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Salinity threshold value of Quinoa (Chenopodium Quinoa Willd.) at various growth stages and the appropriate irrigation method by saline water

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ABSTRACT
Salinity is one of the major agricultural problems in arid and semi-arid regions. Considering the variation of plant’s sensitivity to salinity during growth, a greenhouse study with completely randomized design was conducted to determine the relative salinity tolerance of Quinoa (Chenopodium quinoa Willd.) at different growth stages from seedling establishment to maturity (establishment, flowering and seed filling) by evaluating the Salinity Threshold Value (STV). Eight levels of ECi (i.e., Non-saline, 2, 4, 8, 12, 15, 20, 25 dS m-1) with four replications and five levels (i.e., Non-saline, 10, 15, 20, 25 dS m-1) with three triplications were applied at first and two last growth stages, respectively. A comparison was performed on some growth and yield parameters of plants irrigated by considering STV (T) and plants irrigated permanently by mentioned salinity levels regardless of STV (P) to choose which method (P or T) is better at each salinity level. The STV was evaluated 8, 20 and 15 dS m-1 at each growth stage, respectively. Seedling of Quinoa was more sensitive to salinity than the mature plant. Therefore, after establishment Quinoa has the feasibility of irrigation by high-saline waters. The (P) method was suitable only if the freshwater was available during all growth period of the plant; otherwise at higher salinities irrigation should be performed by considering STV (T method) to minimize the intensity of growth and yield reduction and to prevent yield loss at very high salinities. To achieve this, if high-saline water is available it’s possible to use plant propagation techniques or cultivating Quinoa simultaneously with seasonal rainfall.

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KEYWORDS
Flowering; Gmax; halophyte; irrigation method; seed filling

Introduction
One of the most important limiting factors for economic exploitation and sustainable production in arid and semi-arid regions is salinity stress. Salinity disturbs cellular processes through some mechanisms such as reducing osmotic pressure, less plant water absorption, ion toxicity (Pasandi Pour, Farahbakhsh, and Saffari 2014) and nutritional imbalances which reduces plant photosynthesis and other physiological activities (Bybordi, Saadat, and Zargaripour 2017; Hakim et al. 2010).

Although salinity has a negative impact on plant growth and reduces the agricultural productivity (Abdollahi and Jafari 2012), recent droughts and lack of freshwater resources has led to use saline water and soil resources for agricultural production. Obviously, using such resources requires a well-informed and highly specialized management and also it is important to discuss the plant’s reaction to salinity.

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/lcss.
Salinity Threshold Value (STV) is a parameter used for evaluating salinity tolerance of plants. In a study by Maas and Hoffman (1977) and Maas et al. (1983), the response of the plant to salinity has been described by two lines. The first is a horizontal line related to low concentrations of salinity, which the response of plant yield is not dependent on salinity and there is no yield reduction due to salinity. The second line is related to high levels of salinity and depends on the salt concentration and shows a reduction by increasing salinity. The slope of the second line indicates yield reduction per unit increase in salinity. The point at which the two lines intersect represents the “threshold”. Based on this definition, the maximum soil salinity that does not reduce yield below that obtained under non-saline conditions is “salinity threshold value”. In other words, the threshold value is the maximum permitted salinity without any significant decrease in yield compared to non-saline conditions.

Under saline conditions, the crop yield and threshold value are not only the functions of soluble salts’ amount in the root zone but also depend on the plant species, genotypes (Adolf, Jacobsen, and Shabala 2013; Shabala, Hariadi, and Jacobsen 2013) and growth stage of plant exposure to salinity (Keshavarz and Saadat 2016).

