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Response of Saline Irrigated Quinoa (*Chenopodium quinoa* Wild) Grown on Coarse Texture Soils to Organic Manure

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Abstract

As a result of the increased demand for food, the need to use lower quality water such as saline and waste water in agricultural production increased. The use of saline irrigation water is necessary to provide food for the expected population increases. Salt stress decreases plant growth and yield but negative effects of salt can be reduced by choosing tolerant plants and good agricultural management. Quinoa plants are among the food security plants and are in line with the sustainable development, and are distinguished by their content of unique amino acids and high protein content in their seeds. This study has been conducted to investigate the response of quinoa plant (*Chenopodium quinoa* Wild) irrigated with saline water to organic amendments. The study was conducted in pots and growth chamber to investigate the response of quinoa to water salinity at the germination and vegetative growth stages. The liner relationship was used to assess the threshold value of water salinity in germination and vegetative growth stages. The study evaluated the effects of eleven salinity levels of irrigation water (0.4, 2, 4, 8, 12, 16, 20, 24, 26, 30, and 34 dsm^{-1}) and organic matter application (farmyard manure) at rats of 20 t ha^{-1}. Quinoa seeds were able to resist the high levels of water salinity in the germination stage, however, the seed germination percentage shows that the increase in irrigation water salinity decreases the final germination percentage. The germination of seeds stopped completely at a salinity level of 26 dsm^{-1}, while at a salinity level of 24 dsm^{-1} only 50% of the seeds were germinated. Quinoa yield and its components were significantly affected by increasing the salinity level, on the other hand, the addition of organic manure mitigated the salt stress. Quinoa plants lost 50% of the relative yield at water salinity of 18 dsm^{-1} when no organic amendment was added, while the addition of organic manure increased the threshold value of water salinity up to 34 dsm^{-1}.Adding organic fertilizers to coarse soils increases the ability of quinoa plants to resist saline irrigation water and allows using lower quality water to irrigate these valuable plants. There are many coarse texture soils in arid and semi-arid areas, and improving the level of soil organic matter increases the use of brackish water to irrigate quinoa plants.

Keywords: Quinoa, Irrigation, Salinity, Farmyard manure, Sandy soil

Introduction

It is expected that the world population will be more than 11 billion people in 2100 and most of the population growth will come from developing countries (Pawlak and Kołodziejczak, 2020; Sadigov, 2022). Therefore, these countries will suffer from severe shortages of food and agricultural products (Sadigov, 2022). World scientists specializing in food production are trying to harness all natural resources in order to provide food for the expected population increase (Sadigov, 2022). Because of the importance of food production from non-traditional crops, the United Nations General Assembly considered 2013 as the "International Year of Quinoa" (Ruiz et al., 2014). Food and Agriculture Origination (FAO) promotes quinoa for its adaptability to extreme climate conditions and the nature of plant growth is commensurate with the desert soils spread in developing countries (FAO, 2012). Quinoa plants seem to offer a solution for food sovereignty and security in vulnerable areas (Bedoya-Perales et al., 2018). *Chenopodium quinoa* plants were cultivated in Andean region of Bolivia and Peru, for more than 5000 years ago (Alandia et al., 2020). Quinoa plants are

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distinguished by their high content of protein and minerals e. g., Ca, Fe, Cu, Mg, and Zn (Singh et al., 2021). Seeds of quinoa contain unique amino acids and vitamins (A, B2, and E) and are cultivated for centuries as a leafy vegetable (Singh et al., 2021). Quinoa can fill a part of food gap, since the plant produce a good seed yield under many harsh environmental conditions that are not suitable for traditional crops (Adolf et al., 2013). Quinoa plants can grow in sandy soil of arid and semiarid regions (Hinojosa et al., 2018; Hussain et al, 2020).

