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The Effects of Irrigation with Saline Water (Sodium Chloride) on the Growth of Spinach (*Spinachea oceloracea*. L.)

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Abstract

The global challenges of feeding the ever increasing population have brought about challenges in food production and by extension agricultural crop production such as the use of saline water for irrigation. Though this is the case the saline tolerance by crops differs, hence this study. An experiment was conducted to determine the effects of saline water irrigation on the growth and yield of spinach. The experiment had five treatments, which were irrigated water with varying concentrations of sodium chloride (NaCl), at the rate of 0 dS/m (T_0), 2 dS/m (T_1), 4 dS/m (T_2), 6 dS/m (T_3) and 8 dS/m (T_4). The treatments were laid out in a Completely Randomized Block Design (RCBD) with five replications per treatment. The effects were assessed in terms of the leaf length and width, the number of leaves per plant and the fresh and dry shoot and root mass. The results reflected that salt concentration beyond 2 dS/m had a negative effect on the growth of spinach, as spinach from T_0 and T_1 had the highest overall growth rate. An increase in the concentration of the irrigation water led to a decrease in the yield of the spinach and the size of the roots. It was concluded that that saline water with a concentrations greater than 2 dS/m had a negative effect on the growth of spinach and was therefore not suitable for irrigation purposes. It was also concluded that salinity in the irrigation water, especially beyond 2 dS/m, had a negative effect on the yield and the size of the spinach roots.

Keywords

Effects, Irrigation, Saline Water, Spinach

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1. Introduction

The earth has an abundance of water, but unfortunately, only a small percentage (about 0.3 percent), is even usable by humans. The other 99.7 percent is in the oceans, soils, icecaps, and floating in the atmosphere [10]. Still, much of the 0.3 percent that is useable is unattainable. The attainable bit is subject to pollution and other challenges such as salinization. Water salinization is a global challenge with negative impacts in agricultural crop production, where the quality of the irrigation water drives the yields expected, among many variables [5, 8, 14].

The quality of water for irrigation purposes is determined by the content of the total dissolved salt (TDS) which is a measure of the concentration of soluble salts in a water sample and is commonly referred to as the salinity of the water [13, 11, 2]. The salinity of a soil or water sample is measured using electrical conductivity (EC) with the SI unit being the deciSiemens per meter; dS/m [6]. The concentration of the TDS is directly proportional to the EC of that sample [3]. TDS can also be recorded in milligrams of dissolved solid in one liter of water (mg/L) or parts per million (ppm) which is equivalent to mg/L but is not a favoured unit [1]. The concentrations of the salts in domestic water often limit the

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spectrum of uses or application.

An increase in the salinity of water sources used for human consumption has been said to be one of the issues faced by low-income countries, but one that has not been fully investigated. It is worsened by rising sea levels due to climate change and other contributing factors. Desalination plants are utilized in some countries to partly remove salt and other minerals from water sources, but this is unlikely to be an effective long-term solution for low-income countries affected by the same problem [7, 15].

The suitable range of salinity for irrigation water is 200 – 800 mg/L of dissolved solids. Water salinity measures of up to 2,000 mg/L may be tolerated by certain plant species, given that they are planted on permeable and well-drained soils. These properties make leaching excessive salts from the root zone through the application of heavy irrigation easier [9]. It is worth noting the salinity status classification by TDS is as reflected in Table 1.

Table 1. Salinity status classification by TDS.

Salinity status	Salinity (mg/L)	Description and use
Fresh	<500	Drinking and all irrigation
Marginal	500-1000	Most irrigation, adverse effects on ecosystems become apparent
Brackish	1000-2000	Irrigation of certain crops, useful for most livestock
Saline	2000-10 000	Useful for most livestock
Highly saline	10 000-35 000	Very saline groundwater, limited use for certain livestock
Brine	>35 00	Seawater; some mining and industrial uses exist

(Mayer, *et al.*, 2005).

Though, guidelines such as Table 1 are useful for reference purposes. Low-income countries such as the Kingdom of Eswatini often face clean water challenges with negative impacts to productivity and human health. Clean water in the Kingdom of Eswatini is increasingly becoming a scarce resource [13, 16]. This is a result of a number of factors, most of which are human induced. These include climate change, water pollution and limited access to sources of clean water. It is estimated that agriculture accounts for 70% of the global water use, with the figure rising to more than 90% in arid regions. This means that there is less water available for other uses such as human and livestock consumption, hydropower generation and other industrial uses. Since there are concerns about the use of saline water for domestic and several industrial purposes, there is a need to explore the potential of using saline water for agriculture, to ensure that there is more clean water available for global human consumption now, and for years to come. It is worth noting that Understanding the interaction effects of water, fertilizer, and salinity is of great environmental importance to mitigate soil salinization and improve crop production [4], hence this study. The objectives of the study were (i) to determine the effects of saline water on the growth of spinach and (ii) to determine the effects of saline water on the yield of spinach.