Plant tolerance to salinity varies at different growth stages. The tolerance of most plants is higher at germination stage compared to seedling and primary growth stages (Läuchli and Grattan 2007). Some examples are rice (Heenan, Lewin, and McCaffery 1988), wheat (Saadat 2005; Steppuhn and Asay 2005), barley (Ayers, Brown, and Wadleigh 1952), soybean (Wang and Shannon 1999) and sorghum (Begdullayeva et al. 2007; Saadat and Homaei 2015). Some researchers reported that salinity causes a delay in emergence unless if the salinity is lower than the threshold value (Maas and Grattan 1999). Tolerance of some plants such as sorghum (da Paixão et al. 2007), wheat (Maas and Poss 1989), barley (Pandya et al. 2005), canola (Keshta, Hammad, and Sorour 1999) and also halophytic plants such as *Cakile maritima* (Debez et al. 2004) *Tamarix chinensis*, *Suaeda salsa*, *Atriplex isatidea*, *Apocynum venetum*, *Sesbania cannabina*, *Salicornia europaea*, *Phragmites australis*, and *Limonium bicolor* (Xianzhao, Chunzhi, and Qing 2013) to salinity increases with age (Wahid, Rasul, and Rao 1999). Maas and Hoffman (1977) presented one specified amount as the threshold value of each plant. But regarding the changes of plant sensitivity to salinity during growing seasons, it is important to determine threshold value at each growth stage.

The amount of salt accumulation in soil depends on the method of irrigation (Mahmood 2012; Saadat and Homaei 2015). Continuous irrigation increases the amount of salt accumulation in the soil, while alternative irrigation reduces accumulation of salts and leads to increase in crop production.

Studying about the behavior and reaction of salt-tolerant plants is a method for assessing the mechanisms of salt tolerance in plants (Koyro and Eisa 2008). Quinoa (*Chenopodium quinoa* Willd.) is a facultative halophyte with unique characteristics in salt tolerance (Jacobsen, Quispe, and Mujica 2001). These characteristics have led Quinoa to be a productive and suitable plant for cultivating in arid and semi-arid regions which the lack of water and salinity are their major agricultural problems (Prado et al. 2000). Quinoa has large amounts of valuable nutrients (Geerts et al. 2008) such as protein (Bruin 1964), essential amino acids (Dini, Tenore, and Dini 2005), vitamins (A, B2, E) and minerals [calcium (Ca), iron (Fe), copper (Cu), magnesium (Mg), zinc (Zn)] (Repo-Carrasco, Espinoza, and Jacobsen 2003). Quinoa can be cultivated in a wide range of soil textures ranging from sandy to clayey soils and ranges of pH from 4.5 to 9 (Geerts et al. 2008). This plant is tolerant to drought (Jensen et al. 2000), frost (Jacobsen et al. 2007) and salinity (Jacobsen and Mujica 2003). Quinoa is able to grow and produce at 19 dSm⁻¹ and higher ECs (Wilson, Read, and Abo-Kassem 2002) and also survive in salt concentrations equal to seawater (40 dSm⁻¹) (Jacobsen and Mujica 2003).

*Chenopodium quinoa* Willd. is one of the most salinity tolerant species among different species of Quinoa (Bonailes-Alatorre et al. 2013; Shabala, Hariadi, and Jacobsen 2013). This crop has the ability to adjust its leaf water potential by accumulating salt ions in tissues, enabling the plant to maintain cell turgor and limit the transpiration under saline conditions (Gómez-Pando, Álvarez-Castro, and Eguiuz-De La Barra 2010; Jacobsen, Quispe, and Mujica 2001). However, stomata closure may limit assimilation if the soil water content falls below threshold values that are determined by the salinity of the soil solution (Razzaghi et al. 2012).
Evaluation of STV at different growth stages can be effective in managing the use of saline water for irrigation. Investigating the effects of salinity on the physiological and morphological processes of the plant is very important, since a better understanding of these effects allows optimal management of saline water and nutrition under saline conditions. Besides the seeds that are the main products of Quinoa, the leaves are widely used as food for humans and livestock and constitute an inexpensive source of vitamins and minerals. Generally, the younger leaves are used for human food (Ahamed et al. 1998). Hence, studying the effect of salinity on the productive parameters of Quinoa is of a particular importance.

This greenhouse study was performed to: I) determine the salinity threshold value of Quinoa (*Chenopodium quinoa* Willd.) and to diagnose the most sensitive period among seedling establishment, flowering and seed filling growth stages ii) compare the growth and yield status of Quinoa when considering the threshold value (T) and when irrigating by constant salinity levels without considering threshold value (P).

