Yield, Evapotranspiration and Quality of Greenhouse Grown Strawberry (Fragaria × Ananassa Duch.) Under Combined Drought and K$_2$SO$_4$ Fertigation

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Abstract

Optimization between yield and fruit quality is essential as growing consumers' awareness towards longevity and health hazards. Strawberry (Fragaria × ananassa Duch. var. 'Sonnata') was grown in peat, irrigated to the maximum evapotranspiration (ET$_{max}$) of 0.75, 1.00 and 1.25 with water having electrical conductivities (EC$_{iw}$) of 1.56, 2.55 and 3.94 dS m$^{-1}$. Addition of 5 and 10 mM K$_2$SO$_4$ to the control formulation increased EC$_{iw}$. Fresh fruit yield, first class berry, fresh biomass and leaf area increased with increased ET$_{max}$ but decreased with increased EC$_{iw}$. Contrastingly, the content of sugar and acids in the fruit increased with increased EC$_{iw}$ but decreased with increased ET$_{max}$. Therefore, irrigating to 1.00ET$_{max}$ with EC$_{iw}$ of 2.55 dS m$^{-1}$ of K$_2$SO$_4$ addition can be sustainable for the greenhouse production for strawberry. However a significant increase in the drainage water electrical conductivity (EC$_{dw}$) was observed, no differences were recorded in terms of ET and crop coefficient (Kc) at the 1.25ET$_{max}$ with K$_2$SO$_4$ addition. K values between 0.6 - 0.9 are recommended during the mid-season in irrigation scheduling of greenhouse strawberry. Instead increased leaf concentration of potassium and sulphur decreased the amount of calcium and magnesium concentration. Increased leaching fraction (LF) due to low light intensity around DOY -130 allowed free drainage at 0.75ET$_{max}$ shown five times higher the EC$_{iw}$ than at 1.25ET$_{max}$. Currently, Danish growers are practicing high LF as the sum of drainage and irrigation EC equals to three which can create the threat of secondary salinization.

Keywords: Strawberry; Fruit Quality; K$_2$SO$_4$ Fertigation; Evapotranspiration; Crop Coefficient; Irrigation Scheduling

Introduction

An optimized fertigation practice is essential to have enhanced fruit yield and quality as harmonious integration between water and nutrients accelerates plant growth and development. One of the tremendous benefits of the optimized fertigation is saving water and nutrients without compromising yield and quality [1]. And an optimized fertigation enables incorporation of saline and marginal soils, dunes, mountains slopes and swamps to be agriculturally productive. Also an optimized fertigation reduces weed growth, herbicide usage and increases nutrient and labor use efficiency. Moreover, interplay between the fertigation practices may have added value to the fruit quality such as sugar and acid content, flavour, aroma, colour, antioxidant value etc.

Strawberry (Fragaria × ananassa Duch.) is a high value fruit crop [2] and consumed for its pleasant flavor, enjoyable eating experience and nutritional importance. Strawberry is useful for the treatment of various diseases for instance cancer, brain ageing, cardiovascular and neurological disorders [3]. The total antioxidant capacity (TAC) in strawberry is found to be 10-fold higher than 17 of other fruits studied [4]. In strawberry lots of chemical changes occurs during fruit developmental process as the composition of primary and secondary metabolites in the achenes and the receptacle start changing. The concentration of ellagic acid, free flavan-3-ols and proanthocyanidin decreased but anthocyanins and p-coumaric acid increased with fruit maturation in strawberry [5]. Likewise, the concentrations of total phenolics, ascorbic acid, dihydroascorbic acid and antioxidants decreased but anthocyanin increased with advancing maturation in strawberry [6]. Generally, the achenes found on the outer part of the fruit is enriched with ellagitannin and flavonoids and the receptacle is enriched with proanthocyanidins, flavanol derivatives and anthocyanins [7]. And it is possible to optimize the concentrations of various bioactive compounds as their availability is governed by cultivars, irrigation, fertilization, fruit developmental stages, light, CO$_2$, humidity etc.

Fruit quality is a complex attribute and manipulation of the soil moisture content and salinity in the root zone is one of the ways to achieve higher yield and quality in the green house horticulture
Plant water demand inside greenhouse is shown in terms of evapotranspiration ($E_T$), combining two important phenomena simultaneously occurring inside the greenhouse: evaporation and transpiration. The evaporation ($E_d$) and the ET are useful in estimation of the crop coefficient ($K_c$) and irrigation scheduling. Generally, the ratio of $E_d$ to $E_T$ provided the $K_c$. And the $K_c$ values are affected by climate, crop type, phenology [9], soil nutrient status and root zone salinity [10]. But [11] reported $K_c$ equals to 1.1 for whole crop period in strawberry inside a plastic house, which is questionable. And increasing irrigation amount from 75 to 125% of ET increased yield attributing parameters in strawberry i.e. numbers of leaves, flowers and fruits, shoot biomass, runners, total and marketable yields. Reduction in leaf area, fresh berry yield, individual berry fresh weight, berry water content and berry dry weight of strawberry was observed in deficit irrigation compared to full irrigation and partial root-zone drying treatment [12]. To the best of our knowledge no attempt was made to investigate the effects of root zone salinity on yield and quality of strawberry.

