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The effect of electrical conductivity on growth and development of strawberries grown in deep tank hydroponic systems, a physiological study

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Abstract
The experiment entitled "The effect of electrical conductivity on growth and development of strawberries grown in deep tank hydroponic systems, a physiological study'' was carried out to find the optimum Electrical conductivity for the growth and development of strawberries (cv. Elsanta) in deep tank hydroponics system with E.C levels 1.8, (A) 2.5 (B) and 4.0 (C). Among the three E.C levels 1.8, 2.5 and 4.0, the effect of EC 1.8 was found to be the best for vegetative and yield contributing characters along with other studies of root and shoot. The significant effect of EC 1.8 was observed in fruit weight, total yield, marketable yield, marketable fruit numbers, etc. Besides this the E.C supplied had shown an effect on vegetative growth parameters of strawberries like, leaf number, fresh and dry weight of root, fresh and dry weight of plant, crown and trash. The plant relative growth rate was analysed by examining the factors per plant specific leaf area, the higher E.C concentration showed the negative effect on non marketable yield along with non marketable fruit numbers.

Keywords: E.C, Deep tank, Hydroponics, Growth and development

Introduction

Strawberry is one of the most delicious cultivated soft fruit and has an economic importance. Worldwide strawberry is appreciated due to its flavour and rich vitamin content (Hancock, 1999). Fruits are attractive and sweet in taste. It is one of the most nutritious fruit with aroma and has unique attraction among all other horticultural fruits. Elsanta is one of the most popular strawberry cultivar in last 25 years. It is originated from Institute of Horticultural Breeding, the Netherlands. It is accepted as commercial cultivar because of its large size berry with orange red colour (Hancock, 1999). Strawberry production has been taken by growers by using different production systems of strawberry such as open ground production, protected productions, hydroponics etc. Cultivation of plants without soil is referred as hydroponics. It is the art and science of cultivation of crops with the provision of chemical solutions. (Eastwood, 1947; Douglas, 1976) In hydroponics the desired nutrients are provided to the plants by dissolving them in water (Resh, 2004). In combination with greenhouse, it is high technology, and capital investment. It is also highly productive, conservative water land and protective of the environment. Regulating the aerial and root environment is a major concern in such agriculture systems, production take place inside enclosures designed to control air and root temperature, light, water, plant nutrition, and adverse climate (Jensen, 1997). In order to provide required strength of nutrients to plant it is necessary to maintain EC (Electrical conductivity) concentration of nutrient solution.

Electrical conductivity of any nutrient solution is the indication of the strength of the nutrients in that nutrient solution (Anonymous, 2002). The nutrients are dissolved in water and provided to the plants. Various kinds of nutrients are used for different types of plants, all nutrients being essentially salts containing a positively charged cation part as well as a negatively charged anion part. The fertilizer salt breaks into cation and anion into the nutrient solution given to plant, and is hence capable of conducting electricity, hence a higher nutrient content signifies a greater magnitude of electrical ions and a greater electrical conductivity (EC). Most of the solutions have EC less than 3.0 (Jones, 1997).

Materials and Methods

The experiment was conducted under Glasshouse condition at School of Biological Science, University of Reading UK. The experiment was designed as a randomize block design with three replications and three blocks in each replication. The standard packages of practices and growing conditions were same for all the blocks. The E.C was maintained as per the treatment of particular block. The 'Elsanta' cultivar of Strawberry was selected for the experiment and 30 plants were planted in each treatment in deep tank hydroponic systems provided with three concentrations of Electrical Conductivities (E.C). Cold stored strawberry plants of cultivar 'Elsanta' were planted in the monthMarch 2011 in deep tanks measuring 115 ×10 ×10 cm3(lbh). Nine wooden tanks of this size were used for the experiment. Each tank was comprised of 10 plants (5 in each row). Spacing between the rows was 60cm and 15cm within a row. Each tank had a capacity of 156 litres of nutrient solution. Each strawberry plant was supported by means of a thread so as to ensure the plant stand. The polystyrene square was kept floating on nutrient solution to support the plants, and 10 holes (Apo 15 sq cm size) were made in the polystyrene square where strawberry plants were planted. Roots were suspended in the solution. The polystyrene squares were used with a purpose to protect the nutrient solution from direct exposure to sunlight. Plastic film with black inside and white outside was used as a cover to polystyrene to reflect the excessive heat. Oxygen was provided through an air pump in each tank. Re-circulating pumps were placed inside each tank to keep nutrient solution in circulation. The 3 EC levels were maintained as per the treatment, the tanks were equally divided into 3 groups, viz. A, B, and C, with different EC levels as illustrated below.