2. Methodology

2.1. Research Design

The research was an experiment, with five treatments, which were irrigated water that had varying concentrations of sodium chloride (NaCl), at the rate of 0 dS/m (T_0), 2 dS/m (T_1), 4 dS/m (T_2), 6 dS/m (T_3) and 8 dS/m (T_4). The treatments were laid out in a Completely Randomized Block Design (RCBD) with five replications per treatment. The spinach was planted in plant pots to prevent the saline water seeping into the soil. To prepare the irrigation water, the conversion of units was carried out based on the conversion factors and formulas [8] by Rhoades, *et al.* [12]. To convert an EC of 2 and 4 dS/m to mg/L, 640 was used and for an EC of 6 and 8 dS/m, 800 was used.

2.2. Data Collection and Analysis

The data was collected at 3, 4, 5 and 6 weeks after transplanting. The parameters measured were the leaf lengths and widths, which were measured using a 30 cm ruler as well as the number of leaves per plant. At the end of the sixth week, which marked the end of the experiment, the plants were uprooted and the shoot fresh and dry masses as well as the root fresh and dry masses were measured using an electronic weighing scale. The shoots were first separated from the roots and the mass was measured in bundles. The shoots and roots from each treatment were all measured at once. They were first weighed for the fresh mass. The shoots and roots were then oven dried for 48 hours and then they were weighed for the dry mass. The data were analysed using Microsoft excel software, utilizing analysis of variance (ANOVA), and the least significant means were identified using the paired samples t-test on SPSS with a 5% level of significance.

3. Results and Discussion

3.1. Salinity Effects on the Spinach Leaf Length Results

The results in Table 2 reflected a trend of generally decreasing spinach leaf length with an increase in salinity concentration.

A point in case is the control (0 dS/m) which produced spinach leaf lengths of 9.06 cm, 7.28 cm, 7.16 cm, 7.02 cm and 6.05 cm at concentrations of 0 dS/m, 2 dS/m, 4 dS/m, 6 dS/m and 8 dS/m, respectively.

Table 2. Mean spinach leaf length.

Time (Weeks)	Mean Spinach Leaf Length (cm)				
	Control (0 dS/m)	T_1 (2 dS/m)	T_2 (4 dS/m)	T_3 (6 dS/m)	T_4 (8 dS/m)
3	9.06	7.28	7.16	7.02	6.05
4	10.43	10.02	8.20	8.59	7.64
5	12.48	11.27	10.07	10.71	9.05
6	12.60	11.93	10.94	11.19	9.64

The mean separation test results in Table 3 indicated that there was a significant difference ($P< 0.05$) between the lengths of the spinach leaves across the treatments. The longest leaf (19.3 cm) was obtained from T_0 (0 dS/m) at 6 weeks after transplanting (WAT) and the shortest leaf length (2.6 cm) which was obtained at a concentration of 4 dS/m (T_3) at 3 weeks after transplanting. The results reflected that the length of the spinach leaves decreased with an increase in the salt concentration.

Table 3. Paired samples test results for the effects on the leaf length.

Paired samples		Mean Difference	Standard Error	Sig. (P-value)
Pair 1	T_0	1.7085740	0.8542870	
	T_1	2.0554080	1.0277040	0.044*
Pair 2	T_0	1.7085740	0.8542870	
	T_2	1.7223893	0.8611947	0.001*
Pair 3	T_0	1.7085740	0.8542870	
	T_3	1.9355167	0.9677584	0.001*
Pair 4	T_0	1.7085740	0.8542870	
	T_4	1.6008435	0.8004218	0.000*

* Significant ($P<0.05$).

3.2. Effects of Salinity on Spinach Leaf Width Results

The results in Table 4 reflected a fluctuation in the mean widths was observed from the treatments throughout the period of data collection. The overall results indicated that there was a decrease in the widths of the spinach leaves with an increase in salinity concentration.

Table 4. Mean spinach leaf width.

Time (Weeks)	Mean Spinach leaf width (cm)				
	Control (0 dS/m)	T_1 (2 dS/m)	T_2 (4 dS/m)	T_3 (6 dS/m)	T_4 (8 dS/m)
3	4.84	4.28	4.57	4.52	3.68
4	5.42	5.53	5.06	5.20	4.55
5	5.51	5.84	5.59	5.72	5.09
6	6.22	6.59	6.03	6.04	5.65

The paired samples test results in Table 5 indicated that the mean from T_4 (8 dS/m) was significantly different ($P<0.05$) from the mean from T_0 (0 dS/m). The widest leaf (9.2 cm) was obtained from T_1 (2 dS/m) at 6 weeks after transplanting and the narrowest leaf (1.4 cm) was obtained from T_3 (6 dS/m) at 3 weeks after transplanting. The results also indicated that the mean leaf widths from T_1 (2 dS/m), T_2 (4dS/m) and T_3 (6 dS/m) were not significantly different ($P>0.05$) from the mean leaf width from T0 (0 dS/m).

