchers propose to estimate crop evapotranspiration on the basis of meteorological parameters outside the greenhouse, but in fact, weather conditions outside can not indicate the conditions inside the greenhouse. Scheduling and controlling the amount of plant water administered in a greenhouse is much easier. On the other hand, evaporation from soil surface and excessive water penetration to bed depths can be reduced in greenhouses, as the water use efficiency is increased. One of the problems in arid and semiarid regions such as Iran, especially in the southern part, is frequent water shortage and increasing soil and water salinity. Detrimental effects of salinity on crops are multifaceted and include: (i) reduced water availability, due to the osmotic effect from high concentrations of soluble salts in the root medium; (ii) ion toxicity, as a result of the accumulation of $Na+$ and Cl^-; (iii) oxidative stress resulting from overproduction of reactive oxygen species and (iv) acute $K+$ deficiency as a result of massive $K+$ leak from depolarized cells (Zhu, 2001; Blumwald, Aharon, & Apse, 2000; Munns & Tester, 2008; Shabala & Cuin, 2008). Salt stress impairs major physiological processes such as photosynthesis, protein synthesis and lipid metabolism (Heuer, 2006). New solutions are necessary to mitigate and counteract the detrimental effects of salinity on agricultural crops. The use of halophytic crop species that can tolerate high salt concentrations in the soil and that may allow irrigation with saline water is one of the possible ways to proceed, especially in semi-arid and arid regions of the world. Salt tolerance in plants may comprise an array of interconnected morphological, physiological and biochemical mechanisms on whole plant, tissue, and cellular/molecular levels (Ashraf & Harris, 2004; Tammam, Alhamd, & Hemeda, 2008; Geissler, Hussin, & Koyro, 2009). These mechanisms are related to the four major constraints due to the salinity on plant growth. These constraints include; osmotic effects, restriction of CO_2 gas exchange, ion toxicity, and nutritional imbalances (Koyro, Geissler, Hussin, & Huchzermeyer, 2006; Geissler et al., 2009). To withstand osmotic constraints, plant have to be more restrictive with water loss by a sensitive stomatal closure response. This, in turn, entails that gas exchange be kept low due to a restricted availability of CO_2 for the carboxylation reaction (stomatal limitation) (Huchzermeyer & Koyro, 2005; Flexas et al., 2007). Therefore, a fine-tuned control of gas exchange (H_2O/CO_2) is crucial for plant growth and biomass production under this condition (Romero-Aranda, Soria, & Cuartero, 2001; Gulzar, Khan, Ungar, & Liu, 2005). Regarding the other two constraints, high NaCl concentrations adversely affect the acquisition of essential nutrients as Na^+ competitively inhibits K^+ and $Ca_2{}^+$ uptake, whilst Cl^- restricts anions uptake (Tester & Davenport, 2003; Liu, Duan, Tadano, & Khan, 2006; Tammam et al., 2008), disturbing ion homeostasis within the plant. Moreover, salinity may create specific ion toxicity as disproportionate presence of Na^+ and Cl^- in cellular and intracellular compartments inhibits many enzymatic systems, altering a wide range of important metabolic processes that plant growth is crucially depending on (Blaha et al., 2000; Munns, 2005). The reduction in photosynthesis is usually due to low stomatal conductance, which also reduces the transpiration rate hence, impairing the plant growth (Iyengar & Reddy, 1996). Eggplant has special importance, because it is a major horticultural product of the region and is used as food for everyday consumption in Iran. Eggplant cultivation takes place during the season when water shortage is more pronounced. One of the factors inhibiting growth is high soil pH and water salinity, which are considered nonbiotic stress factors for plants (Homaei, 2002; Abdolkarimzadeh, 2006). Soil and water salinity are among those environmental stress factors that attract greatest attention around the world (Szczerba, Britto, & Kronzucker, 2009). The main objective of our study was therefore to investigate the interaction effects of water salinity stress using different hydroponic media on the qualitative and quantitative characteristics of eggplant, such as yield, water-use efficiency, and evapotranspiration under greenhouse conditions.

2. Materials and methods

We studied eggplant (*Solanum melongena* L.) crops in an unheated two-sided plastic-covered greenhouse with 3.5 m tall, 9.4 m long, and 5.7 m wide in the research fields of the College of Agriculture, Shiraz University, Shiraz, Iran, in 2012 and 2013. The experimental design for this study was factorial based on completely randomized design with four different levels of water salinity, three hydroponic media, and three replicates for every treatment (Table 1).

Water from a nearby well with electrical conductivity of 0.8 dS m^{-1} was chosen as control. Water for the three saline treatments had conductivity of 2.5, 5, and 7 dS m^{-1}; and the three media consisted of cocopeat, perlite, and a 50–50 mixture of the two by volume.

Beginning on 5 May 2012 and 18 May 2013, pots 35 cm in diameter and 60 cm high were filled with equal weights of the cultivation media. The media were brought to field capacity at the beginning of the experiment, by addition of sufficient well water. Fourteen days after transplantation, seeds of the Anamur RZ cultivar of eggplant were sown in plug trays on 19 May 2012 and 1 June 2013 and were germinated under greenhouse conditions. In each year, 36 pots were prepared as above and weighed. A single uniform seedling was transplanted into each pot. So that salt would not accumulate in the root zone, a 15% leaching fraction was allowed whenever irrigation was conducted; irrigation water was therefore applied at more than the amount of field capacity (Ayers & Westcott, 1985). The volume of irrigation water applied to each pot to achieve field capacity was calculated according to the following equation:

$$m_i = mfc - m/1 - LF \quad (1)$$

where: *mfc* is pot weight (g) under field capacity moisture condition, *m* is pot weight (g) before irrigation, m_i is weight (g) of irrigating water, and LF is leaching fraction (%).

The water that drained from each pot was collected in an empty container located beneath the pot. That water was weighed and considered to represent the volume of penetration. Salinity treatments and media were imposed on 17 June 2012 and 9 July 2013. Complete Grow-More fertilizer (20, 20, 20) was added at 1.5 g/L after appearance of the fourth leaf.