Agricultural expansion depends mainly on our ability to use lower quality water in agriculture due to the scarcity of fresh water sources (Ismail et al., 2019). Therefore, there has been a great incentive to use salt tolerance crops rather than conventional ones to allow greater yields in saline agriculture (Hayat et al., 2020). Quinoa plants are halophytic plants that can resist high concentrations of salts in irrigation water, and some quinoa species can be irrigated directly with sea water (Rekaby et al. 2021, Nanduri et al. 2019). The salinity threshold of irrigation water that significantly reduced growth and yield of quinoa lies somewhere between 8 to 16 dSm–1 (Dua-e-Zainab et al., 2021). However, there are other studies confirmed that quinoa plant can tolerate water salinity up to 25 dSm–1 in the germination stage and up to 20 dSm^{-1} at vegetative growth stage (Chaganti et al., 2022). Under field conditions in Iran the seed yield of quinoa ranged between 2 and 3 t ha^{-1} when the plants were irrigated with saline water ranged between 14 to 20 dS m^{-1}, while in another experiment in Urinated Arab Emirates the seed yield was 7–10 t ha^{-1} with the use of saline water had 16–18 dS m^{-1} (Nanduri et al., 2019).

There are many agricultural management practices that can be used to reduce the negative effects of salt stress on plant growth (Ding et al., 2020; Ali et al., 2021). Salt stress negatively influences the plant growth due to the toxic ions and inability of plant to absorb its nutrients and water requirements (Rekaby et al., 2021). The addition of soil organic amendment to the sandy soils is a good strategy to improve the performance of plants under salt stress (Li et al., 2021). Main mechanisms of these positive impacts of organic manures are due to increasing the availability of water and nutrients in the sandy degraded soils by enhancing the soil organic matter content (Ali et al., 2021). The high CEC of organic manures decreases solubility of ions that encourage the dispersal of soil particles, especially sodium, which ultimately leads to better structure and aggregation of soil particles (Eissa, 2019; Ding et al., 2020; Li et al., 2021). Organic amendments improve soil moisture status and nutrients availability (Munns and Tester, 2008; Li et al., 2021; Ge et al., 2022).

Egypt suffers from an increase in the demand for food as a result of the population increase, and fresh water sources are limited (Ali et al., 2019; Abou Hussien et al., 2020). Therefore, there are many attempts to produce some salt-tolerant cereal crops using saline water that is not suitable for producing salt-sensitive crops (Sary, 2021; Rekaby et al., 2021). Quinoa is one of the promising crops due to its tolerance to drought and its suitability for growth in the arid lands spread in Egypt (Mahmoud, 2017; Rekaby et al., 2021).

The current research paper aims to study the effect of different levels of water salinity on the germination of quinoa seeds and to verify the possibility of using organic manure to increase the resistance of quinoa to salt stress. One of the most important problems that reduce the ability of plants to grow when irrigated with saline water is the poor soil content of organic matter (Sarhan, 2021). Therefore, this study assumes that supplying arid degraded soils with organic fertilizers will increase the water salinity threshold limit of quinoa plants.The obtained results will be used to determine threshold value of water salinity in germination and vegetative growth stages.

Materials and Methods

The current research paper contains two experiments to study the response of quinoa plants to the irrigation with saline water. The first experiment was conducted to study the germination of quinoa seeds under different levels of water salinity in Petri dishes in a growth chamber. The second experiment was conducted to investigate the response of quinoa to organic fertilization under different levels of saline water in a pot experiment. Plant material, mature seeds of quinoa (*Chenopodium quinoa* Wild cv Misr1) was provided by the Department of Field Crops Research Institute, Agricultural Research Center, Egypt. The present studies were carried out at the laboratory and greenhouse of the Soil and Water Department, Faculty of Agriculture University, Assiut, Egypt.

