Response of three strawberry cultivars (*Fragaria* × *ananassa* Duch.) to different salinity levels in irrigation water

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ABSTRACT: Irrigation with saline waters is an agricultural practice that becomes increasingly common as competition for fresh water increases. In this study, three strawberry cultivars (*Fragaria* × *ananassa* Duch.) were tested for their salt tolerance. For this purpose, five salinity levels in water with electrical conductivities (EC_i) of 1.1, 1.6, 2.1, 2.5, 2.9 dS/m and river water as control (0.5 dS/m) were used in a randomised design with four replications. Percent leaf damage at two dates and accumulation of salts in soil were determined for each cultivar. Considering the results, Maraline is the most tolerant to salinity. Severe effects of salt on Muir and Tudla growth were observed even at EC_i 1.1 dS/m. The higher the level of EC_i of irrigation water, the higher the soil EC_e produced. In general, the highest soil EC_e's were produced by Muir followed by Tudla experiment.

Keywords: irrigation; saline water; strawberry; salt tolerance; electrical conductivity

In the scope of global population increase and future food production, a matter of high interest is the irrigation of areas where water is a limiting factor for crop production. However, one of the major undesirable environmental effects of irrigated agriculture is the accumulation of salts (salinisation) in the root zone (TANJI 1990). Salinity has pronounced effects on growth of plants because the plant must redirect energy from growing to extracting pure water from the saline water in the root zone. This occurs because increased salt in the soil solution reduces the availability of soil water to plants and can result in a physiological drought condition. The most distinct signs of injury from salinity are reduced crop growth and loss of yield. In extreme cases, water can actually be drawn out of the plant due to osmotic pressure, resulting in dehydration and death (MAAS 1990).

Plant breeding and selection for salinity tolerance have been undertaken to any appreciable extent for only two decades. Initial results are promising and have stimulated new research in genetic salt tolerance, particularly among closely related varieties or strains within a variety. Plant species, and even different varieties within a particular species, differ greatly in their response and tolerance to salinity. The success in plant breeding and gene selection for salinity tolerance studies may greatly expand the ability to use more saline water supplies (AYERS, WESTCOT 1985; MAAS 1990).

The relative salt tolerance of most agricultural crops is known well enough to give general salt tolerance guidelines. Strawberry (*Fragaria* × *ananassa* Duch.) is considered to be a crop that is very sensitive to salinity (MAAS, HOFFMAN 1977; MAAS 1990). It has already been shown that for strawberry the threshold EC value in a soil saturation extract (EC_e) is 1 dS/m (MAAS, HOFFMAN 1977) whereas this value in water (EC_i) is 0.7 dS/m (AYERS, WESTCOT 1985). However, it is important to note that, for a given crop, the relative tolerance to salinity may vary greatly from variety to variety (CHAHABRA 1996; LAUCHLI, EPSTEIN 1990).

As competition for fresh water increases, one of the challenges for today is to maintain or even increase crop production with less water that may often be of low quality (RHOADES et al. 1992). This study was aimed at evaluation of the tolerance of three strawberry cultivars to irrigation water showing different salinity levels.

MATERIALS AND METHODS

To evaluate the response of three strawberry cultivars, Maraline, Muir and Tudla, to different salinity levels in irrigation water, three successive experiments were carried out in the substrate prepared as a mixture of soil and peat, in 14-cm diameter polyethylene pots, one plant per pot. The experiments were set up in a randomised design with four replications per treatment. The soil used for the experiments was clay loam with an average EC_e of 1.87 dS/m, pH of 8.0 and the Sodium Adsorption Ratio (SAR) of 0.05. The concentrations of sodium (Na) and calcium + magnesium (Ca + Mg) present in saturated extracts were 0.17 and 20.7 meq/l, respectively.