**Materials and methods**

**Determining salinity threshold value**

The Salinity Threshold Value (STV) of the Titicaca variety of Quinoa (*Chenopodium quinoa* Willd.) was determined at each growth stages of germination and establishment, flowering and seed filling in a greenhouse study. A completely randomized design experiment was performed with 8 levels of water salinity (i.e., Non saline (control), 2, 4, 8, 12, 15, 20 and 25 dSm$^{-1}$) with four replications for germination and establishment stage and five levels of water salinity (i.e., Non saline (control), 10, 15, 20, 25 dSm$^{-1}$) with three replications for flowering and seed filling stages. The reason for performing two sets of salinity levels in various growth stages was to diagnose the precise STV by having a wider range of salinity levels at early growth stages.

Initially, 25 seeds were cultivated in four replications in a 2 cm depth of a loamy soil and irrigation with eight levels of salinity (i.e., Nonsaline (control), 2, 4, 8, 12, 15, 20 and 25 dSm$^{-1}$) was performed. Irrigation continued until the end of the seedling establishment stage. During this period, counting the number of germinated seeds and established seedlings at each salinity level was carried out daily. Then, the highest salinity level resulted in no significant decrease in the maximum number of seedlings compared to the control, was selected as the STV of germination and establishment stage (Maas and Hoffman 1977) by Duncan test (p < 0.05). Then, re-planting of seeds was carried out in fifteen pots. All pots were irrigated by same water, which salinity was equal to the STV of establishment stage, diagnosed at previous section. After the complete establishment of the seedlings, plants were thinned; so that 5 plants remained in each pot. Then, the fifteen pots were divided into five groups, and five salinity levels (i.e., Nonsaline (control), 10, 15, 20, 25 dSm$^{-1}$) were applied in three replications. Irrigation with treatments continued until the end of flowering. At the end of the flowering stage, the number of plants that were able to produce panicles was counted. Duncan test was performed (p < 0.05) and the highest salinity level, which did not significantly reduce the number of panicles was selected as the STV of flowering stage. Then, the plants obtained from each salinity treatment were harvested separately and some parameters of plant growth including the number of leaves, fresh and dry weights of the panicles, length of stem, panicle and shoot of each plant were measured and recorded.

In order to determine STV at seed filling stage, seeds were re-planted in fifteen pots. All the plants were irrigated by same water with salinity equal to STV of establishment stage until this stage was completed. After thinning and keeping 5 plants in each pot, from establishment to flowering stage, all the plants were irrigated by the same water with salinity equal to STV of the flowering stage, as determined in the previous section. Then the fifteen pots were divided into five groups of triplets and each of the saline treatments mentioned above were applied to each group. Finally, after the complete maturation of the seeds, the plants were harvested. The weight of panicles and seeds obtained from each salinity treatment and also the 1000 weight of seeds were measured. The highest salinity levels with no significant decrease of seed weight (Duncan test, p < 0.05) compared to control was selected as the STV of seed filling stage.
Comparing the methods of salinity application

A further experiment was conducted to determine whether considering STV at each growth stage (T) is better for plant growth and yield or applying constant levels of salinity from the beginning of planting to the end of harvesting without considering STV (P). So, at the same time as the seeds were planted to determine the STV for both flowering stage and seed filling stage, another group of seeds were planted in 15 pots similar to the pots of the last section. Irrigation in these pots was carried out from the beginning of the cultivation to harvesting with constant levels of salinity (i.e., Nonsaline (control), 10, 15, 20, 25 dSm$^{-1}$) and the STV was not observed. The plants were also harvested at the same time with the plants of the last section in flowering and seed filling stages. In other words, the cultivation time, harvest time, irrigation intervals and all other parameters of these pots were exactly the same as the previous stage pots, and the only difference between them was to observe the STV in the previous pots and not to observe it in these pots. Growth parameters including number of panicles, number of leaves, fresh and dry weight of the panicles, length of stem, panicle and shoot of each plant, panicle and seed weight and 1000 seeds weight were measured and noted also in these plants. Then, a factorial experiment was conducted in a completely randomized design on the results of each growth parameter. So that the first factor was the different levels of salinity (i.e., Nonsaline (control), 10, 15, 20, 25 dSm$^{-1}$) and the second factor was the method of salinity application (P or T). Accordingly, a comparison was made between each irrigation method at each salinity level.