Germination experiment

Germination of quinoa seeds at different levels of water salinity was tested in Petri dishes (9 cm diameter). The procedure of germination test was carried according the method described in StoleruVasile et al. (2019). Quinoa seeds were treated with saline water prepared from NaCl solutions at different concentrations: 2, 4, 8, 12, 16, 20, 24, 26, 30, 34, and tab water (control = ~ 0.4) dsm^{-1}. A filter paper was placed in each Petri dish, then a 5 mL of saline water was added to it for one time in the experiment. Quinoa seeds were placed on the moistened filter paper. Quinoa seeds were added to the Petri dish at the rate of 10 seeds per dish and then the dishes were transferred to the growth chamber (25 °C and 70% of relative humidity). The experiment was performed in triplicate and continued for five days. Numbers of germinated seeds were recorded daily for five days and seed was considered germinated if the radicle had extended to 1 mm. The following equation (StoleruVasile et al., 2019) was used to assess the germination rate (GR):

GR = (number of germinated seeds/numbers oftotal seeds) × 100.

Pot experiment

The pots experiment was conducted sequentially after the seed germination test to evaluate the growth and nutrient content in quinoa plants in responses to water salinity. The trial was carried out to study the response of quinoa plants grown on sandy soil to the irrigation with eleven levels of saline water and organic matter application (farmyard manure). Saline water (NaCl solutions) was as follow: control (tab water =~ 0.4), 2, 4, 8, 12, 16, 20, 24, 26, 30, and 34 ds m^{-1}. The organic matter application doses were (0 and 20 t ha^{-1}). The water salinity levels are the same degrees of water salinity that used in the previous germination experiment in order to determine the extent to which the plant can continue to grow after germination under these levels of salinity. Some chemical characterizations of soil and organic matter were described in table 1. The soil used in the study was brought from a private farm (0-20 cm) in Assiut city, Egypt. The soil at this site was sandy and classified as Aridisols: Typic Torripsamments (Soil Survey Staff, 2016).

Treatments were assigned in a split plot design in three replicates. Pots were filled with 1 kg of the studied sandy soil and four seeds were sown in each pot. The plants were thinned to two plants per pot after germination. The plants were irrigated with tap water in the first two weeks, and then were irrigated with the saline water treatments for 120 days. At the end of the experiments, the plants were harvested and the growth parameters were recoded.

TABLE 1. Some chemical characterization of soil and organic manure (OM)

Properties	Soil	OM
pH (1: 1)	7.62	7.12
EC (dS/m)	3.38	8.0
Organic matter (g kg^{-1})	3.10	360
Total nitrogen	0.05	2.4
Clay (%)	6.0	-
Silt (%)	1.6	-
Sand (%)	92.4	-
Texture	Sandy	-
$CaCO_3$ (g kg^{-1})	35.0	-

Soil and plant analysis

Soil mechanical analysis was performed by the pipette method (Burt, 2004). Soil calcium carbonate content was measured using Scheiblercalcimeter (Burt, 2004). Soil reaction (pH) was measured in 1:1 soil-water suspensions using a glass electrode pH meter, while farmyard manure pH was measured in 1:10 suspension. Total soluble salts were determined by measuring the electrical conductivity (EC) of a 1:1 soil: water extracts, while farmyard manure EC was determined in a 1:10 extract. Organic matter content in soil and farmyard manure was estimated by dichromate oxidation method (Burt, 2004). Nitrogen, phosphorus, and potassium in the seeds of quinoa were determined after the digestion of samples in sulfuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2) according to Parkinson and Allen (1975). Nitrogen was measured by Kjeldahl method, P was measured by spectrophotometer, and K levels were measured by flam photometer method (Page, 1982). Crude protein content (%) of seed was calculated as mineral nitrogen x 6.25. Relative yield of quinoa plants was calculating the whole plant dry matter in the treatments/ whole plant dry matter in the control.

Statistical analyses

The statistical analyses of the obtained data were done according to the method described by Snedecore and Cochran (1989). The analysis of variance (ANOVA) was run by the software of Statistical Analysis System (CoStat version 60311). LSD test was performed to compare between means if ANOVA indicated significance differences between treatment. The relationship between the water salinity and the relative yield of quinoa was run by EXCELL software to assess the water salinity threshold limit in germination and vegetative growth stages.