Table 5. Paired samples test results for the effects on leaf width.

Paired Samples		Mean Difference	Standard Error	Sig (P-value)
Pair 1	T_0	0.5658300	0.2829100	
	T_1	0.9623900	0.4812000	0.790
Pair 2	T_0	0.5658300	0.2829100	
	T_2	0.6342647	0.3171323	0.146
Pair 3	T_0	0.5658300	0.2829100	
	T_3	0.6640281	0.3320141	0.353
Pair 4	T_0	0.5658300	0.2829100	
	T_4	0.8387000	0.4193500	0.019*

*Significant ($P<0.05$).

3.3. Salinity Effects on the Number of Spinach Leaves Results

The results in Table 6 indicated that the number of leaves fluctuated as the saline irrigation water got more concentrated. The T_2 (4 dS/m) and T_3 (6 dS/m) treatments had the highest number of leaves after T_0 (0 dS/m). This was unexpected as they both had higher saline concentrations compared to T_1 (2 dS/m), which had the second least number of leaves after T_4 (8 dS/m). Some of the leaves from T_4 (8 dS/m) had wilted, which may have contributed to the fewer leaves. This could be attributed to toxicity due to the high saline concentrations in the irrigation water.

Table 6. Mean number of spinach leaves per plant.

Time (Weeks)	Mean number of spinach leaves per plant				
	Control (0 dS/m)	T_1 (2 dS/m)	T_2 (4 dS/m)	T_3 (6 dS/m)	T_4 (8 dS/m)
3	5	4	4	4	3
4	5	4	5	5	4
5	6	4	5	5	4
6	6	5	6	5	4

The paired mean samples test results in Table 7 indicated that the mean number of leaves for treatment T_1 (2 dS/m) and treatment T_4 (8 dS/m) were significantly different ($P<0.05$) from the mean number of leaves obtained from treatment T_0 (0 dS/m). The mean number of leaves obtained from treatment T_2 (4 dS/m) and treatment T_3 (6 dS/m) were not significantly different ($P>0.05$) from the mean number of leaves obtained from treatment T_0 (0 dS/m).

Table 7. Paired samples mean test results for the effects on the number of leaves.

Paired samples		Mean Difference	Standard Error	Sig (P-value)
Pair 1	T_0	0.577	0.289	
	T_1	0.500	0.250	0.015*
Pair 2	T_0	0.577	0.289	
	T_2	0.816	0.408	0.182
Pair 3	T_0	0.577	0.289	
	T_3	0.500	0.250	0.058
Pair 4	T_0	0.577	0.289	
	T_4	0.500	0.250	0.006*

*Significant ($P<0.05$).

3.4. Salinity Effects on the Spinach Shoot Fresh Mass (S.F.M) and Shoot Dry Mass (S.D.M)

The results indicated that the fresh shoots and dry mass of spinach leaves decreased with an increase in the salinity concentration (Figure 1). Shoots from treatment T_0 (0 dS/m) weighed more than the shoots obtained from other treatments. On the other hand shoots from treatment T_4 (8 dS/m) had the lowest fresh mass (55.39 g) and dry mass (19.21 g).

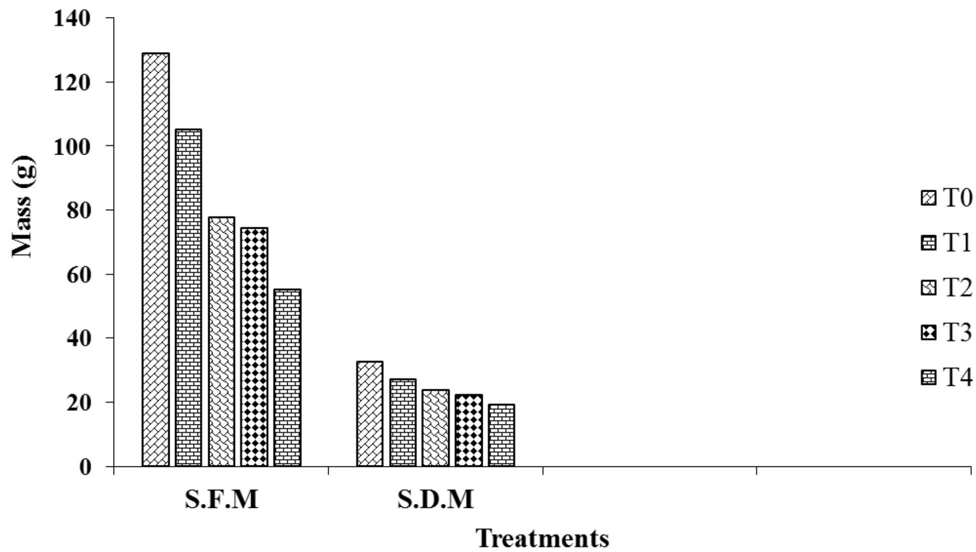

Figure 1. Spinach shoots fresh mass and dry mass.