An automatic weather station was installed in the central part of greenhouse to measure net radiation, air temperature, and relative humidity. The maximum and minimum temperatures of in the greenhouse were determined by a maximum and minimum thermometer and recorded once in each 24 h. The relative humidity was measured by a hydrograph and recorded every 2 h. In addition, a thermometer measured temperature continuously and was read when necessary. A pyrgeometer CM7B and an albedometer CG1/2 were used to measure and record long and short wave lengths and net sun radiation once each 24 h during the growing period. These devices were connected to four integrators (data loggers) to record the data.

The Penman–Mantith-FAO method was used to estimate the reference plant evapotranspiration, after Harmanto, Salokhe, and Tantauc (2005), who used this method for measuring evapotranspiration in greenhouses. The equation used (Allen, Periera,

Table 1
Codes designating the combinations of irrigation-water salinity and growth medium used in greenhouse cultivation of eggplant. Each treatment was replicated three times; subscripts refer to replicate number. Cocopeat–perlite refers to a 50–50 mix of the two media by volume. The entire design was conducted twice, in 2012 and 2013.

Salinity (dS m^{-1})	Cocopeat	Perlite	Cocopeat–perlite
0.8	C $S1_1$	P $S1_1$	CP $S1_1$
	C $S1_2$	P $S1_2$	CP $S1_2$
	C $S1_3$	P $S1_3$	CP $S1_3$
2.5	C $S2_1$	P $S2_1$	CP $S2_1$
	C $S2_2$	P $S2_2$	CP $S2_2$
	C $S2_3$	P $S2_3$	CP $S2_3$
5	C $S3_1$	P $S3_1$	CP $S3_1$
	C $S3_2$	P $S3_2$	CP $S3_2$
	C $S3_3$	P $S3_3$	CP $S3_3$
7	C $S4_1$	P $S4_1$	CP $S4_1$
	C $S4_2$	P $S4_2$	CP $S4_2$
	C $S4_3$	P $S4_3$	CP $S4_3$

Raes, & Smith, 1998) is shown in (Eq. (2)):

$$ET_0 = 0.408\,\Delta\left(R_n - G\right) + \gamma\left[\frac{900}{(T+273\,)}\right]U_2\left(e_s - e_a\right)/\Delta + \gamma\,(1 + 0.34\,U_2) \tag{2}$$

where: ET_0 is the reference evapotranspiration (mm day^{-1}); R_n is the net radiation received on lawn surface, which was measured by the albedometer and pyrgeometer inside the greenhouse (MJ day^{-1} $(m^2)^{-1}$); G is soil thermal flux (MJ day^{-1} $(m^2)^{-1}$); Δ is the gradient of saturated steam pressure diagram relative to temperature (KPa °C^{-1}); γ is the psychometric constant (KPa °C^{-1}); $e_s - e_a$ is deficit vapor pressure surface (KPa); u_2 is daily average wind speed (m s^{-1}); and T is daily average air temperature, all measured at 2 m above ground level (°C).

To determine the net solar radiation, we determined the absorbed energy balance using the absorbed and reflected energy from ground surface of Integrator (data logger) data according to the following equation:

$$R_{nl} = (p\uparrow) - (p\downarrow) \tag{3}$$

where: R_{nl} is net long-wave radiation, $p\uparrow$ is long-wave length (received from the lower sensor of the pyrgeometer) (KJ $(m^2)^{-1}$), $p\downarrow$ is returned radiation of long wave length (received from the upper sensor of the pyrgeometer) (KJ $(m^2)^{-1}$) (Eq. (4)):

$$R_{ns} = (\alpha\uparrow) - (\alpha\downarrow) \tag{4}$$

where: R_{ns} is net short-wave radiation, $\alpha\uparrow$ is reflected radiation of short wave length (received from the lower sensor of the albedometer) (KJ $(m^2)^{-1}$), $\alpha\downarrow$ is received short-wave length (received from the upper sensor of the albedometer) (KJ $(m^2)^{-1}$). The net radiation, Rn, was determined as in (Eq. (5)):

$$Rn = R_{nL} + R_{nS} \tag{5}$$

where: Rn is net solar radiation (MJ day^{-1} $(m^2)^{-1}$).

The man relative humidity was obtained from Eq. (6):

$$RH_{mean} = RH_{max} + RH_{min}/2 \tag{6}$$

where: RH_{max} is the maximum relative humidity (%) and RH_{min} is the minimum relative humidity (%).

To measure the daily evapotranspiration of, we considered each pot a weight lysimeter. Evapotranspiration related to the treatments was estimated by the water-balance method (Moazed, Ghaemi, and Rafiee, 2014) We calculated evapotranspiration by measuring the moisture of each cultivation substrate before irrigation and the amount of irrigation water added to each pot to maintain field capacity. As the pots were weighed daily and weight loss from each day was calculated from their preceding weights only, any possible error due to increase in plant weight was negligible. Evapotranspiration was calculated according to the soil water balance equation:

$$ET_C = I + P + R \pm \Delta S - D_P \tag{7}$$

where: ET_C is daily evapotranspiration under greenhouse conditions (mm day^{-1}); I is the amount of irrigation water (mm); P is the amount of precipitation (mm) (because the present study was conducted in a greenhouse, precipitation was considered zero); R is the surface runoff (mm), which was ignored in the Eq. (7) because the surface runoff was minimal or did not occur in the pot; ΔS is the change of substrate water depth (mm) between two irrigations at the root zone, and D_P is deep percolation (mm).

2.1. K_c value

The values of the crop coefficient (K_c) during the growing periods were determined from the actual and potential evapotranspiration as follows:

$$ET_c = K_c ET_o \tag{8}$$

where: ET_C is crop evapotranspiration (mm day^{-1}), K_C is crop coefficient (average seasonal eggplant coefficient), and ET_O is reference crop evapotranspiration (mm day^{-1}).