Plant experiences complex bio-physico-chemical process when supplying less water than the requirement. Successive accumulation of nutrients and salts in the root zone leads to increased electrical conductivity (EC) of the soil solution which reduced osmotic potential [13]. The reduction in the osmotic potential reduces the symplastic pathway for root water uptake, which is driven by osmosis-induced flow [14]. Increments in the EC of the drainage water ($EC_{iw}$) reduced root turgor pressure and root length densities in tomato (Lycopersicon esculentum Mill.) when irrigated with 171 mM NaCl than non-salinated treatment [15]. [16] reported 1.5 to 2 times higher the $EC_{iw}$ than the EC of irrigation water ($EC_{i}$) at 9 dS m$^{-1}$ in bell pepper (Capsicum annum L.). Similarly five fold increase in the $EC_{iw}$ was recorded in an experiment with pomegranate (Punica granatum L.) at $EC_{i}$ of 8 than 0.8 [17]. Increasing $EC_{iw}$ from 0 to 30 mM of NaCl decreased photosynthetic rate and stomatal conductance, chlorophyll content, transpiration rate, leaf water potential on red raspberry (Rubus idaeus L.) however increased sodium and chloride content of plant tissues and increased root shoot ratio was observed. Moreover, reduction in photosynthesis due to damages in photosynthetic apparatus and Cl- toxicity was discussed rather than stomatal closure [18]. Root zone salinity is monitored by leaching fraction (LF) under varying $EC_{iw}$ levels [16]. The LF adjusts the balance between soil salinity and irrigation water salinity changing the amount of water percolating down from the root zone under a given $EC_{iw}$ [19]. More specifically leaching requirement (LR) is described as the additional amount of water required to maintain the target root zone salinity [16], however the LR is highly influenced by soil-plant-greenhouse complex.

Strawberry is grouped into a sensitive crop towards salinity with threshold value of 1 dS m$^{-1}$ and slope of 33% m dS$^{-1}$ based on the fruit yield [20]. So, there is a limited opportunity for improving fruit quality by increasing root zone salinity without yield reduction. Increasing ECiw from 2.6 to 8.6 dS m$^{-1}$ decreased the fruit number, leaf area, number of leaves, leaf dry weight, number of crowns, number of inflorescences, flower and fruit per inflorescence and fruit per plant but increased in the fruit dry matter content. Moreover, the concentration of reducing sugars per fruit increased under shaded conditions and titrable acidity (TA) in fruits increased due to increasing salinity both under shaded or unshaded conditions [21]. Total biomass, leaf area, dry matter production, chlorophyll content, average fruit weight and number of fruits per plant were reduced in ‘Oso Grande’ and ‘Camarosa’ varieties of Strawberry under 35 mM NaCl treatment compared to non-salinated treatment. Increasing NaCl salinity decreased quality of ‘Elsanta’ and ‘Korona’ varieties of strawberry. Exposure to NaCl decreased the amount of sugars, organic acids and soluble solids. The reduced consumer acceptance to the fruit under NaCl stress is due to decline in succrose content and increase in acetic acid [22]. Contrastingly, increased in the activity of superoxide dismutase and the content of glutathione, phenols and anthenocyanins were observed under moderate NaCl stress in less salt sensitive ‘Korona’ whereas the content of ascorbic acid decreased [23]. Furthermore, long-term exposure to salinity increased the TAC, selected nutrients as well as lipid peroxidation. Also salt stress increased the contents of free and essential amino acids in ‘Elsanta’ and increase of reduced glutathione and better fruit taste was observed in ‘Korona’ [24]. Decrease in total fresh fruit yield, total number of fruits, fruit size, and numbers of runners as well as the length of the longest runner were recorded while increasing salinity from 0 to 8 dS m$^{-1}$ [25]. Salinity in the rhizophere reduced plant growth by 44% and 90% and fruit yield by 27% and 64% in ‘Korona’ and ‘Elsanta’ respectively. ‘Korona’ retained most of its Cl- in roots and crowns but in ‘Elsanta’ the maximum Cl- content was detected in petioles. Here strawberry is discussed as a Na+ excluder as the Na+ content of both ‘Elsanta’ and ‘Korona’ were below 3 ppm whereas the Cl content increased up to 70 to 80 ppm in ‘Korona’ and ‘Elsanta’ respectively [26].