Electrical Conductivity used for the experimentationin various tanks

Type of Tank	E.C (dSm^{-1})
A	1.8
B	2.5
C	4.0

Tanks and treatments were allotted randomly in each block. Randomized block design was used for the present investigation. The essential nutrientswere applied in the form of stock solution to each tank. However the solution to each tank was different in EC values as per the E.C treatment. An EC meter was used to measure EC of the solution. Each tank was provided with a nutrient solution of specific E.C level. E.C and pH level was maintained throughout the experimental period. The pH of nutrient solution was maintained at 5.8 by adding H_3PO_3.Harvesting of the ripened fruit was done twice in a week, during morning hours (9 AM to 11 AM). The fruits attaining ripening stage 80%) were harvested without disturbing unripefruits. The berries were collected in the plastic punnets. The grading of the fruit was done based on the shape, size and colour of the fruits later on the fruits were categorized into two parts asmarketable fruits and unmarketable fruits by following weight as one of the criteria. The fruits having weight more than 8 gms were considered as marketable and rest of the fruits were classified as un-marketable.Fresh weight of the fruit from each treatment was measured after the classification. The harvested fruits were kept in oven at 70 ˚C in a paper bag. Later the fruits were taken out of oven and dry weight of the fruits was recorded. The leaves of the plant were classified into three categories, young, middle, and old. The classification was based on the age of the leaves, solely by the visual inspection. Numbers of leaves of each category for all the plants in the experiment were noted.

Harvest index per plant was calculated by using the following formula:

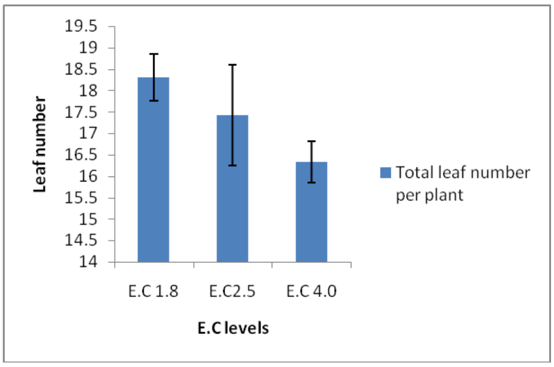
$$\frac{\text{Fruit Dry Weight}}{\text{Fruit Dry Weight} + \text{Leaf Dry Weight} + \text{Crown Dry Weight} + \text{Truss Dry Weight} + \text{Root Dry Weight}}$$

The data was analyzed for significance of different treatments of E.C. The two way ANNOA test was conducted considering the E.C as a factor and remaining data as variance.

Results and DiscussionPlant biomass above ground

Leaf number

The uneven supply of different E.C levels of nutrient solution also affected the production of leaves per plant (Figure 3.1) but the effect was statistically same, hence the number of leaves produced by the plant were not significant (P=0.252). The LSD at 5% for this variable was 2.4.