Transplants, uniform in appearance, were planted into the pots on 22 March. Until the plants established, they were irrigated with river water that was used as control treatment. After establishment of plants (1.5 months after transplanting), saline water treatments were started on 5 April, and continued until the end of growth, according to the technique of continuous exposure to salts. Water was applied carefully depending on the plant's need, generally once a week, with an average amount of 250 ml per plant given per one watering. In addition to control treatment (S_C), five irrigation waters with different EC_i levels were used. Although, the EC_i's of 1.0, 1.5, 2.0, 2.5 and 3.0 dS/m were intended, the real average EC_i levels were 1.1 (S_1), 1.6 (S_2), 2.1 (S_3), 2.5 (S_4) and 2.9 (S_5) at the end of study for each cultivar (Table 1). During the preparation of saline waters, it was aimed to hold the SAR values around 0.9, which is the SAR value of the control, in order to eliminate the effects of SAR. For this purpose, different ratios of $NaHCO_3$, $CaCl_2$ and $MgCl_2$ were mixed to prepare targeted saline irrigation waters for each treatment. A total 2.25 l of water for each plant was used in nine waterings. A composite sample was taken during each watering to plants. These samples were analysed for EC_i, pH, Na and Ca + Mg by using a salinity appraisal laboratory set (Hach Salinity Kit). The average water quality values including EC_i, pH, Na, Ca + Mg and SAR are presented in Table 1.

Table 1. Chemical characteristics of irrigation water

Treatment	EC_i (dS/m)	pH	Na (meq/l)	Ca + Mg (meq/l)	SAR
S_C	0.5	8.0	1.1	3.2	0.9
S_1	1.1	7.7	2.1	10.1	0.9
S_2	1.6	7.6	2.7	15.8	1.0
S_3	2.1	7.6	3.1	20.7	1.0
S_4	2.5	7.5	3.6	25.7	1.0
S_5	2.9	7.4	4.0	30.0	1.0

At the transplanting stage and just before saline treatments were initiated, a total of 20 g of fertiliser, a mixture of ammonium sulphate ($[NH_4]_2SO_4$), triple superphosphate (TSP) and potassium sulphate (K_2SO_4) with the ratio of 1:1:2, respectively, was added to each pot, following the instruction of Handcock (1999). The experiments were terminated on 3 July (2 months after plant establishment). In order to determine and evaluate the accumulation of salt in the soil used for each cultivar, soil samples were taken from each replication of the treatments at the end of the experiments. For the soil samples, saturated paste extracts were prepared and analysed for EC, pH and Na. In addition to soil samples, % leaf damage (percent of damaged leaves – in relation to total leaf number per plant) for each treatment and cultivar was calculated. For this purpose, the number of total leaves and damaged leaves was counted at two different stages, 29 (first observation) and 59 (final observation) days after saline treatments were initiated.

All statistical analyses were performed using Statistical Analysis System (SAS, 1999). The General Linear Models (GLM) procedure was used to perform analysis of variance. Tukey test was used to separate means for the data. Unless otherwise noted, all statistical tests were performed at the 0.05 level of significance.

RESULTS AND DISCUSSION

Salinity effects on leaf damage

The experimental plants displayed optimum growth before the salinisation commenced. When the first death of a whole plant was observed in the S_5 treatment, the first count of leaves in each plant was accomplished. It was 29 days after the beginning of salinity treatments. In general, irrigation with water having higher EC_i levels (S_3, S_4 and S_5) resulted in death of plants, especially in the cultivar Tudla followed by Muir at the final observation.

Soil characteristics and percentage of leaf damage at different treatments, for each cultivar, are presented in Table 2. In general, the percentage of leaf damage in each cultivar, either at the first or at the final date of observation, increased with the increased EC level of applied irrigation water. At the

Table 2. Soil characteristics and percentage of leaf damage of three different cultivars, depending on irrigation water