Strawberry grown with all macro and micronutrients having an EC of 0.6 dS m$^{-1}$ increased the content of quercetin, kaempferol and ellagic acid compared to EC 1.2 and 2.4 dS m$^{-1}$ treatment [27]. Nitrogen (N) supply in the transplanted field of strawberry does not influence the yield but affected during nursery stage which controls floral bud initiation and consequently the yield [28]. Contents of esters, soluble carbohydrates and amino acids increased at 3 and 6 mM N supply than 0.3 mM [29]. Increasing N concentrations from 0 to 0.25 mM decreased leaf nitrate reductase activity but varied with plants’ size as higher nitrate reductase activity was recorded in small size plant and vice versa [30]. Foliar application of phosphoric acid decreased total soluble solids (TSS) but increased TA and anthocyanin content [31]. Potassium (K) fertilization reduced negative effect of NaCl on strawberry [32]. Similarly, higher TSS to TA ratio was observed under 10 mM K$_2$SO$_4$ application together with 35 mM NaCl stress [33]. However, a reduction in primary fruit weight and total fresh fruit weight were observed under 5 or 10 mM of K$_2$SO$_4$ or CaSO$_4$ together with 35 mM NaCl application [33].

Beside a combined study of drought and fertigation practices has not been reported yet in the strawberry. Plant nutrient uptake and soil moisture level are interrelated to each other and alternation to one
of the factors changed usefulness, availability and concentration of
the other. And increment in the fruit quality is not possible just by
manipulation of one of the two factors. Therefore, we hypothesized
that changed fertigation does have an impact on Strawberry fruit
quality and attention has to be paid for the optimality of water
and nutrients in the root zone. Hence the study aimed at response
of yield, ET and quality of greenhouse grown strawberry under
drawn combined drought and K₂SO₄ fertigation.

Materials and methods

The experiments were conducted under 30 weighable lysimeter
trays inside greenhouse under the Department of Horticulture,
Aarhus University, Årslev, 5792, Denmark from 12th March to 12th
June, 2010. The maximum daily temperature, sunshine, humidity
and CO₂ concentration recorded throughout the experimental
period is shown in the Figure 1. Strawberry (Fragaria × ananassa
Duch. var. ‘Sonnata’) was grown in peat with irrigation water having
electrical conductivities (ECₒ) of 1.56, 2.55 and 3.94 dS m⁻¹. Based on
the average of the back day measured maximum evapotranspiration
(ETₒ, max) different trays were irrigated with 0.75, 1.00 and 1.25 ETₒ, max.
Hereafter, different fertilizer and irrigation treatments are noted as
EC⁻1.56, EC⁻2.55 and EC⁻3.94 and 0.75ETₒ, max, 1.0ETₒ, max, and 1.25ETₒ, max
respectively. Single bear rooted cold stored plant was potted in a 1.1
Litre pot and nine potted plants were kept in a tray of 0.79 m × 0.79 m.
Each pot was supplied with two pressure compensated drippers
with 2.2 L h⁻¹ flow rate (Netafim, Israel) and covered with a plastic
lid to minimize water losses due to evaporation. The composition
of different nutrients used in the ECₒ formulation is shown in the
Table 1 and increased in the ECₒ was due to the addition of 5 and
10 mM of potassium sulphate to the control formulation. Water
balance method used for the measurement of the ET (mm, equation
1) every 2-3 day.

Table 1: Nutrient compositions of the irrigation water supplied to the different treatments.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Cl (ppm)</th>
<th>Na (ppm)</th>
<th>N-(NO₃⁻) (ppm)</th>
<th>N-(NH₄⁺) (ppm)</th>
<th>P (ppm)</th>
<th>K (ppm)</th>
<th>B (ppm)</th>
<th>Ca (ppm)</th>
<th>Mg (ppm)</th>
<th>Fe (ppm)</th>
<th>Zn (ppm)</th>
<th>Mn (ppm)</th>
<th>Cu (ppm)</th>
<th>S (ppm)</th>
<th>Mo (ppm)</th>
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<tr>
<td>EC⁻1.56</td>
<td>23</td>
<td>11</td>
<td>127</td>
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<td>21</td>
<td>226</td>
<td>0.23</td>
<td>143</td>
<td>26</td>
<td>1.24</td>
<td>0.44</td>
<td>0.45</td>
<td>0.12</td>
<td>91</td>
<td>&lt;0.01</td>
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<tr>
<td>EC⁻2.55</td>
<td>35</td>
<td>17</td>
<td>106</td>
<td>5.3</td>
<td>27</td>
<td>432</td>
<td>0.21</td>
<td>125</td>
<td>29</td>
<td>0.95</td>
<td>0.42</td>
<td>0.19</td>
<td>0.11</td>
<td>187</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>EC⁻3.94</td>
<td>41</td>
<td>22</td>
<td>125</td>
<td>6.5</td>
<td>28</td>
<td>919</td>
<td>0.24</td>
<td>138</td>
<td>32</td>
<td>0.93</td>
<td>0.43</td>
<td>0.49</td>
<td>0.11</td>
<td>385</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Figure 1(i): Maximum daily (i) sunshine (mmol m⁻² s⁻¹), temperature(°C)

Figure 1(ii): Maximum daily (ii) relative humidity (%) and
CO₂ (ppm) recorded inside the green house throughout the
experimental period 2010. Data shown are average of the three
maximum values recorded in every 15 minutes.

\[
ET = I - Dr + \Delta W
\]  

where \( I \) is the irrigation (mm), \( Dr \) is the drainage (mm) and
\( \Delta W \) is the change in stored root-zone water (mm).