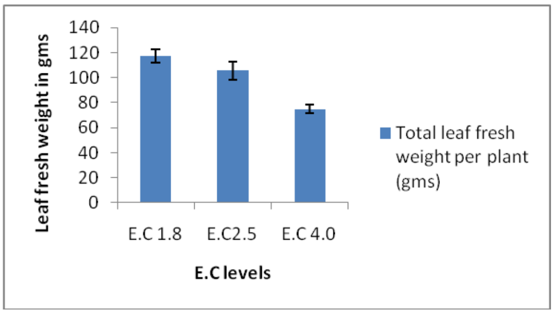
The vertical bar shows the standard error of the average of the treatment.

Fig 1: The effect of different E.C levels on leaf number per plant

Fresh weight of plant parts

The E.C levels also had the effect over the total fresh weights of leaves, crown and truss. The Plants grown in EC 1.8 gave highest fresh weight of plant parts but it was statistically same to that of EC 2.5 and superior over EC 4.0 level. There was gradual decrease in fresh weight with increase in EC level.

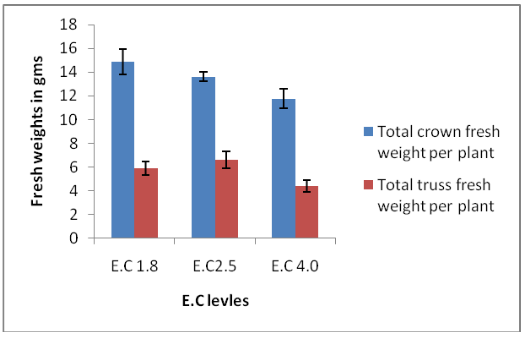
The ANOVA test revealed that the E.C levels had a significance effect on the leaf fresh weight. ($P< 0.01$). The LSD at 5% for this variable was 13.79. The fresh weight of the leaves of plants grown with E.C treatment 1.8 was statistically non-significant to that of EC 2.5 but superior over EC 4.0 level (Figure 2).



The vertical bars show the standard error of the average of the treatment.

Fig 2: Effect of E.C levels on the leaf fresh weight

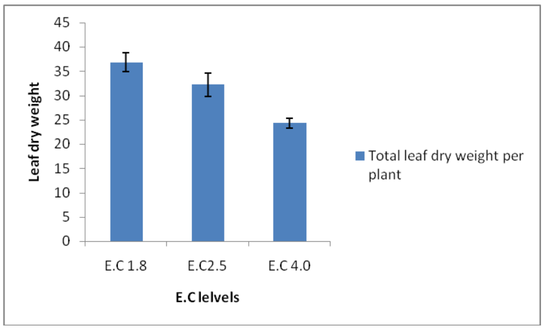
The ANOVA test proved that the E.C treatments had the significant effect on the total crown fresh weight per plant (P=0.05). The LSD at 5% for crown fresh weight per plant was 2.5 and the plants grown with E.C treatment 1.8 had showed maximum weight than all other treatments but statistically did not show any difference on EC 2.5 and superior over EC 4.0 (Figure 3).
The ANOVA test also showed the significant effect of the E.C levels on the total truss fresh weight per plant. (P= 0.018) The LSD at 5% was 1.4 and the significant difference was found in the truss fresh weight of the plants grown E.C 1.8 and 4.0.



The vertical bars show the standard error of the average of the treatment

Fig 3: Effect of E.C levels on the crown and truss fresh weight.

Dry weight of plant parts.
The plant dry weights were also affected by the application of different E.C treatments. The statistical test (ANOVA) for the dry weight of leaves per plant showed the significant effect by different concentration of nutrient solutions (P<0.01). The LSD at 5% for this variable was 2.0 and the leaves from the plants grown in EC 1.8 attended highest dry weight than that of EC 4.0, while it was statistically same to EC 2.5 (Figure 4).