The crop coefficient was obtained from the ratio of plant crop evapotranspiration to reference evapotranspiration. Plant coefficient can differ for each individual plant according to time and place. In our investigation, plant coefficient was obtained from the ratio of evapotranspiration from Eq. (7) to reference evapotranspiration calculated from Eq. (2).

2.2. Crop evapotranspiration under saline conditions

From the results of Eq. (8), the effect of salinity on eggplant evapotranspiration was determined by Eq. (9) as an adjusted crop evapotranspiration. The adjusted crop evapotranspiration under salinity stress condition can be determined by multiplying the stress coefficient (K_S) by K_C in Eq. (8).

$$ET_{c-adj} = K_c K_s ET_o \tag{9}$$

where: ET_{C-adj} is crop evapotranspiration (mm day^{-1}), K_C is the crop coefficient, K_S is the stress coefficient under saline conditions, and ET_O is reference crop evapotranspiration (mm day^{-1}).

K_S is 1 in the absence of salinity stress; values less than 1 indicate salinity stress. K_S was calculated by means of Eq. (10) (Allen et al., 1998):

$$K_S = 1 - b/K_y(100)(EC_e - EC_{threshold}) \tag{10}$$

where: K_S is the stress coefficient under saline conditions; b is the slope, which is the percentage yield loss per unit increase in electrical conductivity of the saturated soil (substrate) extract beyond the threshold value; K_y is the crop yield coefficient; EC_e is the electrical conductivity of soil (substrate) saturated extract (dS m^{-1}) (by the Buchner funnel method); $EC_{ethreshold}$ is the threshold soil (substrate) salinity (dS m^{-1}) beyond which yield decreases.

2.3. Relative evapotranspiration and eggplant yield reduction

To estimate the reduction of crop yield under water-use deficiency, we used the simple linear equation (Stewart & Hagan, 1973; Doorenbos & Kassam, 1979; Rijtema & Endrodi, 1970; Hanks, 1974; de Wit, 1958) that follows:

$$(1 - Y_a/Y_m) = k_y(1 - ET_a/ET_m) \quad (11)$$

where: $(1 - Y_a/Y_m)$ is relative yield reduction, Y_a is actual yield from salinity treatment (g), Y_m is maximum yield from control treatment (g), k_y is crop yield response factor under salinity (water-use deficiency; $k_y \le 1$ if the plant is tolerant; $k_y \ge 1$ if the plant is sensitive to water stress); ET_a is actual eggplant evapotranspiration for saline water treatment (mm day^{-1}), ET_m is eggplant evapotranspiration in the control treatment (mm day^{-1}).

2.4. Relative yield (Y_a/Y_m) and salinity

The salinity tolerance model presented by (Maas & Hoffman, 1977) was used for fruit yield and dry weight of eggplant. The substrate's threshold salinity and gradient beyond threshold for each of the growth parameters were calculated. Eq. (12) shows salinity tolerance presented by (Mass & Hoffman, 1977):

$$Ya/Ym = 1 - (EC_e - EC_{ethreshold}) \times \frac{b}{100} \quad (12)$$

where: Y_m is maximum yield from control treatment (g); Y_a is actual yield from a salinity treatment (g); EC_e is electrical conductivity of soil (substrate) saturated extract (dS m^{-1}) (by the Buchner funnel method); $EC_{ethreshold}$ is the threshold of soil (substrate) salinity (dS m^{-1}) beyond which the yield decreases; b is the slope value, which is the percentage yield loss per unit increase in electrical conductivity of the saturated soil (substrate) extract beyond the threshold value.

Harvested fruits in each treatment were weighed as they were, wet, and the diameter of each fruit was measured. At the end of the growth period, eggplant plants were cut 1 cm above the growth-medium surface, and shoots were oven dried at 70 °C to a constant weight for measurement of dry weight. Roots of harvested plants were also separated from the growth medium, the medium was washed from the root of each pot.

According to the yield and evapotranspiration in each treatment, we calculated the water use efficiency in each treatment by dividing yield by real plant evapotranspiration as shown in Eq. (13):

$$WUE = Y/ET_C \quad (13)$$

where: WUE is water use efficiency (kg m^{-3}), Y is crop yield (kg), and ET_C is real evapotranspiration (m^3).

Statistical analysis used SAS software and the Duncan test, and a probability level of 5% was used to compare the measured data. Excel software was used for conducting other calculations, charts, and regression lines.

3. Results

Fig. 1 shows the daily temperature variations in the greenhouse during the growing periods in 2012 and 2013. Results indicated that mean daily temperatures during the growth periods were 23.89 °C in the first year and 25.2 °C in the second. The average temperature in the second year was 1.31 °C higher. Fig. 1 also shows the maximum and minimum temperatures and their average values after irrigation treatments were started.

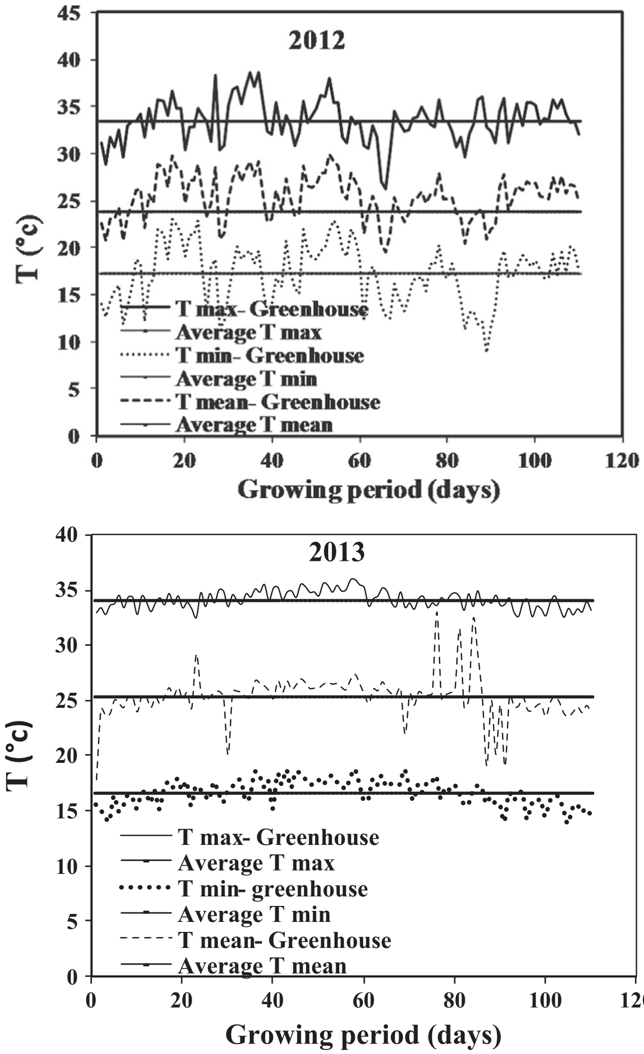

Fig. 1. Maximum, minimum, and mean daily temperatures inside the experimental greenhouse for the duration of the experiment in 2012 and 2013.