Nine treatments consisting of three irrigation and three
fertilizers were completely randomized into 27 trays together
with three replications. Other three trays were used for the
measurement of evaporation (\( Eₒ \)) allocated randomly inside the
greenhouse. For the measurement of the \( Eₒ \) nine 1.1 Litre pots were
filled with peat and kept in a tray of 0.79 m × 0.79 m but no plants.
Each pot was supplied with two pressure compensated drippers
with 2.2 L h⁻¹ flow rate and left uncovered. Water balance method
shown in the equation 1 was also used for the measurement of the
\( Eₒ \). The ratio of ET to Eₒ provided the crop coefficient (Kc) values.
And the measurement of the ECₒ and the drainage water electrical
conductivity (ECₒ) was taken every 2-3 day using an EC meter
(Crison Instruments S.A., Barcelona, Spain).

All the plants were treated with EC⁻1.56 and 1.0 ETₒ, max for the
first two weeks and the treatments begun afterwards. Fruit were
harvested at 138, 147, 151 and 161 days of the year 2010 (DOY),
respectively 67, 76, 80 and 90 days after the transplanting. Fresh
biomass recorded immediately after the last harvest. Leaf area was
recorded in 12 fully expanded young leaves sampled out of nine
different plants grown in the same tray. Leaf area was
recorded by

Measurement of the titrable acidity (TA) and total soluble solids
(TSS) was performed at 200 gm of the fruit sampled from the three
latter harvests. The fruit sample was homogenized in a waring
blender with 100 g of water. And 47 g of homogenized sample
was centrifuged at 12000 rpm for 10 minutes at a temperature
between 0 °C. About 7g of the supernatants were used for the TA
determination by titration with 0.1 N NaOH to pH 8.1 and calculated as mg of the citric acid per gram sample. TSS was determined by placing 1-2 drops of supernatants solution on refractometer and expressed as (°Brix), also equivalent to g TSS per 100 g of the sample or percentage (%). Double checking of the TA and TSS was performed for each measurement to avoid potential errors.

All the statistical analyses including analysis of variance (ANOVA), mean comparison with tukey HSD test and interactions study were performed with SAS statistical software version 9.2 (SAS Institute Inc., USA).

Results

Daily records of the ET and $E_o$ in mm day$^{-1}$ are shown in the Figure 2(i). During the early and the late crop period, $E_o$ was higher than ET but in the mid-crop period the values for $E_o$ and ET were similar. However, no differences were observed in ET values of strawberry inside the green house under three different levels of $K_2$SO$\_4$ fertigation i.e. EC-1.56, EC-2.55 and EC-3.94 irrigated with the 1.25ET$_{\text{max}}$. As the values for $E_o$ varied from 1.42 to 7.88 mm day$^{-1}$ the maximum and minimum values of ET were 4.05, 4.26, 3.73 and 0.29, 0.25, 0.30 mm day$^{-1}$ respectively at EC-1.56, EC-2.55 and EC-3.94 treatments. And the maximum values were factor of 5.55, 13.96, 17 and 12.4 to the minimum values for $E_o$ and ET respectively at EC-1.56, EC-2.55 and EC-3.94 treatments. Likewise, accumulated amount of ET and $E_o$ in mm are shown in the Figure 2(ii). For 84 days of the experiments, plant consumed 178, 185 and 178 mm of water respectively at EC-1.56, EC-2.55 and EC-3.94 treatments. Twice as much as the amount of water simultaneously evaporated and transpired through plants’ surface was solely evaporated from the trays without plant within the same period which was 357 mm. And the shape of the curves for $E_o$ and ET along DOY seemingly double sigmoidal.