Results and Discussion

Effect of saline water on seed germination and quinoa growth

The irrigation of quinoa plants with saline water significantly reduced the germination rate and plant growth. Increasing the level of salinity in irrigation water from 0 to to 8 dS m^{-1} did not cause any negative effects on the germination of quinoa seeds (Fig 1). The germination rate ranged between 0 and 100%; the highest value was found in the tap water treatments, while the lowest value was found in the highest levels of water salinity (34 dS m^{-1}). The germination rate of quinoa seeds was 63% at a water salinity of 24 dS m^{-1}. The use of saline water of 20 and 24 dS m^{-1} minimized the germination rate by 10 and 38% compared to the tap water (0.4 dS m^{-1}).

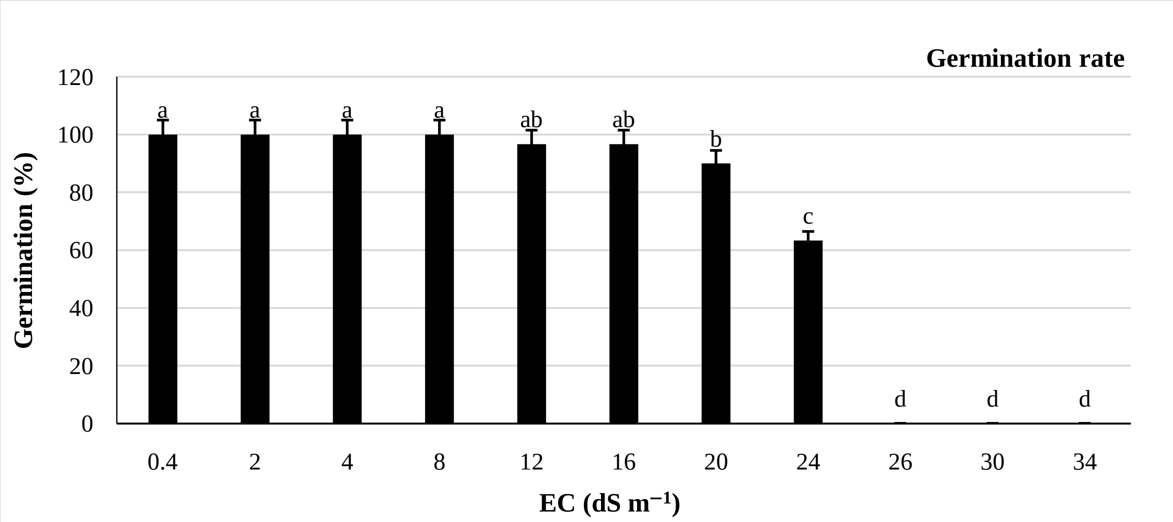

Fig. 1 Germination rate under different levels of water salinity.
Same letters on each bar mean significance differences according LSD$_{0.05}$.

The data illustrated in Fig 2 show the relationship between the water salinity and the germination rate, the presented equation was used to calculate the critical point of water salinity which causes 50% lose in the germination. The value of R2 for the estimated equation equals 0.87 in the germination stages and the Pearson correlation coefficient (r) is highly significant. The results of R^2 and Pearson correlation coefficient indicated the possibility of the obtained equation to describe the relationship between water salinity and germination rate. The use of saline water with EC value of 24.5 dS m^{-1}inhibited the germination of quinoa seeds to less than 50%.