Treatment	EC_e (dS/m)	pH	Na (meq/l)	% leaf damage (first observation)	% leaf damage (final observation)
			Experiment 1 (Maraline)		
S_C	4.74 [A]d [B]	7.89	2.83 d	16 c	21 c
S_1	5.49 cd	7.89	4.00 c	29 bc	31 c
S_2	6.80 bcd	7.88	4.50 bc	26 bc	40 bc
S_3	8.09 abc	7.88	5.62 ab	55 ab	70 ab
S_4	8.62 ab	7.88	6.05 a	62 a	74 ab
S_5	8.90 a	7.87	5.83 a	75 a	77 a
P > F	**	NS	**	**	**
MSD	2.14	–	1.16	31	35
			Experiment 2 (Muir)		
S_C	7.11 d	7.88	2.92 d	6 d	25 b
S_1	8.74 c	7.88	4.94 c	24 cd	62 ab
S_2	9.24 c	7.88	4.98 c	41 bcd	58 ab
S_3	10.06 bc	7.87	6.11 b	53 abc	75 a
S_4	11.36 ab	7.87	7.77 a	66 ab	80 a
S_5	12.00 a	7.86	8.21 a	92 a	92 a
P > F	**	NS	**	**	**
MSD	1.41	–	1.12	41	44
			Experiment 3 (Tudla)		
S_C	7.28 b	7.91	3.31 b	15 b	30 b
S_1	8.50 ab	7.87	4.21 ab	69 a	72 a
S_2	8.51 ab	7.86	4.72 ab	75 a	82 a
S_3	9.64 ab	7.86	4.79 a	74 a	88 a
S_4	9.89 a	7.86	5.20 a	83 a	92 a
S_5	10.57 a	7.85	5.35 a	95 a	95 a
P > F	*	NS	*	**	**
MSD	2.59	–	1.41	27	33

For Table 2 and 3:
[A]each value is the mean of four replications, [B]within columns, means followed by the same letter are not statistically different according to Tukey test value of MSD (0.05), *, **significant at the 0.05 and 0.01 probability levels, respectively, NS – non-significant

first observation, with the control irrigation water only 16, 6 and 15% of leaf damage were recorded, whereas water with the highest EC level (S_5) caused 75, 92 and 95% leaf injury in Maraline, Muir and Tudla, respectively. The leaf damage occurring in control treatments was probably due to a high EC_e value of initial soils (1.87 dS/m) rather than to the EC_i value of river water (0.5 dS/m). Similarly, at the final observation, the percentages of leaf damage were 21, 25 and 30 for the control and 77, 92 and 95 for the S_5 treatment.

For both Maraline and Muir, the percentage of leaf damage in the S_2 treatment at the first and final observation was not significantly different from those in the S_1 and control, whereas S_3, S_4 and S_5 treatments were significantly different from those of the control treatments at a 0.01 probability level. In Tudla, leaf damage in the control treatment was significantly different from that in the other treatments at the first and final observation. Considering Tukey's minimum significant difference (MSD) values and mean separation presented in Table 2, it may be concluded that the detrimental effects of EC levels in water start around 1.6 dS/m for Maraline, whereas severe damage in Tudla was observed even with lower EC_i level (in the treatment S_1).