Calculated values of crop coefficient ($K_c$) for the green house grown strawberry is shown in the Figure 3(i). Such $K_c$ values varied from 0.15, 1.18 to 0.25 from early, mid and late crop period. Nonetheless no differences were observed in $K_c$ values for EC-1.56, EC-2.55 and EC-3.94 treatments. Also, EC$_{dw}$ shown in the Figure 3(ii) differed significantly between fertigation treatments. Variation in the EC$_{dw}$ was recorded just a week after the treatment initiation. The values for EC$_{dw}$ at EC-3.94 were three times and two times higher than the EC-1.56 and EC-2.55 respectively during mid and late crop period. The highest recorded value of EC$_{dw}$ at EC-1.56, EC-2.55 and EC-3.94 treatments were respectively 5.34, 8.14 and 16 dS m$^{-1}$ during late crop period. Nutrients analysis in the drainage water at DOY 113 and 147 is shown in Table 2. Increasing EC$_{dw}$ increased the concentrations of the potassium and sulphate in the drainage water during both observations. Higher concentrations
of potassium were recorded at DOY 147 than DOY 113 at EC-2.55 and EC-3.94 treatment but not at EC-1.56 treatment. The sulphate concentrations were slightly lower at DOY 147 than DOY 113. Calcium concentrations in the drainage water increased with increasing ECiw during both periods but lower concentrations of Ca were observed at DOY 147 than 113. Other nutrients for instance NO₃ and NH₄⁺ sources of nitrogen in the drainage water decreased in increasing ECₐ at DOY 113 but first decreased and increased at DOY 147. Similarly, the concentrations of P, Na and Cl were about the same at DOY 113 but increased in increasing ECₐ at DOY 147. Moreover, the concentrations of Mg were similar for EC-1.56 and EC-2.55 treatments but increased at EC-3.94 during both periods. Nonetheless, irrespective of increased in the ECₐ other nutrients in the drainage water did show any pattern.

![Figure 4](image_url)

**Figure 4:** Mean±standard error of total fruit yield, first class berries, fresh biomass in gm plant⁻¹ and leaf area in cm² leaf⁻¹ under various ET max and irrigation water electrical conductivities (ECiw, dS m⁻¹) shown respectively at i, iii, v, vii and ii, iv, vi, viii. Small cases letters represent significant difference between the treatments.

Total fruit yield, first class berry weight and fresh biomass in gm plant⁻¹ are shown in Figure 4(i) to 4(vi). Increasing ETₘ₉ from 0.75 to 1.25 significantly increased yield, first class berry weight and biomass as shown in Figure 4 (i, iii and v) respectively. On the other hand, increasing ECₐ from 1.55 to 3.94 significantly decreased yield, first class berry weight and biomass as shown in Figure 4 (ii, iv and vi) respectively. But no interaction between ETₘ₉ and ECₐ was observed for all the parameters studied. Similar results were recorded for leaf area cm⁻² leaf⁻¹ as shown in Figure 4 (vii and viii). Overall, yield, first class berry weight, biomass and leaf area were similar when reducing irrigation from 1.25 ETₘ₉ to 1.00ETₘ₉ but a significant reduction was observed at 0.75ETₘ₉. Also, yield, first class berry weight, biomass and leaf area were similar when increasing ECₐ from EC-1.55 to EC-2.56 but a significant reduction was observed at EC-3.94 treatment. Moreover, the effect ETₘ₉ and ECₐ on fruit quality parameters for instance TA and TSS is shown in Figure 5. A significant reduction in TA was observed with increasing DOY and ETₘ₉ as shown in Figure 5(i) and (ii) respectively but a significant increment in TA was observed when increasing ECₐ from EC-1.55 to EC-3.94 as shown in Figure 5(iii). However, no interaction between ETₘ₉ and ECₐ was observed for TA. On the other hand, a significant increment in TSS was observed with increasing DOY as shown in Figure 5(iii). Furthermore, a significant interaction between ETₘ₉ and ECₐ was observed for TSS value recorded during the experiment (Figure 6).

Plant grown at 1.00ETₘ₉ with EC-3.94 showed significantly higher value of TSS than the plant grown at 1.00ETmax with EC-1.56 or the plant grown at 1.25 ETₘ₉ with EC-2.55 or EC-1.56. Also, the TSS value from the 0.75ETₘ₉ treatments was higher than 1.25ETₘ₉ but the differences were not significant.

![Figure 5](image_url)

**Figure 5:** Mean±standard error of total soluble solid (TSS, °Brix) and titrable acidity (TA, citric acid equivalent mg g⁻¹) under various irrigation water electrical conductivities (ECiw, dS m⁻¹), DOY and ETₘ₉. Small cases letters represent significant difference between the treatments.