Table 8. Spinach yield loss proportions.

Treatments	Yield Losses (%)	
	S.F.M	S.D.M
T1	18.4	16.2
T2	39.6	26.7
T3	42.2	32.6
T4	57.0	37.4

The results in Table 8 reflected that there was a reduction in the yield of spinach as the salinity concentration in the irrigation water increased. The highest yield losses for both the spinach fresh mass (S.F.M) and spinach dry mass (S.D.M) were 57% and 37.4%, respectively. These were observed on spinach shoots obtained from treatment T_4 (8 dS/m), which had the highest concentration of salt in the irrigation water. The lowest yield losses for the S.F.M (18.4%) and S.D.M (16.2%) were observed on spinach shoots obtained from treatment T_1 (2 dS/m), which had the lowest concentration of salt in the irrigation water.

3.5. Salinity Effects on the Root Fresh Mass (R.F.M) and Root Dry Mass (R.D.M)

The results reflected that there was a decrease in the R.F.M and R.D.M with an increase in the salinity of the irrigation water (Figure 2). The lowest mass observed for both R.F.M (9.62 g) and R.D.M (1.21 g), was from roots obtained from T4 (8 dS/m), which had the highest concentration of salt in the irrigation water. The highest mass observed for both R.F.M (21.57 g) and R.D.M (3.61 g) was on roots that were obtained from T_0 (0 dS/m).

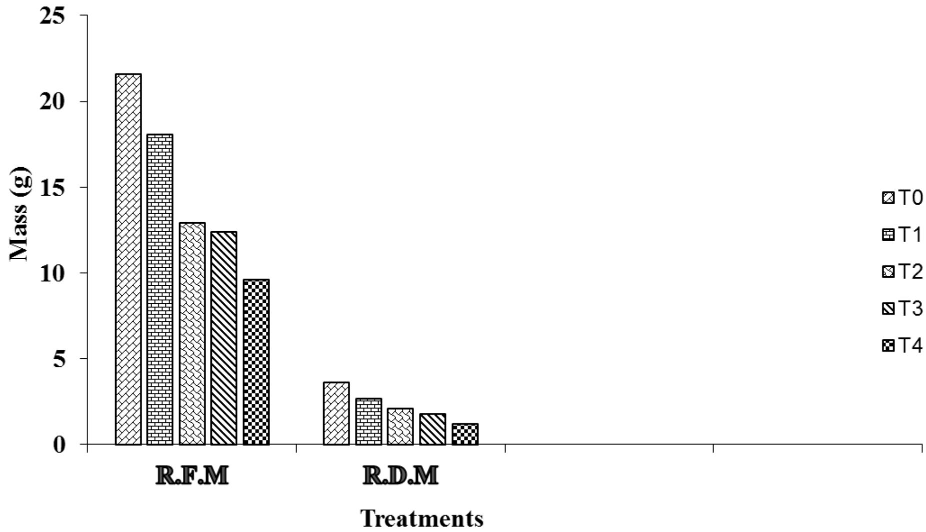

Figure 2. Spinach root fresh mass and dry mass.

4. Conclusions

The effects of saline water irrigation on the growth of spinach reflected that there was a decrease in the growth rate with an increase in the salinity of irrigation water. It was concluded that saline water with a concentration greater than 2 dS/m had a negative effect on the growth of spinach and was therefore not suitable for irrigation purposes. The effects of saline water on the spinach varied with the parameters observed. Treatment T_2 (4 dS/m) and T_3 (6 dS/m) had more leaves per plant compared to T_1 (2 dS/m). This was unexpected as they had higher salt concentrations in the irrigation water. This could be attributed to the fact that irrigation water with salt concentrations between 4 and 6 dS/m stimulates bud development, hence the number of leaves observed.

The effects of saline water on the yield of spinach indicated that the yield and size of the spinach roots decreased with an increase in the salinity of the irrigation water. It was concluded that salinity in the irrigation water, especially beyond 2 dS/m, had a negative effect on the yield and the size of the roots. The size of the roots may have influenced the plant's water and mineral uptake from the soil, hindering growth. The small roots may have been a result of the osmotic stress that the plants were experiencing due to high levels of salinity in the soil and water.

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