The required water salinity treatments were prepared by diluting the high saline water made from the natural salt of Hoz-E-Soltan Lake (N3459 E5056), Iran. The chemical properties of high saline stock solution are reported in Table 1. The Duncan test and the factorial experiment were performed by SAS 9.0 software (SAS Inc., Cary, NC).

Results and discussion

Threshold value determination

Germination and establishment

Due to no significant difference between $G_{\text{max}}$ of 8 dSm$^{-1}$ and control, by Duncan test ($p < 0.05$) the STV of Quinoa at germination and establishment stage was 8 dSm$^{-1}$ (Figure 1). According to the definition of Maas and Hoffman (1977), the germination percentage would not decrease at 8 dSm$^{-1}$ and lower salinity levels but decreases at upper levels of salinity. The $G_{\text{max}}$ of 8 dSm$^{-1}$ occurred with a 5 days delay compared to lower salinity levels (Figure 2).

The steepest slope of germination percentage in the saline soil for nonsaline to 8 dSm$^{-1}$ occurred between 48 and 96 hours and for 12 dSm$^{-1}$ occurred after 96 hours and no germination was observed for 15 dSm$^{-1}$ and higher salinities (Figure 2).

The rate of seed germination is often limited by low soil water potential (Bullied, Acker, and Bullock 2012). Unlike germination in the saline solution which osmotic potential caused by the presence of salts, is the only factor affecting water absorption by seeds, in saline soil germination is influenced by soil matric and osmotic potentials; therefore, germination is decreased by reduction of both of these potentials.

The low STV of establishment in soil (8 dSm$^{-1}$) indicated the high sensitivity of Quinoa for the establishment in saline soil. This result is in agreement with the experiment of Jacobsen, Jørgensen, and Stolen (1994) and Jacobsen et al. (1999) which indicated that Quinoa’s most critical period is seedling establishment. Most studies indicated that the sensitivity of plants to salinity at establishment stage is higher than germination stage. This is in agreement with the observations of the present study; because

<table>
<thead>
<tr>
<th>EC dSm$^{-1}$</th>
<th>PH</th>
<th>CO$_3^{2-}$ Mgl$^{-1}$</th>
<th>HCO$_3^{-}$ Mgl$^{-1}$</th>
<th>Cl$^-$</th>
<th>Ca$^{2+}$</th>
<th>SO$_4^{2-}$ Mgl$^{-1}$</th>
<th>Mg$^{2+}$</th>
<th>Na$^+$</th>
<th>K$^+$</th>
<th>B</th>
<th>TDS Mgl$^{-1}$</th>
<th>SAR (Mmol$^{-1}$)$^0.5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>394</td>
<td>7.2</td>
<td>0</td>
<td>0.13</td>
<td>127.7</td>
<td>0.92</td>
<td>0</td>
<td>0.29</td>
<td>80.5</td>
<td>0.014</td>
<td>0.002</td>
<td>212</td>
<td>592</td>
</tr>
</tbody>
</table>
some seeds were able to germinate at higher salinity levels but seedlings could not establish and decayed before establishment. The more sensitivity of establishment stage compared to other growth stages has also been observed in wheat (Udovenko and Alekseeva 1973), barley (Ayers, Brown, and Wadleigh 1952), cotton (Abul-Naas and Omran 1975), maize (Maas et al. 1983) and soybean (Wang and Shannon 1999).

Researchers indicated that although soil salinity causes delayed germination, if the salinity level does not exceed the STV, the germination percentage would not decrease in most plants (Maas and Grattan 1999) and this shows the necessity of recognizing the STV at each growth stage.

Flowering
Salinity had a significant decreasing effect on Quinoa at flowering stage, too. The number of panicles was significantly lower than control at 25 dSm$^{-1}$. Therefore, the STV of Quinoa at the flowering stage was 20 dSm$^{-1}$. A field study in Southern Italy indicated that the yield of Quinoa had no significant difference when irrigated with 22 dSm$^{-1}$ saline water, resulting from mixing approximately 1:1 ratio of seawater to freshwater, compared to a freshwater control (Pulvento et al. 2012).