The data illustrated in Fig 3 shows the relationship between the water salinity and the relative yield of quinoa, the presented equation was used to calculate the critical point of water salinity which causes 50% lose in quinoa growth. The value of R^2 for the estimated equation equals 0.92 and 0.88 in the case of control and organic manure, respectively, and the Pearson correlation coefficient (r) is highly significant. In the current study, the critical level of water salinity (which reduced the growth by 50%) was 18 and 34 dS m^{-1}, respectively, in the case of control and organic manure application. The maximum dry matter production was found in the tap water treatment, while the lowest values were found in the highest salinity level (34 dS m^{-1}). The use of saline water with EC value of 18 and 34 dS m^{-1} inhibited the relative yield to less than 50% in the case of control and organic manure application (Fig 3), thus the critical point of saline water in the vegetative growth was considered 18 and 34 dS m^{-1} for the mentioned treatments. Quinoa plants are belonging to the halophyte plants that can tolerate the high levels of salinity (Panuccio et al., 2014; StoleruVasile et al., 2019). Our results are in agreement with those obtained by Panuccio et al. (2014) and Chaganti et al. (2022). Increasing the concentrations of NaCl (100-400 Mm) in saline water did not have significant effects on the germination of some quinoa cultivars (Panuccio et al., 2014; Chaganti et al., 2022).