3.1. Reference crop evapotranspiration (ET_0)

Fig. 2 shows the daily variations in ET_0 during growth periods in 2012 and 2013. The minimum and maximum ET_0 were 4.55 and 6.95 mm day^{-1}, and the average was 5.81 mm day^{-1} in the first year. Values for the second year were 5.83 and 7.96 mm day^{-1} and the average was 7.03 mm day^{-1}. Total ET_0 after application of the irrigation treatments was 639.95 mm in the first year and 773.63 mm in the second.

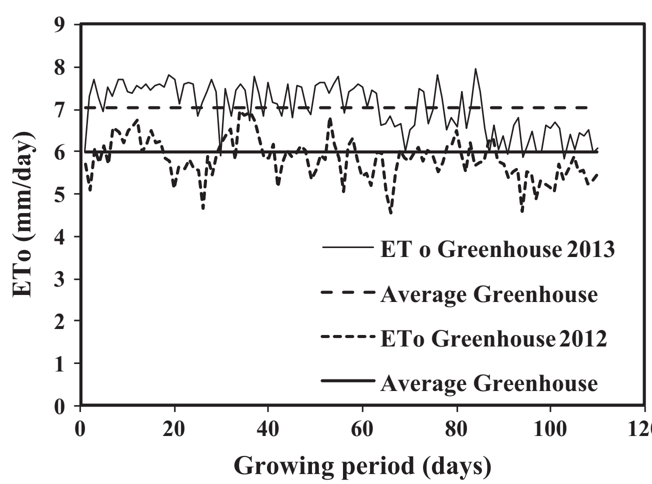

Fig. 2. Reference crop evapotranspiration (ET_0) during growing periods in 2012–2013.

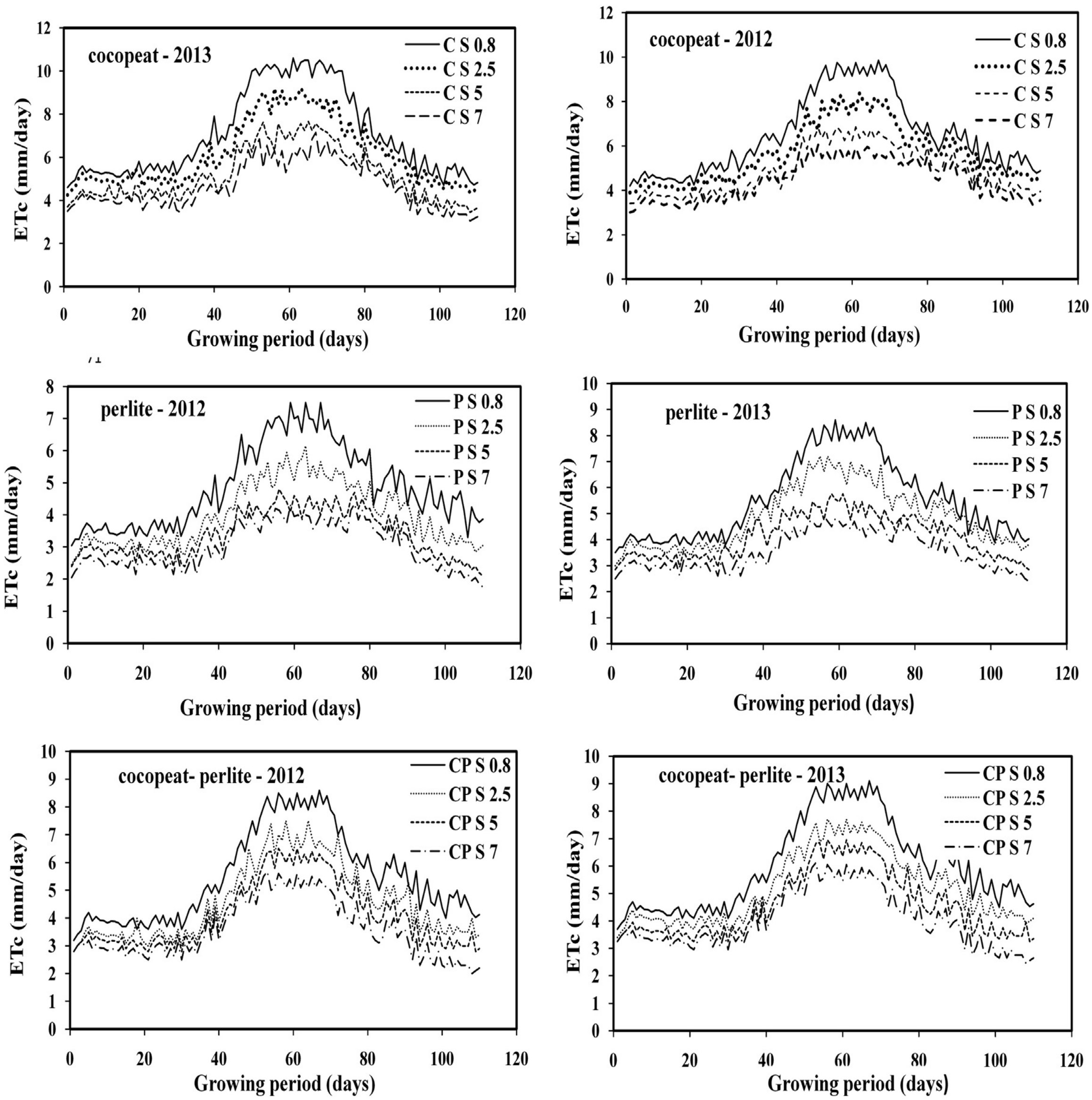

Fig. 3. Eggplant evapotranspiration in three different growth media irrigated with different water salinities in 2012 and 2013.