Nutrient content of the leaf sampled from various ECₐ treatments is shown in Figure 7 in g Kg⁻¹ of leaf dry weight. All five different nutrients observed namely nitrogen (N), potassium (K), calcium (Ca), sulphur (S) and magnesium (Mg) responded differently. And the concentration of those nutrients in leaf was similar in all the irrigation treatment. A significant increase in K along with N and S was observed at EC-3.94 than EC-1.56. In contrast a significant reduction in Ca and Mg at EC-3.94 than EC-1.56 was recorded. Moreover, the amount of N, K and S increased from 24.25, 16.06 and 2.72 to 26.7, 22.35 and 1.07 g Kg⁻¹ of leaf dry weight respectively when increasing ECₐ from 1.56 to 3.94. Likewise, the amount of Ca and Mg in the leaf decreased from 16.06 and 2.72 to 6.87 and 1.47 g Kg⁻¹ of leaf dry weight respectively when increasing ECₐ from 1.56 to 3.94.
Discussion

Variation of the ET due to the climatic factors is common to the outdoor cultivation and similar results were observed inside greenhouse too. Comparing results in the Figures 1 and 2, the daily changes of ET and Eo followed the same pattern as the daily changes of the maximum values for the solar radiation. In the Figure 1, the maximum values for solar radiation, temperature, relative humidity and CO₂ concentration shown were the averages of the three maximum data points for the day recorded in every 15 minutes. However, the maximum values for the daily temperature, relative humidity and CO₂ concentration were stable and did not influence the daily ET. It might be the fact that light played major role in the stomata conductance [34]. Moreover, crop ET recorded were similar with increased concentration of the K₂SO₄ fertigation at 1.25 ETmax (Figure. 2), however K₂SO₄ fertigation significantly increased the root zone salinity (Figure. 3). Earlier K₂SO₄ was used in alleviating Strawberry from the NaCl stress [32,33]. One of the reasons why elevated K concentration in the root zone did not influence the ET could be the effect of K in the guard cells osmoregulation [35]. The concentration of the K in the guard cells increased rapidly which increased turgor and opened the stomata after a while in the morning. But in the noon, K concentration decreased and increased in the sucrose concentration kept the guard cells opened for an appreciable period and stomata closed after fading of the sucrose concentration [35]. Another reason could be the cytoplasmic K concentration in plant cell is around 150mM equivalent to 6000 mg per Liter [36]. Such a high concentration of K in the cytoplasm is required to maintain ionic strength, structural stability, enzyme activity and physico-chemical characteristic inside the cell. As soon as the K concentration drop below the critical level no longer the biosynthetic activity maintained in the same efficiency. In sunflower (Helianthus annus L.) any drop below 10% of the K in the dry matter resulted a drop in the production and the maximum yield is achieved only when cytoplasmic and vacuolar K concentration are equal [36]. Contrastingly, a significant reduction on ET in tomato (Lycopersicon esculentum Mill.) was observed under combined NaCl, CaCl₂ and boron salinity [37]. Likewise, reduction of ET was observed in several other crops for instance corn (Zea mays L.), alfalfa (Medicago sativa L.), melon (Cucumis melo L.) [38,39], tomato [37,38], tall wheat grass [Agropyron elongatum (Host) P. Beauv.] [39], onion (Allium cepa L.), bell pepper (Capsicum annuum L.), sunflower [40,16], and broccoli [41]. In agreement with the daily ET, insignificant differences were observed in leaf water.
potential, osmotic potential and stomatal conductance under K$_2$SO$_4$ fertigation at the 1.25 ET$_{\text{max}}$ in the current study (data not shown). Nonetheless a significant reduction of leaf water potential and stomatal conductance was recorded in pomegranate under exposure to salt stress of combined NaCl and CaCl$_2$ [10]. So, response of the plant based on the physiological stress indication based on the types of the salt applied.

Crop coefficient (K) approach is currently being used in irrigation scheduling of several crops [9]. In strawberry K value of 1.1 was reported for a whole crop period inside a plastic house [11]. Generally, K values changes with the weather parameters, crop growth stages [9], nutrient status and salinity in the root zone [10]. To the best of our knowledge the K value for the strawberry inside the greenhouse has not been reported yet. In the Figure 3(i), K values from 0.15, 0.9 to 0.25 from early, mid and late crop period is shown. These values are important in scheduling irrigation of strawberry inside greenhouse and other agro-climatic zones. However, the highest value of the K, equals to 1.18 was observed in the mid-season due to reduction in Eo below ET at low light intensity around DOY 128, and K values between 0.6 to 0.9 is recommended for mid-crop period in Strawberry. For comparison a successive decline in K values was recorded in cucumber under ECiw of 1.5, 3.2 and 5.1 dS m$^{-1}$ respectively [42]. In pistachio, reducing irrigation from full to deficit conditions decreased the K value from 1.15 to 0.8 [43]. The yearly change in K value was recorded in citrus [Citrus sinensis (L. Osbeck)], from 0.57 in a 1-year-old plant to 1.12 in a 4-year-old plant [44]. In the case of grapevine, K changed from 0.4 to 1.0 from bud burst to peak season under freshwater irrigation [45]. At irrigation threshold of 40, 60 and 90%, the K of cotton changed, respectively, from 0.51, 0.9 and 0.99 in the initial stage to 0.92, 1.2 and 1.2 in mid-season and to 0.38 and 0.58 at the end of the season under freshwater irrigation [46]. In two young pomegranate varieties K values varied from 0.17 to 0.60 from saline to fresh irrigation [10] during mid-season. But in this study similar K values were observed under varying K$_2$SO$_4$ fertigation at the 1.25 ET$_{\text{max}}$.