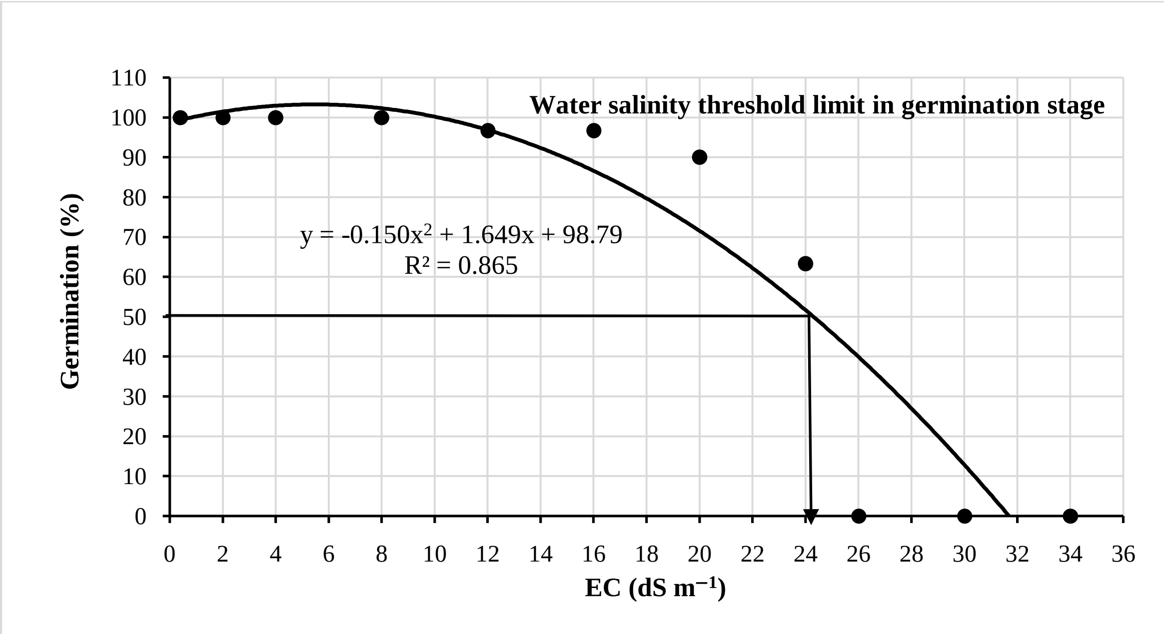

Fig. 2. Water salinity threshold limit in germination stage

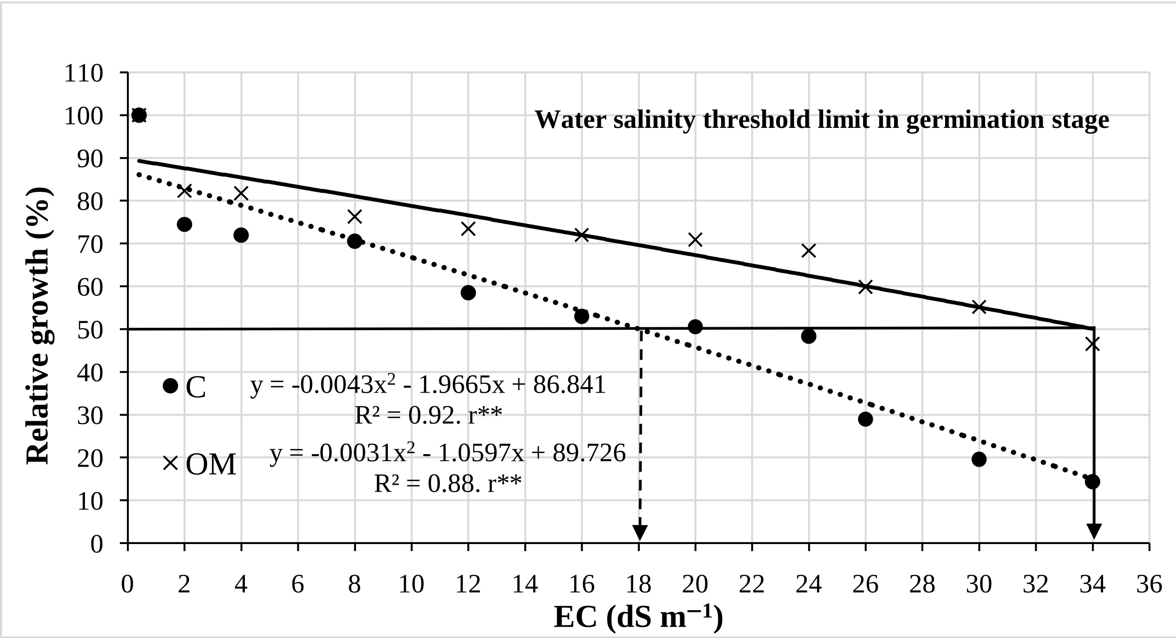

Fig. 3, Water salinity threshold limit in vegetative growth stage

The use of saline water up to 400 Mm resulted in a germination rate of 80% (Panuccio et al., 2014). Quinoa has a strong defense system against salt by secreting some antioxidant enzymes (Adolf et al., 2013). Some studies have shown that quinoa plants can resist saline irrigation water up to 40 dS/m and the plant can be irrigated by sea water (Hariadi et al., 2011; Adolf et al., 2013; Panuccio et al., 2014). Although the quinoa plants tolerated the high concentrations of salt, the high levels of water salinity caused a clear decrease in the germination rate. Similar results were reported by Stoleru et al. (2019). Increasing the salt concentrations in the plant growth media inhibited the germination due to high osmotic potential and toxic ions e. g., Na+ and Cl− (Shahzad et al., 2021). Increased osmotic pressure and toxic ions weaken the ability of the seeds to absorb water, and thus the germination process fails, and the seedlings may be exposed to drought (Causin et al., 2020; Chaganti et al., 2022).

Response of quinoa growth to organic manure under water salinity stress

Increasing the levels of water salinity significantly reduced the growth parameters of quinoa (Table 2). The maximum growth parameters i. e., shoot dry weight and plant height were found in the tap water treatment, while the lowest values were found in the highest salinity level (34 dS m^{-1}). Quinoa growth and seed yield at the end of the experiment were significantly reduced with increasing the water salinity (Table 2). Salt stress may inhibit quinoa growth due to the reduction of soil available water and low translocation of carbohydrates and nutrients from the leaves to the growing shoots (Hussain et al., 2018; Ding et al., 2022). The lower dry biomass yield may be due to the low synthesis of chlorophyll and tillers number (Gómez-Pando et al., 2010; Ali et al., 2021). Increasing level of water salinity reduced the seed yield due to reducing the f branches number of quinoa plant that are bearing the panicle that contains the seeds (Gómez-Pando et al., 2010; Hussain et al., 2020). Salt stress reduced the plant biomass and seed yield (Hussain et al. 2020). The plants of quinoa cultivated on the sandy soil amended with the organic manure were more tolerant to salt stress than that without amendments (Table 2).