3.2. *Actual crop evapotranspiration*

Daily actual eggplant evapotranspirations are shown in Fig. 3 for both growing seasons. The highest values in both years were in cocopeat with control salinities,.610.28 mm in the first and 662.2 mm in the second year (Table 2). Under the least concentrated of the saline treatments, evapotranspiration in cocopeat was reduced 10% in the first and 10.6% in the second year. Under the most saline treatment, although evapotranspiration in cocopeat was reduced by 34.64% in the first and 33.52% in the second year the lowest values occurred in perlite in both years. In pearlite, even the least saline treatment condition reduced evapotranspiration 18% in the first and 11% in the second year and in the most saline treatment, the reductions were 39.72% in the first and 36.92% in the second year in the mixed growth medium, the reductions were intermediate 35.74% in the first and 34.46% in the second year in the most saline treatment. Fig. 3 also shows that the actual evapotranspiration at initial and late stages of growth are lower than in the middle stage for all treatments. In short, eggplant evapotranspiration decreased as water salinity increased.

Table 2
Average amounts of eggplant evapotranspiration (mm) in different growth media.

Salinity (dS m^{-1})	(2012)			(2013)		
	Cocopeat	Cocopeat–perlite	Perlite	Cocopeat	Cocopeat–perlite	Perlite
S1 (0.8)	610.28	577.58	515.32	662.2	632.28	588.28
S2 (2.5)	544.22	480.15	420.65	592.05	566.26	522.19
S3 (5)	453.19	426.15	365.99	499.53	475.11	431.27
S4 (7)	398.9	371.16	310.66	440.25	415.06	371.14

3.3. K_C *value*

Crop coefficients (K_C), can be determined by using Eq. (8), and were there are similarities in consecutive years. In the second year, in cocopeat under control salinity levels they were estimated to be 0.86, in the initial stages of growth, 1.3 in middle stages, and 0.95 in the late stages. In the mixed growth medium, the values were 0.77, 1.2, and 0.88, and in perlite, they were 0.68, 1.05, and 0.8. Fig. 4 shows variations of crop coefficient during plant growth for the control treatment in different growth media. As shown there,

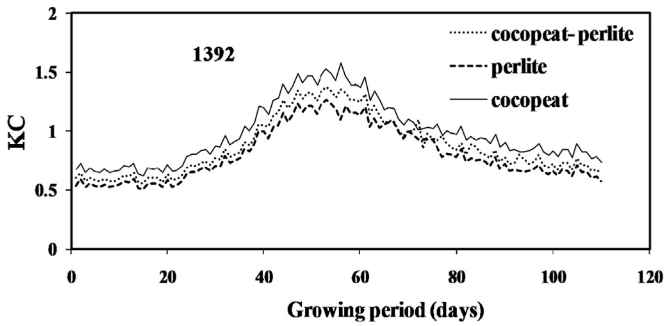

Fig. 4. Eggplant crop coefficient at control salinity in different growth media in 2012.

the highest values of were obtained in cocopeat, showing that the highest evapotranspiration occurred in cocopeat during the growing periods.

3.4. Crop stress coefficient

Table 3 and Fig. 5 show values of crop stress coefficient obtained from three replications at initial, middle and ending stages in the different growth media. The highest stress coefficients occurred in cocopeat, and the lowest in perlite. As Fig. 5 shows, values in cocopeat, perlite, and the mixture were reduced from the initial of growth period to the middle (development) stage, but the salinity stress coefficient was higher at the late stages of growth.

Fig. 6 shows that sensitivity coefficients in the first year were are 1.27 in cocopeat and 1.18 in the mixed medium, indicating significant sensitivity to salinity and water stress, whereas the sensitivity coefficient of 1.09 in perlite indicated only moderate sensitivity to salinity. In the second year of cultivation, the sensitivity coefficients were 1.33 in cocopeat and 1.23 in the mixture, again showing significant sensitivity to salinity, whereas the sensitivity in perlite was 1.17, showing only moderate sensitivity. These results reveal that cocopeat retained more salt than did perlite, because of its finer pores; it also had higher saturated extraction salinity than perlite. On the other hand, crop yields in cocopeat and the mixture were higher than those in perlite.

Fig. 7 shows the relationship between yield and salinity level in the three growth media. Results for the two years were similar. In the second year, the gradient for relative yield in relation to salinity was 0.06, and threshold salinity tolerance of cocopeat relative to yield was 1.91. The in the mixed growth medium in the second year were 0.07 and 1.86, whereas those in perlite were 0.09 and 1.5. Results showed that threshold salinity tolerance in perlite was less than that in cocopeat or the mixture.

3.5. Plant physical properties

Table 4 shows the average fruit yield and eggplant vegetative growth parameters for the treatments in both years. After harvesting, the crop yield, fruit wet weight, fruit diameter, and plant height were determined. Fruit yield was affected significantly ($p < 0.05$) by salinity treatments. Increasing the salinity of irrigation water significantly reduced the fruit yield. The highest fruit yield (2600 g plant^{-1}), obtained in cocopeat at control salinity levels, and was significantly different from all other treatments in the second year. The lowest yield was 906 g plant^{-1} in the highest salinity treatment in perlite in the first year.

3.6. Water-use efficiency

Table 5 shows mean comparison and interaction effects of salinity and growth medium on water-use efficiency in the two years. Duncan's test revealed significant differences among treatments. Increasing the salinity of irrigation water leads to reduction of water-use efficiency. The lowest water-use efficiency was seen in the highest-salinity treatment in perlite; it was significantly different from control treatment and the lowest-salinity treatment. The middle salinity treatment led to another significant reduction of water-use efficiency. The highest water use efficiency was seen in the control treatment in cocopeat.