Cumulative water demand varied by growth period, crop type and weather parameters. In the Figure 2(ii), cumulative water demand of strawberry for 84 days varied from 178, 185 and 178 mm respectively at EC-1.56, EC-2.55 and EC-3.94 treatments. Similarly, the cumulative water demand of 414, 336 and 255 mm were recorded in strawberry respectively at irrigation levels of 1.25, 1.00 and 0.75 ET$_{\text{max}}$ for 198 days (from 4 December to 20 June) in Japan [11]. Moreover, the cumulative ET in pistachio was 1024 to 784 mm year$^{-1}$ from full to deficit conditions [43] and in grapevine was 1087 to 1348 mm year$^{-1}$ [45], in Broccoli was 233 to 328 mm during spring and 274 to 344 mm during autumn [41] and in pomegranate was 544, 461, 420, 302 and 186 mm year$^{-1}$ in 2008 [10] and increased to 838, 568, 602, 316 and 195 mm year$^{-1}$ in 2009 with respect to EC-0.8, EC-1.2, EC-2.8, EC-5 and EC-8.5, treatments [41]. As strawberry is an annual crop and the cumulative water demand is close to other annual crop for instance Broccoli, however no differences were observed in terms of cumulative water demand was observed under K$_2$SO$_4$ fertigation at the 1.25 ET$_{\text{max}}$.

Both soil moisture and nutrient status play a vital role to the ET, growth and yield of a plant. Here, increased K$_2$SO$_4$ fertigation has the same effect on the ET and K at 1.25 ET$_{\text{max}}$ but significantly increased the EC$_{\text{iw}}$. Such an increased in the EC$_{\text{iw}}$ significantly decreased leaf area, fresh biomass, first class berries and total fruit weight at EC-3.94 treatment. And reduction in yield attributes could be due to the increased EC$_{\text{iw}}$ that hindered the uptake of P, Mg and Ca as increased concentration of P, Ca and Mg were observed in the drainage water at DOY-147 (Table 2). Moreover, nutrient analysis in the leaf sample shown an increased K and S in the nutrient solution decreased the leaf Ca and Mg concentration expressed on the basis of g per Kg of leaf dry matter (Figure. 7). On the other hand increased irrigation amount from 0.75 to 1.25 ET$_{\text{max}}$ significantly increased leaf area, fresh biomass, first class berries and total fruit weight (Figure. 4). So increasing EC$_{\text{iw}}$ above 2.56 dS m$^{-1}$ of K$_2$SO$_4$ and decreasing irrigation amount below 1.00 ET$_{\text{max}}$ is not sustainable for the strawberry production inside the greenhouse. Similarly increasing salinity above 2.8 dS m$^{-1}$ and decreasing water amount below 0.75ET$_{\text{max}}$ was found unsustainable for the production of ‘SP-2’ variety of pomegranate in Israel [47]. However, yield under fertigation strategy is a crop specific, for instance, a 50% reduction in pepper yield (Capsicum annuum L) was observed at EC of 4.5 dS m$^{-1}$, while 50% reduction in tomato yield was observed in at EC of 9 dS m$^{-1}$. Furthermore, 70% reduction in potential yield for pepper and 90% reduction in potential yield for melon were shown at ECiw of 3 dS m$^{-1}$ [40]. Moreover, at 125% of potential ET, significant differences were observed with 0, 150, 200 and 250 kg ha$^{-1}$ of nitrogen applications in terms of broccoli (Brassica oleracea L) head and nitrate content in the head during spring and autumn seasons, but such differences due to nitrogen applications were insignificant under 50, 75 and 100% of ET treatment [41].