Comparing the sensitivity of Quinoa in two growth stages of seedling establishment and plant flowering indicated an increase in the tolerance of Quinoa after the seedling stage and during growth season. In a greenhouse study on Quinoa, Jacobsen, Quispe, and Mujica (2001) indicated that tolerance at the seedling stage is not necessarily connected with tolerance during the maturity stage.

Seed filling
According to the importance of Quinoa seed, which is the main product of Quinoa, determining the effect of salinity on the seed yield is very important. Salinity had a significant effect on Quinoa seed weight. The
significant effect of salinity on seed weight of Quinoa was reported in several studies (Koyro and Eisa 2008; Razzaghi et al. 2012).

According to the results of Duncan test (p < 0.05), the STV of Quinoa at seed filing stage was 15 dSm\(^{-1}\) due to no significant difference between the weight of seeds in control and 15 dSm\(^{-1}\) treatments. Similar results were obtained from the research of Razzaghi et al. (2012) which indicated that salinity causes a significant decrease in seed number, seed yield, and harvest index. However, once the salinity level reached to 20 dSm\(^{-1}\) in the irrigation water before the seed-filling period, there would be no further change in seed yield.

Considering the results, the STV of Quinoa at germination and seedling establishment, flowering and seed filling stages of growth were 8, 20 and 15 dSm\(^{-1}\), respectively (Table 2). Therefore, the establishment in saline soil was the most sensitive and flowering was the most tolerant stages of Quinoa growth among the various stages of growth in saline soil and when irrigated by saline water. The result indicated an increase in Quinoa tolerance to salinity after the complete establishment of the seedling.

This result was in agreement with the results of Jacobsen, Quispe, and Mujica (2001) that reported the change of Quinoa’s tolerance to salinity at different stages of growth and the lower tolerance at early growth stages of this plant (Jacobsen et al. 1999).

### Comparing the methods of salinity application

**Flowering stage**

Salinity had a significant decreasing effect on all vegetative parameters of Quinoa (Table 3). Stem, panicle and generally the shoot height, panicle fresh and dry weight and the number of panicles and leaves were damaged by salinity. The plants grown in saline condition were significantly smaller (Figure 3E,G) and produced less leaves and less and weaker panicles especially in (P) method (Table 4). This result is in agreement with Long (2016) which concluded that when salinity increases over optimum levels, Quinoa plant height will be inhibited. Salinity stress affects the function of the genes that stimulate the progression of the cell cycle, thus, through its effect on cell division and cell development, leads to inhibition of growth (Bурсsens et al. 2000). The decrease in stem growth due to salinity stress reduces the number of leaves and panicles (Steppuhn and Wall 1997). The significant decreasing effect of salinity on the number of Quinoa leaves is also mentioned by Long (2016).

Also, the comparison between the differences of plant status in irrigation by considering STV at various growth stages (T) and constant salinity levels (P) indicated a significant effect. The main difference between (P) and (T) becomes clear from the fact that in (P) method, the EC\(_i\)s of 20 and 25 dSm\(^{-1}\) were so high for the seed to germinate and for the seedling to establish; therefore, seedlings decayed and no plants survived and matured at these high salinities. But in (T) method, the EC\(_i\) at earlier growth stages was suitable for seedling establishment and did not cause the plant decay. Therefore, there were plants formed in 20 and 25 dSm\(^{-1}\) in (T) method. This result indicates the importance of considering the STV at each growth stage of the plant. Because it reduces the seedling decay caused by high salinity levels at early growth stages of the plant.

Another point is that although the best yield was obtained from constantly irrigating by freshwater (NS×P) but by increasing EC\(_i\) the curve of (P) sharply decreased while the curve of (T) had a steady trend for all vegetative growth parameters; So that there was no significant difference between 10 and 15 dSm\(^{-1}\) and also 20 and 25 dSm\(^{-1}\) in (T) method. In other words, the slope of yield reduction was sharper in (P) compared to (T) (Figure 3B,C). By increasing the EC\(_i\) and decreasing the quality of irrigation water, the importance of considering STV became more evident; because the yield loss was much more severe in (P) method.