4. Discussion

Our results showed that increasing electrical conductivity of irrigation water reduces the total yield and mean fruit weight of eggplant. The reason is that high salinity has considerable effects on osmotic potential and consequently causes less water absorption by the plant and consequently less water flow toward fruits (Gül & Sevgican, 1992). Savvas and Lenz (2000) and Unlukara, Kurunc, and Yurtseven (2010) found similar results, showing that the salinity threshold tolerable for eggplant in hydroponic cultivation is 1.5 dS m^{-1}, whereas Moazed et al. (2014) suggested 2.5 dS m^{-1}; our results suggest the same value 2.5 dS m^{-1}. The relationship between yield and evapotranspiration under saline condition showed that the eggplant salinity stress coefficients in cocopeat and the cocopeat–perlite mixture are higher (indicating greater sensitivity) than those in perlite (indicating moderate sensitivity). Stewart and Hagan (1973) have proposed a model to predict crop yield by using evapotranspiration rate during the plant growing season. According to this model, the relation between relative evapotranspiration and relative yield is that the yield may decrease due to water stress. According to the repots (Hagan, 1973) the yield response factor (K_y) has been used to evaluate plant tolerance to water stress (Doorenbos & Kassam, 1979). As reported (Hagan, 1973), when $K_y \le 1$, it indicates that the plant is tolerant to water stress and if $K_y \ge 1$, it indicates that the plant is sensitive to water stress. Other scientists (Stewart et al., 1977; Shalhevet, 1994; Katerji, van Hoorn, Hamdy, Mastrorilli, & Karam, 1998) have used same analytical method for salinity related studies.

(Shalhevet, Heuer, & Meiri, 1983; Savvas & Lenz, 1996) found that eggplant is moderately sensitive to salinity. Cocopeat's extended and fine porosity, although it leads to greater accumulation salt content and higher salinity saturated extract than shown by perlite, also permits greater water-holding capacity under the same salinity conditions. Of the three growth media we used, cocopeat provided the best growth conditions because of its physical and chemical properties, including water- and air-holding

Table 3
Average salinity stress coefficient in different growth media under different regimes of irrigation-water salinity at three different growth stages.

Salinity(dS m^{-1})→ Growth Stage ↓	0.8 C S12	2.5 C S2	5 C S3	7 C S4	0.8 CP S1	2.5 CP S2	5 CP S3	7 CP S4	0.8 P S1	2.5 P S2	5 P S3	7 P S4
Initial	1	0.88	0.82	0.76	1	0.86	0.82	0.68	1	0.86	0.77	0.66
Mid	1	0.80	0.72	0.64	1	0.82	0.72	0.63	1	0.75	0.65	0.54
End	1	0.85	0.77	0.72	1	0.84	0.74	0.64	1	0.79	0.70	0.63

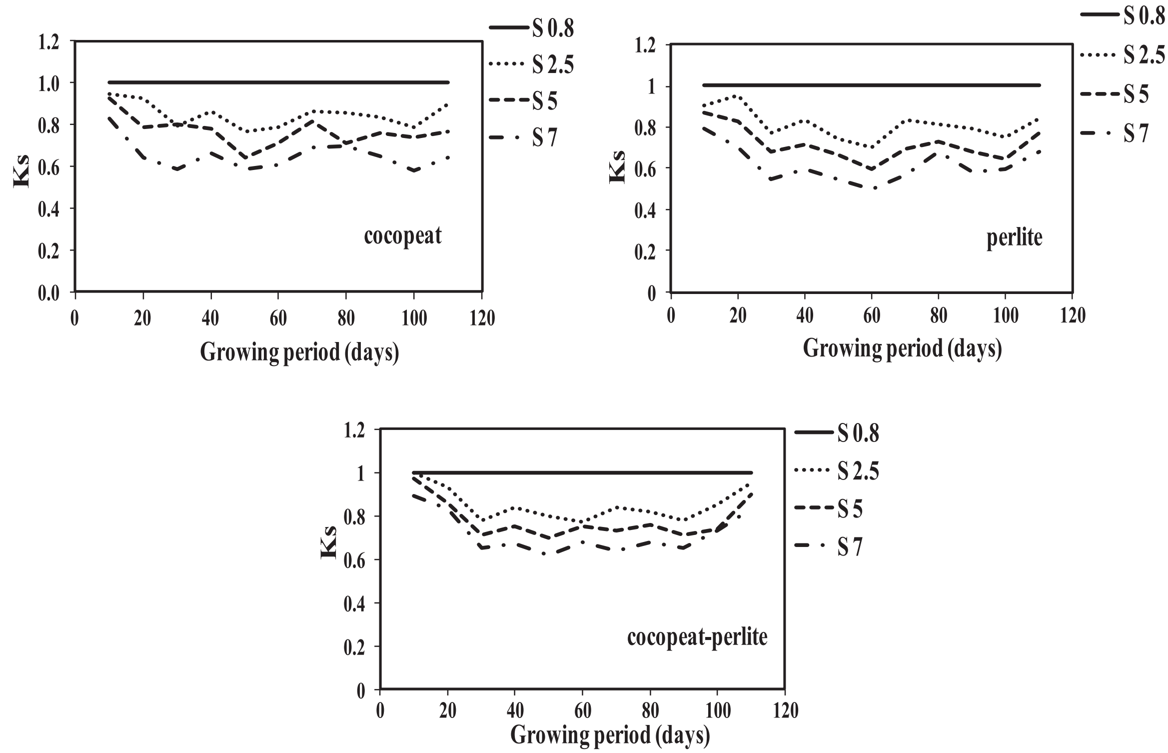

Fig. 5. The average eggplant salinity-stress coefficient in different growth medias and irrigation water salinities in 2013. "S" is salinity, and its followed number is in dS m^{-1}.