| Treatments  | EC(dS m$^{-1}$) | Cl(p-ppm) | Na(p-ppm) | N-(NO$^-$) (ppm) | N-(NH$_4^+$) (ppm) | P(ppm) | K(ppm) | B(ppm) | Ca(ppm) | Mg(ppm) | Fe(ppm) | Zn(ppm) | Mn(ppm) | Cu(ppm) | S(ppm) | Mo(ppm) |
|-------------|----------------|------------|-----------|-----------------|-------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| DOY - 113   |                |            |           |                 |                   |        |        |        |        |        |        |        |        |        |        |
| EC-1.56     | 3.28           | 106        | 101       | 199             | 1.5               | 83     | 185    | 0.17   | 398    | 95     | 1.34   | 1.57   | 0.63   | 0.16   | 229    | <0.01  |
| EC-2.55     | 4.18           | 87         | 83        | 153             | 0.4               | 62     | 559    | 0.17   | 419    | 90     | 1.12   | 1.56   | 0.57   | 0.16   | 448    | <0.01  |
Observation to the fruit quality parameters is important for the fertigation management decision. Reduction of the TA and TSS was shown respectively in (i) and (iii) of the Figure 5 with DOY. Such a variation in TA and TSS along with DOY could be due to fruiting order. Fruiting in strawberry is categorized as primary, secondary and tertiary fruits [27]. Primary fruits harvested earlier are bigger with high acid and low sugar content than the tertiary fruits and vice versa. Also primary fruits mature earlier were exposed to the treatment for a shorter period than the secondary and tertiary fruit. On the other hand, increased ECiw under K₂SO₄ fertigation increased acid content as shown in the Figure 5(iv). Likewise, increased antioxidant capacity, phenolic compounds, rosmarinic and chicoric acids were reported in basil (Ocimum basilicum L.) at 5 mM K than 1 mM K concentration [48]. Moreover foliar K application increased fruit sugars, ascorbic acid and β-carotene in Musk-melon (C. melo L.) [49]. However these authors did not show the effect of ET_max on fruit quality parameters under K fertilizer. Here a significant reduction in the TA was observed with increasing ET_max shown in the Figure 5(ii). Also an interaction between ET_max and ECiw is shown in the Figure 6. Where K concentration increased TSS to all ET_max but only significant when 1.00 ET_max was applied. The highest TSS was observed at EC-3.94 and the lowest at EC-1.56 at the 1.00 ET_max. Earlier an improvement in fruit quality due to increased salinity in the root zone was observed. For instance, an accumulation of high sugars and proline were recorded in one-year-old olive trees (Olea europaea L.) grown under salt stress than control both in the roots and leaves [50]. And the TSS content in melon was observed higher at ECiw of 7 dS m⁻¹ [51] and 6.1 dS m⁻¹ [52] than non-salinated treatment. Similarly, juice sugar and acid content in citrus was higher at ECiw of 2.5 dS m⁻¹ versus 0.44 dS m⁻¹ [53]. Increased acids, soluble solids and sugar content have also been observed in tomato irrigated with saline water [15]. Also [54], observed increased juice pH of Concord grapes (Vitis labrusca L.) under increased K fertilization. So increased K₂SO₄ showed the same effect on strawberry as it was reported earlier in different crops.

Management of the soil, plant and greenhouse complex is being challenging day by day. As it is shown in the Figures 1 and 2, the maximum value of the daily solar radiation has an effect on the daily ET, ultimately similar effects is shown in the EC_{iw} (Figure 8). Suddenly, dropped in the solar intensity around DOY 112 to 140 dropped Eo and ET values. Such a drop in the ET values in these periods dropped the ET_{max} levels and increased LF unexpectedly. Increased LF allowed us to record free drainage and to record EC_{iw} even at 0.75ET_{max}. Obviously, increased salt accumulation under 0.75ET_{max} increased EC_{iw} and revelation of such a mystery below the ground is taken with high importance. It was generated by the genuine physical measurement, however some software such as HYDRUS and MODFLOW are currently working on simulating leachate EC. Besides, the measurement of the EC_{iw} and monitoring unsaturated zone below the ground can be successful in irrigation scheduling of the field crops [52]. Relating this finding to the Danish growing situations, strawberry growers’ around Denmark are scheduling irrigation as the sum of irrigation and drainage equals to three [55]. Evidently, such practice requires high LF and pollutes the ground water. This could be one of the reasons why Danish growers are shifting the growing media from peat to coconut fiber. Plant can have enough O₂ even though there is high LF because the coconut fiber is highly porous. Moreover, plants roots acts like a desalination factory avoids uptake of excess salts and nutrients. Successive accumulation of the salts and the nutrients in the root zone increased the EC_{iw} and increased the threats of secondary salinization.

**Conclusion**

Use of K₂SO₄ fertigation significantly decreased fresh fruit yield, first class berry weight, biomass and leaf area but increased TA and TSS. Whereas, increasing irrigation regimes increased fresh fruit yield, first class berry weight, biomass and leaf area but decreased TA and TSS. A significant increase in EC_{iw} was recorded at 1.25ET_{max} however no differences were observed in terms of ET and K by K₂SO₄ fertigation. As K is commonly being used for irrigation scheduling of field crops, K values between 0.6 to 0.9 is recommended during mid-crop season for strawberry grown inside the greenhouse. Five times higher the EC_{iw} at 0.75ET_{max} than 1.25ET_{max} was recorded when free drainage was possible under 0.75 and 1.00ET_{max} around DOY 130 during the period of low light intensity. Consequently, salt build up under deficit irrigation increased root zone salinity and have an effect on an improvement in fruit quality. On the other hand, increasing irrigation amount leached the salts down to the ground water and can cause the problem of the secondary salinization. Therefore, irrigating to 1.00ET_{max} with ECiw of 2.55 dS m⁻¹ of K₂SO₄ addition can be sustainable for the greenhouse production for strawberry.

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