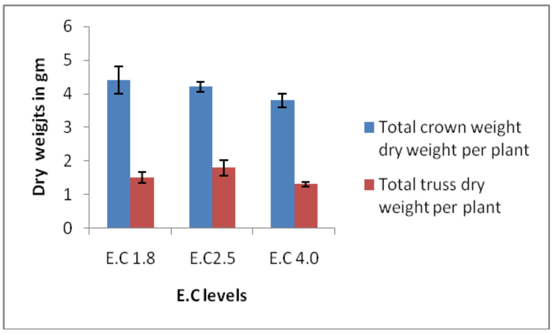


The vertical bars show the standard error of the average for the treatment

Fig 4: The effect of different E.C levels on dry weight of leaves

The ANOVA test for the crown dry weight per plant showed that the E.C levels did not have any significant effect on total crown dry weight (P= 0.30). All the EC levels were statistically same.
The ANOVA test showed the significant effect of the E.C treatments over the truss dry weight per plant (P= 0.020) The LSD at 5% was 0.35, and the plants grown with E.C treatment 2.5 has shown the highest values for this variable, and there is no significant difference found in the values obtained from the plants grown in E.C treatment 1.8 and 4.0 (Figure 3.5).

Plant Biomass below ground level
Fresh root weight
The uneven supply of E.C had the effect on the growth and development of root fresh weight.
The ANNOVA test indicated that E.C had significant effect on the fresh weights of roots (P<0.01). The LSD at 5% was 14.72.

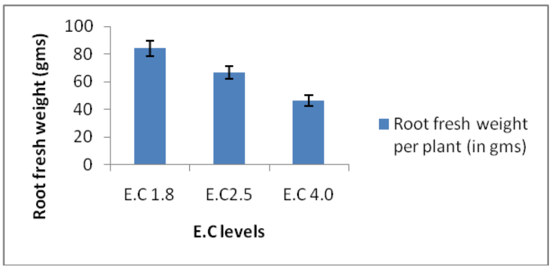


The vertical bars show the standard error of the average of the treatment

Fig 5: The effect of different E.C levels on dry weight of crown and truss.

The roots of the plants grown with EC treatment 1.8 had highest fresh weight, which was statistically superior to EC 2.5 and 4.0. The results indicated that increasing EC reduces mass. The roots of the plants grown in E.C treatment 1.8 produced 20.68% and 44.94% more fresh weight of roots respectively than those of E.C 2.5 and 4.0 (Figure 6).

Dry root weight
The provision of uneven supply of the different concentrations of nutrient solution affected the dry weights of roots and the ANOVA test proved that there was a significant effect of EC levels on the dry weights of roots. (P= 0.035) The LSD at 5% is 1.2.
The roots of plants grown in EC 1.8 had attended higher dry weights, which is slightly higher than those of EC 2.5 but statistically same. The values obtained as dry weight of the roots from the plants grown with E.C treatment 2.5 were superior over EC 4.0 (Figure 7).



The vertical bars show the standard error of the average of the treatment

Fig 6: The response of different E.C on fresh weights of roots.

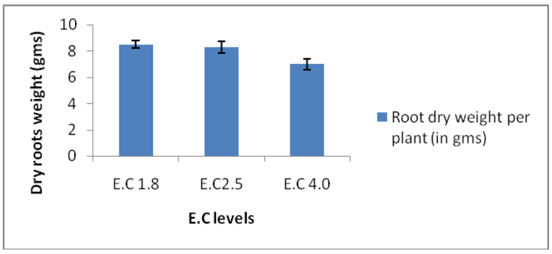
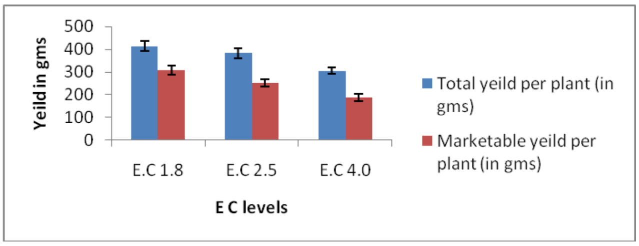


Fig 7: The vertical bars show the standard error of the average of the treatment

Reproductive yield

Total yield and marketable (Economic) yield

The provision of uneven electrical concentration affected the total as well as marketable yield of strawberries in the absolute terms and results were statistically significant. The different levels of EC affected both yield characters and production was highest in EC level of 1.8.It was gradually decreased with the increase in EC level of 2.5 and 4.0 respectively (Figure 8). ANOVA test was used as a statistical tool to test the significant effect of EC levels (P= 0.006 for total yield and P= 0.001 for marketable yield).