<table>
<thead>
<tr>
<th>Table 2. Threshold value of Quinoa at different growth stages.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Growth stage</strong></td>
</tr>
<tr>
<td>Threshold value (dSm(^{-1}))</td>
</tr>
</tbody>
</table>
As an example, by increasing EC from control to 15 dSm\(^{-1}\) the panicle fresh weight reduction was 69.2% and 20.4% in (P) and (T), respectively, and the shoot height decrease for (P) was 60.9% whereas it was 27.8% for (T). The slope of yield reduction in (T) was less due to the similar condition of plants until establishment. Because in (T) method all plants were irrigated by the STV of establishment stage (8 dSm\(^{-1}\)) and after complete establishment irrigation by treatments (i.e., non-saline, 10, 15, 20 and 25 dSm\(^{-1}\)) started; therefore they had relatively same vigor at establishment stage. While in (P) method treatments were applied from the beginning of planting and continued with constant quality until harvesting; therefore, at establishment stage, the vigor of the plants irrigated by higher salinity levels was much less than freshwater.

This issue indicates that considering STV at earlier growth stages increases the tolerance of the plant to salinity and makes the irrigation of plants with higher levels of salinity at maturity stage possible, without significant loss in the plant canopy.

**Seed filling stage**

Salinity had a significant decreasing effect on the weight of panicles and seeds both in (P) and (T) methods, but not on 1000 seeds weight. Similar to vegetative stage, no germination and no seedling establishment was observed for 25 dSm\(^{-1}\) in (P) method due to high salinity level and therefore the final yield was zero. But by observing the STV at earlier stages of growth, a 50% of max yield was achieved at 25 dSm\(^{-1}\). This achievement indicates the importance of STV observance at each stage of growth. Although, the 50% yield reduction due to salinity in (T) method indicated that even if STV is considered at earlier growth stages, the occurrence of high salinity stress at the latest growth stages of the plant can cause panicle and seed weight reduction.

The remarkable point is that unlike vegetative stage, the highest panicle and seed weight was not obtained from constantly irrigating by freshwater (NS×P), but from considering STV (NS×T). Also, in a comparison between different salinity levels of P treatment, it is obvious that the optimal panicle and seed weight was achieved from 10 dSm\(^{-1}\) rather than freshwater (Figure 3H). This result was in agreement with the results of Jacobsen, Mujica, and Jensen (2003) and Adolf, Jacobsen, and Shabala (2013) who indicated that the biomass production, seed yield, and harvest index of Quinoa were higher under moderately saline conditions (10–20 dSm\(^{-1}\) than non-saline conditions. Because Quinoa is a halophyte crop (Ruiz et al. 2016) and like other halophytes needs some salt for proper yield.

Also, an increase in Quinoa seed quality in the presence of salt was obtained from a study by Wu et al. (2016). They found that under saline soil conditions, not only Quinoa did not show any marked decrease in seed quality, but also Protein content even increased under high salinities. Irrigating Quinoa by water with salinity equal to the STV, not only provides the possibility of using saline water resources and leads to a lower cost of production, but also provides the context to achieve a higher yield. So, observing the STV is more economical anyway.

Regardless of the salinity level of 25 dS m\(^{-1}\) with no germination, no plants, and no seeds in (P) method; salinity had no significant effect on 1000 seeds weight. Therefore, the method of salinity application and increasing salinity level would not depress 1000 seeds weight except by preventing the formation and growth of the plant which generally leads to lack of seed yield.

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### Table 3. Summary of statistical analyzes of variables at flowering stage.