capacity and low volumetric weight. Cocopeat has 50–100 times the cation exchange capacity of perlite. It provides more stability of pH, which affects absorption of nutrients (Cho, Park, Jun, & Chung, 2006; Benito, Masaguer, De Antonio, & Moliner, 2005). The highest yield was obtained in cocopeat and the lowest in perlite, perhaps because of cocopeat's higher field capacity as measured by gravimetric methods. Increasing electrical conductivity of irrigation water leads to decreased plant evapotranspiration and

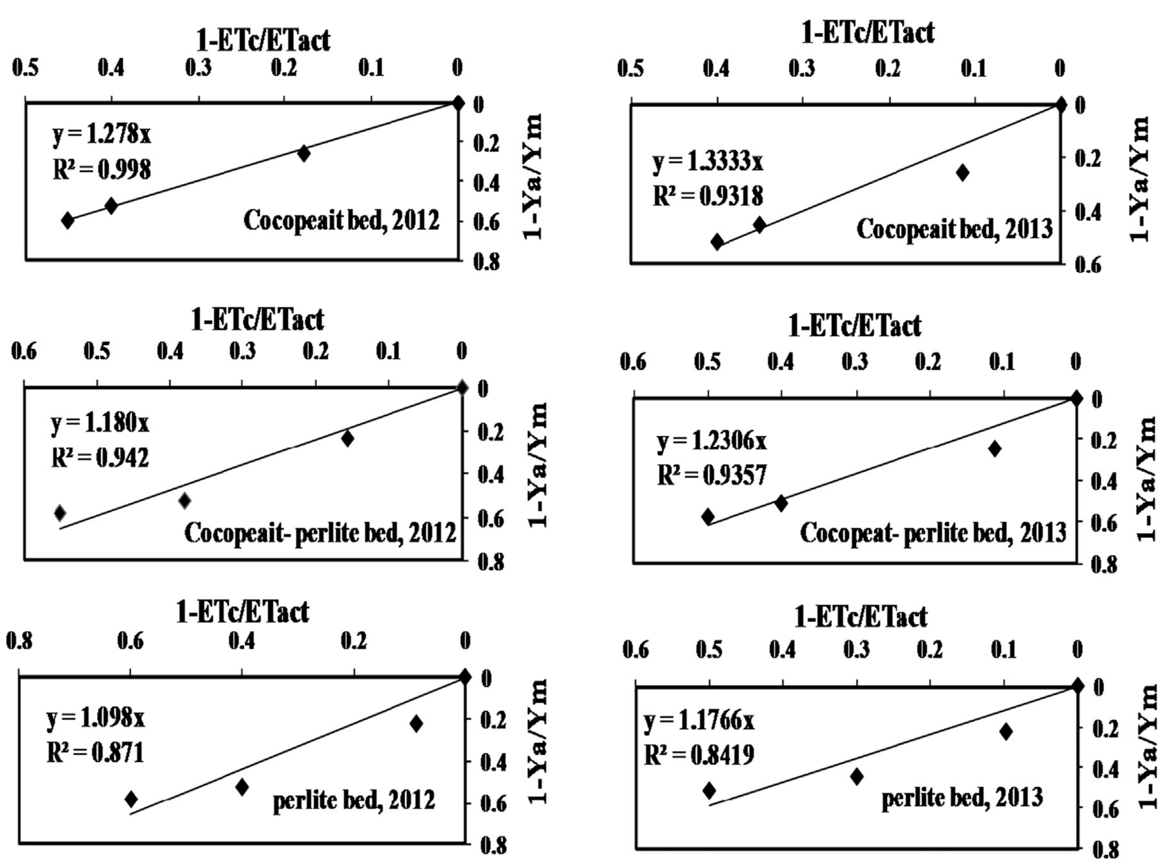

Fig. 6. Average relative yield and evapotranspiration reduction in three different growth medias during 2012 and 2013.