The vertical bars show the standard error of the average of the treatment

Fig 8: The effect of different E.C levels on total and marketable yield of strawberries

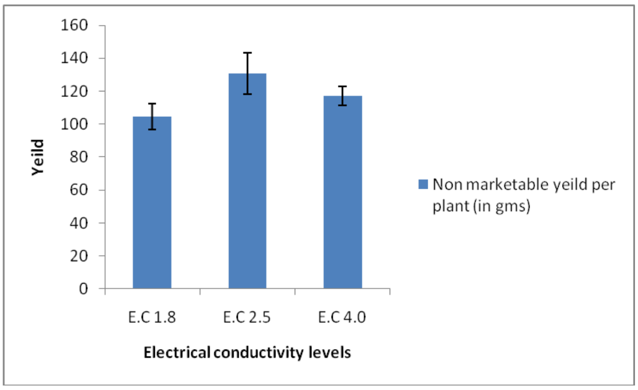
The LSD for total yield per plant at 5% level was 61.7 and plants grown in E.C treatment 4.0 produced the lowest yield than the plants grown in E.C treatment 1.8 and 2.5. No significant difference was found in total yields obtained from the plants grown in E.C treatments 1.8 and 2.5. Although the treatment 1.8 and 2.5 was statically same the plants grown under E.C treatment 1.8 produced 8.38% higher yields than plants grown under E.C treatment 2.5 and 26.33% higher yields compared to plants grown under E.C treatment 4.0. (Figure 8)

The LSD for marketable yield/plant at 5% was 55.3 and significant difference was found in the marketable yield obtained per plant from the all E.C treatments. The plants grown with E.C 1.8 produced 22.62% and 39.16% higher marketable yield respectively than the plants grown under E.C 2.5 and 4.0 (Figure 9).

Total number of fruit and marketable number of fruit

The different concentrations of nutrient solution affected total number of fruits and marketable number of fruits /plant. The total number of fruits per plant was not significant; the ANOVA test did not show any significant effect due to EC levels (P=0.143)

There was significant effect of EC levels on marketable number of fruits /plant, the EC level of 1.8 gave statistically highest number of marketable fruits/plant. It was followed by EC level of 2.5 and 4.0 (P< 0.01).The LSD at 5% was 3.5. The increase in the concentration of E.C level caused the reduction in the marketable fruit production. The plants grown in E.C 1.8 have produced 18.86 % and 37.40 % more marketable fruits respectively than E.C 2.5 and 4.0.

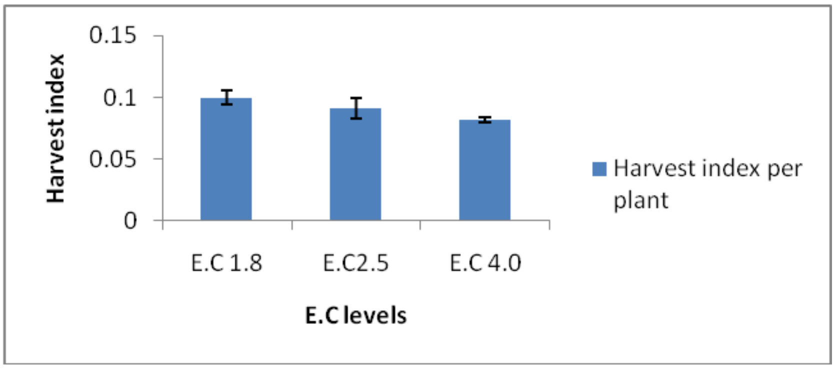


The vertical bars show the standard error of the average of the treatment

Fig 9: The effect of different E.C levels on nonmarketable yield of strawberries.