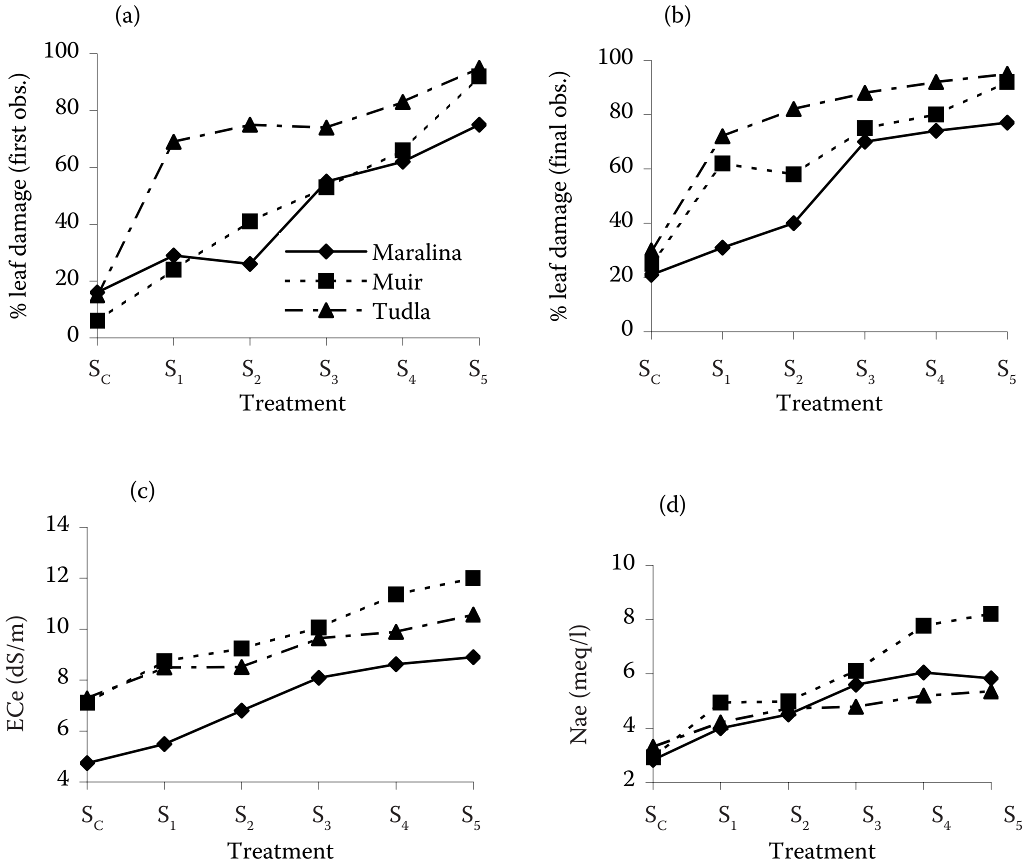

Fig. 1. Effects of irrigation water with different EC_i's on: (a) soil EC_e, (b) soil Na_e, (c) % leaf damage (first observation), (d) % leaf damage (final observation)

For comparison of the cultivars, effects of salinity treatments on % leaf damage are shown in Fig. 1a at the first and Fig. 1b at the last date of observation. The results of statistical analysis are also presented in Table 3 to compare the % leaf damage caused by salinity in different cultivars. Visual inspection of these figures and results contained in Table 3 leads to the following conclusions: (1) percentage of leaf damage increased with the increased EC level of irrigation water in all cultivars under study; (2) among the three cultivars, Maraline is the most resistant cultivar to salinity up to an EC level of 1.6 dS/m; (3) even though the percentage of leaf damage at

Table 3. Comparison of leaf damage to three different strawberry cultivars, resulting from the use of irrigation water with different levels of salinity

Cultivar	Irrigation water treatment					
	S_c	S_1	S_2	S_3	S_4	S_5
% leaf damage (first observation)						
Maraline	16[A]	29	26 b[B]	55	62	75
Muir	6	24	41 b	53	66	92
Tudla	15	69	75 a	74	83	95
P > F	NS	NS	*	NS	NS	NS
MSD	–		26	–	–	–
% leaf damage (final observation)						
Maraline	21	31 B	40 b	70	74	77
Muir	25	62 Ab	58 ab	75	80	92
Tudla	30	72 A	82 a	88	92	95
P > F	NS	*	*	NS	NS	NS
MSD	–	39	36	–	–	–

Table 4. Mean soil EC_e and Na values of three different cultivars, depending on irrigation water

Cultivar	Irrigation water treatment					
	S_c	S_1	S_2	S_3	S_4	S_5
EC_e (dS/m)						
Maraline	4.74	5.49	6.80	8.09	8.62	8.90
Muir	7.11	8.74	9.24	10.06	11.36	12.00
Tudla	7.28	8.50	8.51	9.64	9.89	10.57
Mean	6.38	7.57	8.18	9.26	9.95	10.49
Na_e (meq/l)						
Maraline	2.83	4.00	4.50	5.62	6.05	5.83
Muir	2.92	4.94	4.98	6.11	7.77	8.21
Tudla	3.31	4.21	4.72	4.79	5.20	5.35
Mean	3.02	4.38	4.73	5.50	6.34	6.46

both observations was the lowest in Maraline, there were no significant differences between cultivars within the treatments, except for S_1 and S_2. In these two treatments, Tudla's damage was significantly different from that of Maraline or Muir at the first (only for S_2 treatment) and from Maraline at the final observation (for both S_1 and S_2 treatments); (4) even in the S_1 treatment, the leaf damage was higher than 60% in Tudla and Muir at the final observation; (5) Tudla, the least resistant cultivar, showed an immediate response to the salinity between that of Maraline or Muir; (6) the severe effects of salinity in Maraline started from the concentration present in the S_2 treatment.