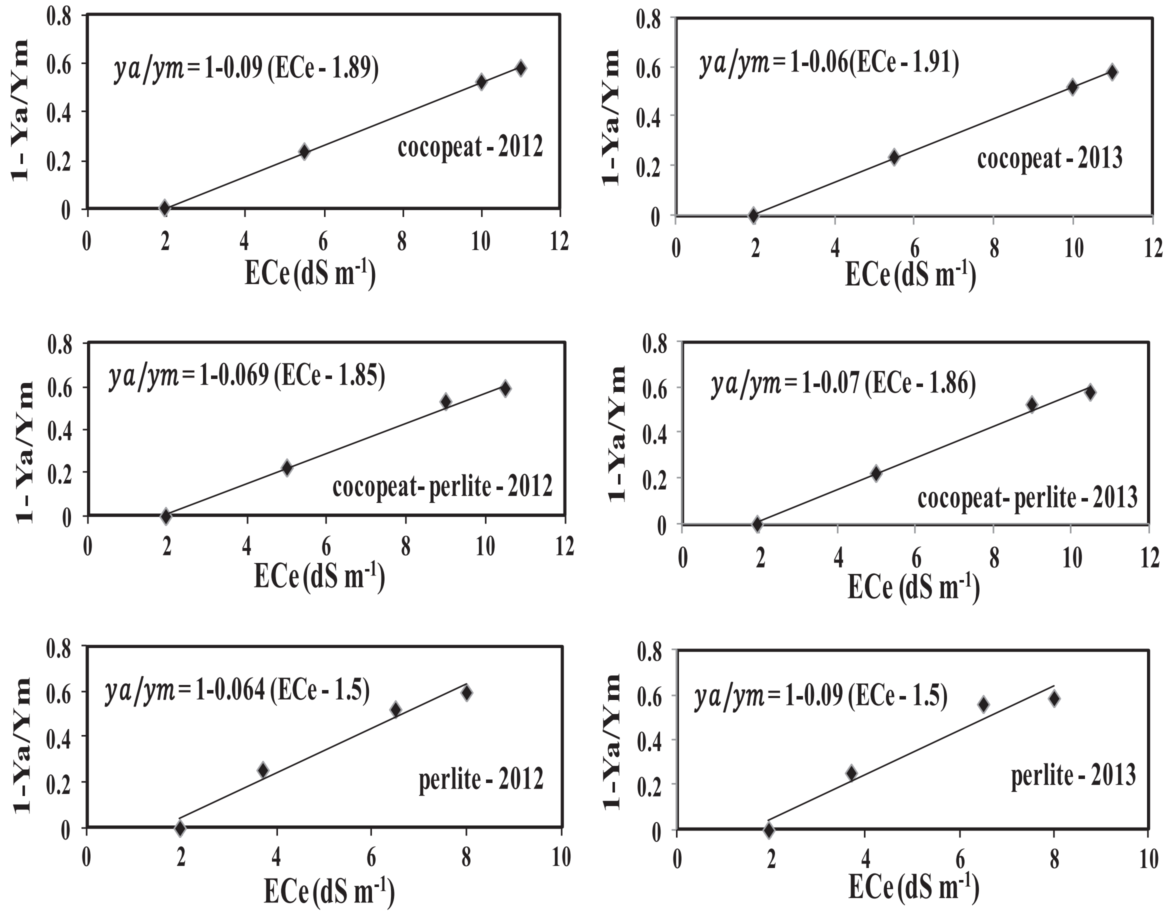

Fig. 7. Relationship between water salinity and relative yield reduction in three different growth medias during 2012 and 2013.

water use efficiency. Water-use efficiency is an important criterion for water consumption by plants. Allen et al. (1998) reported that presence of salt in soil water solution decreased evapotranspiration, causing the plant to use more energy to obtain water from soil. The presence of salt decreases the potential energy of soil water solution. The interaction effects between salinity and growth medium showed that cocopeat and the cocopeat–perlite mixture did not differ significantly in production of yield, whereas perlite produced less yield.

5. Conclusion

In conclusion, eggplant yield and its components (fruit weight, fruit diameter, plant height, and shoot dry weight) as well as evapotranspiration, irrigation and water-use efficiency of eggplant decreased significantly as the salinity level of irrigation water increased. It is concluded that the cocopeat–perlite mixture significantly improved the quantitative and qualitative properties of eggplant yield, although the highest yield was observed in cocopeat alone. The highest evapotranspiration values occurred in cocopeat with control levels of water salinity, and the lowest

Table 4
Average amounts of fruit yield and eggplant vegetative growth properties in the three growth medias. Numbers followed by the same letters (column and row) do not differ significantly (Duncan test, $p < 0.05$).

Treatment	(2012)					(2013)				
	Yield (g plant^{-1})	Fruit weight (g)	Fruit diameter (cm)	Plant height (cm)	Shoot dry weight (g plant^{-1})	Yield (g plant^{-1})	Fruit weight (g)	Fruit diameter (cm)	Plant height (cm)	Shoot dry weight (g plant^{-1})
C S1	2510 a	233 a	6.03 a	76 a	37 a	2600 a	240 a	6.6 a	78.6 a	41 a
C S2	1953 c	197 c	5.2 bc	68 bc	32 ab	2020 c	205 b	5.6 bc	70 abc	33 bc
C S3	1193 e	128 e	4.5 de	56 ef	28 bc	1233 e	140 d	5 d	57.7 ef	28.7 bcd
C S4	1043 fg	110 fg	4.2 def	50 g	25 bcd	1093 f	125 fg	4.5 e	53.5 ef	32 bc
P S1	2253 b	224 b	5.8 a	73 ab	35 ab	2290 b	234 a	6 b	72.8 ab	33.5 bc
P S2	1676 d	186 d	5.2 bc	60 de	30 ab	1713.7 d	192.7 c	5.5 bc	60.6 de	30 bcd
P S3	998 g	115 f	4.5 de	52 fg	25 bcd	1020 f	131.5 ef	5.29 cd	57 ef	23 d
P S4	906 g	98 h	3.9 f	48 g	21 d	960 f	119.2 g	4.12 e	50.3 f	25 cd
CP S1	2493 a	230 ab	6 a	77 a	38 a	2573.5 a	237 a	6.3 a	74 a	39.5 a
CP S2	1930 c	190 cd	5.5 ab	64 cd	33 ab	1963 c	197 bc	5.9 b	69 bcd	35.1 ab
CP S3	1160.5 ef	123 e	4.7 cd	57 ef	30 ab	1230 e	135 de	5.2 cd	61 cde	26.5 bcd
CP S4	1033 fg	105 gh	4 ef	53 fg	26.8 bcd	1073 f	124 fg	4.3 e	56.4 ef	29 bcd

Table 5
Mean main and interactive effects of water salinity and growth media on water-use efficiency (kg m^{-3}). Numbers followed by the same letters (column and row) do not differ significantly (Duncan test, $p < 0.05$).

Salinity (dS m^{-1})	(2012)			(2013)		
	Cocopeat	Perlite	Cocopeat–perlite	Cocopeat	Perlite	Cocopeat–perlite
0.8	55.62 a	49.68 b	53.64 a	59.58 a	55.03 b	57.69 a
2.5	48.69 b	44.86 b	45.29 c	54.49 b	49.25 bc	50.24 cb
5	35.52 d	31.84 e	33.54 de	36.80 c	40.04 bc	36.65 c
7	35.52 d	30.53 de	32.97 de	37.79 c	35.10 c	38.92 c

occurred in perlite. In addition, our determination of eggplant stress coefficient, eggplant crop coefficient, and the mean comparison and interaction effects of salinity and cultivation beds represent novel findings.

It is therefore recommended that salinity effects on eggplant production should be taken into account for water consumption calculations in order to prevent over-applications of saline waters hence, prevent yield loss. The water use efficiency decreases with increasing salinity, indicating that for eggplant under saline conditions, more water is used per unit of production as compared to non-saline conditions. In case of saline water use for irrigation of eggplant in greenhouses, the water salinity level lower than 2.5 dS m^{-1} is recommended in order to reduce yield losses. Cocopeat and the cocopeat–perlite mixture are more reliable substrates than perlite in greenhouse eggplant cultivation.

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