TABLE 2. Effect of saline irrigation water and organic manure on quinoa growth

Water salinity (dS m^{-1})	Shoot dry weight (g/pot)		Seed weight (g/pot)		Plant height (cm)	
	C	OM	C	OM	C	OM
0.4	8.31	17.66	1.60	5.03	33.50	44.00
2	6.39	13.95	0.99	4.73	33.00	43.00
4	6.22	13.82	0.91	4.73	30.00	42.50
8	6.21	13.29	0.78	4.03	25.00	40.67
12	5.07	12.66	0.73	4.01	24.50	40.50
16	4.60	12.34	0.65	4.00	22.00	37.50
20	4.46	12.20	0.55	3.90	21.50	37.00
24	4.25	12.12	0.54	3.39	20.50	37.00
26	2.34	10.69	0.53	2.90	18.50	30.50
30	1.47	10.02	0.47	2.51	17.00	26.50
34	1.00	8.29	0.42	2.28	15.50	26.33
Mean	4.57	12.46	0.74	3.77	23.73	36.86
$L.S.D_{0.05}$ Organic matter	0.55		0.48		0.69	
$L.S.D_{0.05}$ Salinity	0.84		0.40		1.40	
$L.S.D_{0.05}$ Interaction	1.18		0.56		1.98	

C= control, OM= organic manure (20 t ha^{-1})

TABLE 3 Effect of saline irrigation water and organic manure on the seed quality

Water salinity (dS m^{-1})	Seed protein %		Seed N %		Seed P %		Seed K %	
	C	OM	C	OM	C	OM	C	OM
0.4	25.81	20.56	4.13	3.29	2.72	4.27	0.89	2.93
2	24.28	20.56	3.89	3.29	2.36	4.12	0.84	2.75
4	22.75	20.42	3.64	3.27	2.22	3.62	0.79	2.38
8	22.31	20.34	3.57	3.26	2.05	2.81	0.74	2.34
12	21.22	18.38	3.40	2.94	2.03	2.67	0.71	1.58
16	21.15	15.78	3.38	2.54	1.90	2.61	0.68	1.42
20	20.78	18.38	3.33	2.94	1.76	2.34	0.68	1.22
24	20.34	18.16	3.26	2.91	1.50	1.43	0.63	1.19
26	19.25	17.94	3.08	2.87	0.88	1.36	0.61	1.12
30	17.94	17.50	2.87	2.80	0.87	1.25	0.61	1.06
34	17.06	15.31	2.73	2.45	0.73	1.02	0.89	1.02
Mean	21.17	18.49	3.00	3.29	1.73	2.5	0.74	1.73
$L.S.D_{0.05}$ Organic matter	ns		ns		0.18		0.10	
$L.S.D_{0.05}$ Salinity	0.84		0.40		1.40		1.64	
$L.S.D_{0.05}$ Interaction	2.32		0.37		0.26		0.12	

C= control, OM= organic manure (20 t ha^{-1}).