<table>
<thead>
<tr>
<th>S.O.V</th>
<th>Number of panicles</th>
<th>Panicle fresh weight (g)</th>
<th>Panicle dry weight (g)</th>
<th>Leaf number</th>
<th>Stem height (cm)</th>
<th>Panicle height (cm)</th>
<th>Shoot height (cm)</th>
<th>Seed weight (g)</th>
<th>Panicle weight (g)</th>
<th>1000 seeds weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC</td>
<td>4</td>
<td>16.20**</td>
<td>21.87**</td>
<td>2.08**</td>
<td>204.75**</td>
<td>356.26**</td>
<td>8.22**</td>
<td>471.46**</td>
<td>326.13**</td>
<td>502.61**</td>
</tr>
<tr>
<td>PT</td>
<td>1</td>
<td>20.83**</td>
<td>0.26**</td>
<td>2.15**</td>
<td>256.96**</td>
<td>118.72**</td>
<td>0.16**</td>
<td>127.80**</td>
<td>575.35**</td>
<td>902.11**</td>
</tr>
<tr>
<td>EC×PT</td>
<td>4</td>
<td>6.16**</td>
<td>10.78**</td>
<td>1.66**</td>
<td>177.63**</td>
<td>70.05**</td>
<td>2.83**</td>
<td>99.70**</td>
<td>114.80**</td>
<td>191.07**</td>
</tr>
<tr>
<td>Error</td>
<td>20</td>
<td>0.40</td>
<td>0.28</td>
<td>0.00</td>
<td>2.85</td>
<td>2.28</td>
<td>0.17</td>
<td>3.09</td>
<td>7.00</td>
<td>10.93</td>
</tr>
<tr>
<td>CV</td>
<td>17.09</td>
<td>17.94</td>
<td>6.04</td>
<td>11.26</td>
<td>11.97</td>
<td>25.55</td>
<td>12.35</td>
<td>12.46</td>
<td>12.5</td>
<td>6.50</td>
</tr>
</tbody>
</table>

Notes: ns Not Significant. *Significant at the ≤0.05 probability level. **Statistical Significant at the ≤0.01 probability level.
Figure 3. The interactive effect of different levels of ECi and different methods of salinity application on Number of panicles (A), Panicle fresh weight (B), Panicle dry weight (C), Leaf number (D), Stem height (E), Panicle height (F), Shoot height (G), Seed weight (H), Panicle weight (I) and 1000 seeds weight (J).
Table 4. Effect of water salinity on different parameters of Quinoa at flowering stage. Mean comparisons were conducted with Duncan test at 5%.

<table>
<thead>
<tr>
<th>Source</th>
<th>Number of panicles</th>
<th>Panicle fresh weight (g)</th>
<th>Panicle dry weight (g)</th>
<th>Leaf number</th>
<th>Stem height (cm)</th>
<th>Panicle height (cm)</th>
<th>Shoot height (cm)</th>
<th>Seed weight (g)</th>
<th>Panicle weight (g)</th>
<th>1000 seeds weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC (Water Salinity)</td>
<td>NS</td>
<td>5.00</td>
<td>2.73</td>
<td>2.10</td>
<td>20.70</td>
<td>23.33</td>
<td>3.36</td>
<td>26.69</td>
<td>25.14</td>
<td>31.52</td>
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Notes: *The mean values followed by the same letters are not significantly different (Duncan’s test) at p < 0.05.

Conclusions

The results of the present study indicated that the establishment in soil is the most sensitive and the flowering stage is the most resistant growth stages of Quinoa to salinity. Considering the increase in Quinoa tolerance to salinity after complete establishment in the soil, it is recommended to perform irrigation by water with salinity equal or less than 8 dS m$^{-1}$ (STV of Quinoa at establishment stage) from planting to the end of the establishment. Quinoa has the feasibility of irrigation by high-saline waters after establishment. To achieve this, it is possible to use plant propagation techniques or cultivating Quinoa simultaneously with seasonal rainfall.

Salinity had a significant decreasing effect on the growth and yield of Quinoa at various growth stages. But, the intensity of growth and yield reduction strongly depended on the method salinity is applied (P or T). The STV consideration at various growth stages not only makes it possible to obtain yield by use of higher salinity levels of irrigating water but also moderates the growth and yield reduction trend and leads to more final yield. When the EC$_s$ of available water is high, it is recommended to consider STV at earlier growth stages in order to prevent yield loss of the mature plant. The (T) method is also more economic due to higher product stability than (P) method.

Notes

1. Threshold Value Treatment.
2. Permanent Treatment.

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References