Harvest index

The supply of different E.C affected the harvest index of the plants. Statistically, ANOVA test did not show any significant effect of different E.C treatments on the harvest index per plant (P= 0.372). Plants grown under the E.C treatment 1.8 had the highest harvest index with no significance difference with the E.C treatment 2.5. The increase in the E.C concentration reduced the harvest index per plant (Figure 10).



The vertical bars show the standard error of the average for the treatment

Fig 10: The effect of different E.C levels on the harvest index.

Discussion

The different E.C levels of the nutrient solution have shown significant effect on various vegetative and growth characters of the strawberry. It was observed that the plants grown with various EC levels differed in production of biomass but the results were not significant to each other. It was interesting to note that the effect on individual characters of vegetative growth viz, fresh weight of the plant, leaf weight, and truss weight was statistically significant in EC level of 1.8 than EC 4.0 but no significant with EC level 2.5, indicating that statistically they were same. Most of the vegetative parameters mentioned above had shown significance over higher concentration of the EC. Over all plant biomass viz, fresh and dry weight of plant, crown and truss weight of plants was decreased with the increase in the E.C concentration and therefore water stress would have caused such reduction. The increase in the nutrient solution concentration, the plant roots were forced to uptake the maximum minerals but at the same time increase in mineral concentration, restricted roots from water absorption and ultimately caused water stress. This was forced stress on the plants which resulted into reduction of vegetative characters at higher concentration and vice versa. The water deficit caused numerous changes in physiological and biological process of the plant (Krzysztof Klamkows ki and Waldemar Treder, 2006). The leaves of strawberry are large and the plant has shallow deep root system, the water requirement of strawberry was more but was subjected to stress causing water deficits (Keutign and Pawelzik 2009).The lower EC level was found to be the best for most of the characters than other treatments. D Anna et.al (2003) also reported that increase in the salinity resulted in to reduction of plant growth and leaf area. Similar results were also reported by Saied at all (2005), Li and Stanghellini observed that the higher E.C exceeding to (6.5) caused the reduction in leaf number and individual leaf area in tomato. Another same result was reported by Krzysztof Klamkows ki and Waldemar Treder (2008) where the water stress in Elsanta variety caused the reduction in the leaf area. The similar trends were also reported by Romero-Aranda, R., Soria, T., Cuartero, J., (2001.) Yilmaz and Kina (2008) also studied the influenced of NaCl salinity on vegetative and chemical changes of Strawberry and reported that, the vegetative growth was generally restricted with the increase in the application of salt. Most of the leaf characters in present research were not significant due to EC levels.

There was significant effect of different EC levels on fresh weight of the roots. The best root weight was observed in EC level of 1.8 followed by EC level of 2.5 and 4.0.It was with scientific basis that the roots always responds best to optimum EC level. The EC level of 1.8 being lowest among all was proved to be the suitable for root growth than other two treatments. The dry weight of the root was also higher in the EC level of 1.8 however it was not significant to EC 2.5 and statistically significant over EC level of 4.0. Similar results were reported by Bisko (2010). The fresh biomass yield and dry matter of shoots and roots of variety Elsanta was reduced significantly with the increasing in application of NaCl.

The uneven supply of nutrient concentrations considerably affected on the physiological process of plants grown in them. The chlorophyll content of the leaves were increased with respect to their age from initial stage to maturity, and maximum leaf chlorophyll content was observed in the leaves of plants grown in high E.C (4.0) the similar results were found by Romero-Aranda *et al*., (2001) the chlorophyll content per leaf increased with the salinity in the tomatoes. The E.C treatment did not have any significant effect over the efficiency of plant photosystem II.