The addition of organic manure to the sandy soil reduced the negative effects of water salinity. Organic manure increased the shoot dry weight, seed yield, and plant height by 172, 173, and 55% over the non-amended soil. The threshold water salinity in the presence of organic manure was 34 dS m^{-1}, while this value was 18 dSm^{-1} in the soil without organic amendment. Organic manure addition increased the critical point by 89%. The application of organic manure to the sandy soil significantly enhanced the growth and seed yield. Organic manure mitigated the adverse effects of saline water and improved quinoa productivity. The salt conditions affect the structure of the soil as a result of the increase of sodium ions on the soil colloids, while the addition of organic matter improves the structure, which enhances the soil aeration and provides optimal conditions to increase the root growth (Joshua et al., 1998; Ali et al., 2021). Organic manure application improved soil quality indexes e. g., physicochemical and biological properties leading to growth improvement and increasing yield and productivity (Din et al. 2020; Liu et al., 2021; Li et al., 2021). Organic manure addition to the sandy soil improved the water holding capacity allowing to reduce the hazardous effects of saline toxic irons e. g., Na+ and Cl- (Ding et al., 2020; Ali et al., 2021; Lui et al., 2021). The use of agricultural wastes as organic fertilizers improve the quality of the soils and allows the recycling of wastes that may lead to environmental pollution, which allowed sustainable development (Ali et al., 2021; Li et al., 2021). Saline conditions in soil inhibit the activity of soil microorganisms and enzymes, thus, the root environment of the plant becomes less able to provide optimal conditions for growth (Liu et al., 2021). Organic amendments mitigated the salt stress by improving the activity of soil microbes and enzymes, thus improving plant growth (Ding et al., 2020; Liu et al., 2021; Li et al., 2021).The decomposition of organic fertilizers supplies the soil with organic compounds and nutrients necessary for the activity of microorganisms, and the quality of the soil increases (Ali et al., 2021).

Effect of water salinity and organic manure on seed quality

The data in Table 3 show the effect of water salinity on the protein and nutrient content of quinoa seeds. Increasing the levels of salinity in the irrigation water significantly reduced the protein and nutrients content in the seeds. On the other hand, the addition of organic manure to the saline irrigated quinoa significantly increased the concentrations of P and K in quinoa seeds compared to the non-amended soil.Salt stress stimulates the secretion of secondary metabolites such as antioxidant enzymes and non-antioxidant compounds to scavenge harmful substances produced under the stress such e. g., reactive oxygen species (ROS) (Abeed et al., 2021; Ali et al., 2021). The salinity stress leads to an imbalance in nutritional and hormonal status in plants (Kumar et al., 2019; Yang and Guo, 2018). The plant growing under saline conditions directs most of its energy to secrete compounds that help to resist salt stress, and thus the nutrients uptake is reduced (Ali et al. 2021; Abo-Elyousr et al., 2022). Under the current study, increasing the water salinity reduced the uptake of N, P, and K by quinoa plants. These negative impacts of salt stress on nutrients uptake are also confirmed by other studies e. g., Ding et al. (2020), Li et al. (2021), Liu et al. (2021), and Abo-Elyousr et al., 2022). The results obtained proved the ability of organic matter to reduce the negative effects of salt on the growth of quinoa and to improve the absorption of nutrients, especially P and K. The addition of organic matter affects the nutrients uptake by adding nutrients to the soil after the decomposition of organic matter which increase the nutrients availability (Li et al., 2021; Liu et al., 2021). On the other hand, application of carbon-rich organic materials form complexes with essential elements that increase their availability and thus increase the ability of the plant to absorb them (Abo-Elyousr et al., 2022). The addition of organic matter improves the soil properties and increases the activity of soil enzymes, which improves the root growth and helps in absorbing the plant nutrients (Li et al., 2021; Liu et al., 2021).

Conclusion

In spread in arid and semi-arid regions there are large areas of sandy texture soils that are characterized by their lack organic matter and nutrients. The use of saline water in irrigation of plants grown in coarse soils increases the salt stress on plant growth. The addition of organic manure to the sandy soil in the current study increased the salt tolerance of quinoa plant up to 34 dS m^{-1}. The current study provides an opportunity for sustainable development in arid degraded sandy soils, as well as the use of saline water in food production. Traditional crops are not suitable for cultivation in the harsh climatic conditions that prevail in arid regions. Halophytic plants such as quinoa are suitable for these harsh climatic conditions and are suitable for food production using limited quality water resources. Quinoa is one of the halophytic plants that has promising properties to withstand many harsh environmental conditions. Several studies are required on the chemical composition of seeds under saline conditions, as well as testing the most appropriate farm management methods to maximize plant productivity when irrigated with saline water.

Conflicts of interest

There are no conflicts to declare.

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