Salinity effects on soil

Table 2 presents EC_e, pH and Na values of the analysed soil. Soil EC_e measurements for the samples after saline water application showed that there was an accumulation of salts in soil used for the experiment. For soil EC_e values, the control treatment was significantly different from the S_4 and S_5 treatments for all cultivars. There were no significant differences between the treatments in terms of soil pH values. The mean pH value averaged over all treatments was 7.88 for Maraline, and 7.87 for Muir and Tudla experiments. Similarly to the soil EC_e, soil Na contents for all treatments were significantly different from the control treatment (except for S_1 and S_2 in the Tudla soil).

The mean soil EC_e values averaged over all experiments were 6.38, 7.57, 8.18, 9.26, 9.95 and 10.49 dS/m for the control, S_1, S_2, S_3, S_4 and S_5, respectively (Table 4). The approximate relationship between the electrical conductivity of irrigation water (EC_i) and soil salinity is $EC_e = 1.5\ EC_i$, if about 15% of the applied water is drained from the crop root zone (Ayers, Westcot 1985). However, EC_e values averaged over all cultivars (Table 4) were 3.62 (for S_5) to 6.88 (for S_1) times higher than EC_i in the S_5 and S_1 treatments. The reason for the high accumulation of salts in the soil, compared to the salt contained in the irrigation water, is probably the lack of leaching and high evapotranspiration.

Effects of salinity treatments on soil EC_e level and Na content are also presented in Fig. 1c for the first and in Fig. 1d for the last observation. Among the soils of three cultivars, the Maraline soil had the lowest EC_e for all treatments, whereas, in general, the highest EC_e and Na salt accumulation in soil were observed for the Muir experiment.

CONCLUSIONS

Muir and Tudla cultivars are more sensitive to salts in irrigation water than Maraline. Even though all cultivars can tolerate higher soil EC_e, Maraline is the only one that can tolerate higher EC_i than those given as the maximum for the appearance of symptoms and the survival of plants by Maas and Hoffman (1977). Sodium bicarbonate caused immediate damage to the plants of Tudla even at the low EC_i levels, whereas only at the end of the growth period it caused severe symptoms on leaves appearing in plants of Maraline and Muir. The higher the EC_i of applied irrigation water, the higher the soil EC_e produced.

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Reakce tří kultivarů jahodníku (*Fragaria* × *ananassa* Duch.) na různý stupeň zasolení závlahové vody

ABSTRAKT: Závlaha slanou vodou se v zemědělství stává stále běžnější, protože se zvyšuje nedostatek sladké vody. V práci jsme testovali tři kultivary jahodníku (*Fragaria* × *ananassa* Duch.) z hlediska jejich tolerance vůči obsahu solí. K tomuto účelu jsme v pokusu s náhodným uspořádáním se čtyřmi opakováními použili pět stupňů zasolení vody charakterizovaných elektrickou vodivostí (EC_i) 1,1; 1,6; 2,1; 2,5; 2,9 dS/m a říční vodu jako kontrolu (0,5 dS/m). U každého kultivaru jsme ve dvou termínech vyhodnotili procentuální poškození listů a akumulaci solí v půdě. Výsledky ukázaly, že slanost půdy nejlépe snášel kultivar Maraline. Silné účinky soli na kultivary Muir a Tudla jsme zjistili již při hodnotě vodivosti EC_i 1,1 dS/m. Čím vyšší hladinu vodivosti EC_i závlahové vody jsme použili, tím vyšší byla vodivost EC_e půdy. Všeobecně nejvyšší hodnoty půdní vodivosti EC_e byly zjištěny u kultivaru Muir, následovaného kultivarem Tudla.

Klíčová slova: závlaha; zasolená voda; jahodník; tolerance vůči obsahu solí; elektrická vodivost

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