The yield contributing characters of the strawberry has significance due to different EC levels. The yield of any crop is the most economic and qualitative aspect and is of paramount importance.

The present study revealed that there was very good result due to EC level of 1.8.In this treatment the characters like total yield and marketable yield /plant was highest than EC levels of 2.5 and 4.0. This was due to the suitable EC level for plants. The plants have comparatively less stress. The strawberry plants grow well in lower level of EC. This was supported by Caruso et.al (2011) and it was observed that the lowest E.C (1.3) was effective for the fruit production in a spring season of strawberry. There was gradual decrease in the yield level due to higher EC as the plant face stress conditions which ultimately affected the yield of strawberry. The similar result was reported by Mavrogianopoulos et. al (1999) and it was seen that addition of NaCl in the nutrient solution caused the significant effect on the total yield of melon. The total yield of Melon was reduced with the increase of NaCl in the nutrient solution.

The number of nonmarketable fruits and non marketable yield of strawberry was not affected due to EC levels. The difference was statistically non significant. These characters are non desirable and the values recorded were very meagre, that was the reason that there was no significant effect of different EC levels. The increase in the E.C concentration caused the fruit quantity hence maximum non marketable yield was obtained from the plants grown 4.0 EC than lower concentrations, however results are not significant. Similar trend was observed in total number of fruits. Statistically there was no difference in the total number of fruits /plant at various EC levels. The trend was merely numerical and did not have any significance. The similar results were obtained by Awang and Atherton (1994) observed that higher salinity did not affect the number of fruits in strawberry but it caused the reduction in the fresh and dry weight of fruit. This is in the line of present work where the number of fruits were not affected but the fresh weight of the fruits were higher in the lower concentration 1.8 of EC than rest of the treatments.

The fruit quality was the directly related to the E.C level which is confirming to research work of Caruso *et.al*(2011).The weight of the fruits harvested from the plants grown in EC level 1.8 was better than 2.5 and 4.0 EC levels respectively. The average number of marketable fruits per plant and average fruit weight of the strawberry was significantly affected by the EC levels. The EC level of 1.8 was proved to be the best in recording more number of fruits and weight of the fruits than EC level of 2.5 and 4.0. Both the characters are yield contributing characters and have positive effect in increasing the fruit yield and marketable fruits. It also indicated that although the total number of fruits per plant was statistically same the bigger size fruits were produced on the plants grown in EC 1.8 than other two concentrations of EC.

Conclusion

Based on the findings of the present investigation it can be concluded that among the three concentrations of EC levels studied for strawberry production under the deep tank hydroponic systems, the EC level of 1.8 is better than EC level of 2.5 and 4.0.most of the growth parameters, biomass production and yield contributing components give better response at EC level of 1.8 than EC level of 2.5 and 4.0. The plant response for the characters viz. number of leaves, fresh weight of plant, leaf weight, crown weight dry weight of roots were not significant to EC 2.5.The EC level of 1.8 significantly induced best yield contributing characters of marketable number of fruits, average weight of fruits, marketable yield and harvest index. The non marketable yield, plant biomass above ground did not respond significantly to any of the EC level.

The E.C level of 1.8 was found better for many characters and affected the vegetative growth plants. Maximum number of leaves, fresh and dry weight of leaves, fresh and dry weight of root was significant in EC treatment 1.8. Plant biomass produced above ground was found little bit more in the plants grown in E.C treatment 2.5 since the plants grown in them had produced slightly more values for the other plant part like crown weight. Highest supply of E.C level caused the reduction in the reproductive as well as vegetative yield of plants grown in them. The quality fruits with respect to size and weight can be harvested by growing them in 1.8 EC. The chlorophyll content of the plants increases with age and found maximum in the leaves of plants grown with EC 4.0.

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