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Influence of NaCl Salinity and Different Substracts on Plant Growth, Mineral Nutrient Assimilation and Fruit Yield of Strawberry

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Abstract

A hydroponic culture was carried out with strawberry cv. 'Camarosa' to investigate the effects of four salinity levels and four different substrates on plant growth, mineral nutrient assimilation and fruit yield of strawberry. Total dry weight accumulation of plants was not inhibited at low salinities, but it was significantly inhibited at 60 mM NaCl. Dry mass (DM) partitioning in NaCl-stressed plants was in favor of crown and petioles and at the expense of root, stem and leaf, whereas leaf, stem and root DM progressively declined with an increase in salinity. Specific leaf area (SLA) and leaf area ratio (LAR) significantly decreased in cv. 'Camarosa' at 60 and 90 mM. Results also showed that the presence of NaCl in the root medium induced an increase in total Na^+ content of the plants in the shoot and root. Despite Na^+ and K^+, the increase in total inorganic ions resulted from increasing salinity, with Ca^{2+} and Mg^{2+} concentrations decreasing in shoot and increasing in roots with an increase in salinity. For all micro- and macroelements however, significant concentration changes related to different substrates were not detected in the present experiments. Results also showed a significant decline of Fe content of 40% and 49% in shoot and root, respectively.

Keywords: coco peat, dry matter partitioning, ion relation,water content

Introduction

Salinity is one of the major environmental factors limiting plant growth and productivity (Flowers *et al.,* 1997). The detrimental effects of high salinity on plants can be observed at the whole-plant level as the death of plants and/or decreases in productivity. Many plants develop mechanisms either to exclude salt from their cells or to tolerate its presence within the cells (Greenway and Munns, 1980). The earliest response is a reduction in the rate of leaf surface expansion, followed by a cessation of expansion as the stress intensifies. Most commonly, high Na^+ and Cl^- cause the salt stress. Salt stress has a threefold effect; it reduces water potential, causes ion imbalance or disturbances in ion homeostasis, and toxicity. This altered water status leads to initial growth reduction and limitation of plant productivity. Since salt stress involves both osmotic and ionic stress (Hageman and Murata, 2003; Hayashi and Murata, 1998), growth suppression is directly related to total concentration of soluble salts or osmotic potential of soil water (Tabatabaei *et al.,* 2008; Greenway and Munns, 1980). Salt stress affects all the major processes such as growth, photosynthesis, protein synthesis, and energy and lipid metabolism. Elevated NaCl levels in the root medium reduce mineral nutrient assimilation, especially of K^+ and Ca^{2+}, resulting in ion imbalances of K^+, Ca^{2+}, and Mg^{2+} compared to Na^+ (Gabr, 1999; Khan *et al.,* 2000a, b;), as well as in negative effects on enzymes and membranes. This results, for example, in an inefficient generation of ATP, an impaired assimilation of nitrogen and in an atypical protein metabolism (Alam, 1999; Brady *et al.,* 1984; Mansour, 2000). Strawberry is considered as a NaCl salinity sensitive species, but differences between cvs. exist (Kaya *et al.,* 2002; Keutgen and Pawelzik, 2009). Selection of the best substrate for hydroponic strawberry producers with different water quality is one of the most important problems in Iran. Negative influences of NaCl salinity on strawberry plant growth and fruit productivity have been reported by Awang and Atherton (1995a, b), Awang *et al.* (1993), D'Anna *et al.* (2003), Keutgen and Pawelzik (2009). The salt stress results in the development of leaf necrosis and accelerated leaf senescence, thus reducing photosynthetic capability of the plants. In consequence, assimilation of carbohydrates available for fruit production is reduced (Giuffrida *et al.,* 2001; Keutgen and Keutgen, 2003; Saied *et al.,* 2005). Little information on the distribution of macronutrients and micronutrients and fruit yield of strawberry plants in different substrate under NaCl salinity has been published, and there is little information about strawberry growth and fruit yield in different salinity and substrate (Awang and Atherton, 1994; Keutgen and Pawelzik, 2009; Turhan and Eris, 2004).

The present study aimed to investigate the influence of NaCl salinity under different substrates on the distribution

of dry matter, fruit yield, macronutrients and micronutrients in the plant organs of strawberry cv. 'Camarosa'. The hypothesis tested was whether a relative tolerance may be due to different substrates. Moreover, it was investigated whether a relatively higher salt-tolerance was related with the ability to retain higher concentrations of Na^+ in the roots and whether this capacity interfered with macronutrient uptake by roots. Because NaCl salinity impairs leaf metabolism in sensitive species, photosynthesis is reduced and carbohydrate production is limited. This should result in a lower strawberry fruit yield.

Materials and methods

Plant material and growth conditions

Experiments were conducted from the end of October to the mid of June during 2009 and 2010 in Rafsanjan, Iran, with strawberry (*Fragaria ananassa* cv 'Camarosa'). Cold stored strawberry plants with a well-developed crown of 8-10 mm diameter were established in mid-November to mid-June during 2009 and 2010 in 15 liters black plastic bags and fixed under an open hydroponics system. Day/night temperature ranged between 23-28/14-18°C. The bags were watered two or three times a day depending on greenhouse temperature by mineral nutrients with 200 mL per plant of modified Hoagland solution (Tab. 1) with a complete set of nutrients and a pH adjusted to 6.5 using nitric and sulfuric acids. Three weeks after planting, NaCl treatments were initiated with 200 mL of the solutions containing 0, 30, 60 or 90 mM NaCl seven times a week to each plant. The EC and pH of drainage water from pots were checked every week, and an additional 200 mL of distilled was applied to minimize EC and pH changes in the root zone. Four different substrates including 100% Coco peat (M1), 100% Coco chip (M2), 70% Coco chip + 30% Perlite (M3) and 70% Coco peat + 30% Perlite (M4) with four salinity levels of 0, 30, 60 90 mM NaCl (equal to 1.7, 3.5, 5 and 7.4 $dS.m^{-1}$) were used in four replications. The salinity treatments plus different substrates was arranged in a completely randomized design with 3 replicates per treatment and 12 plants per unit in the experiment. Surpluses of solutions were allowed to pass the containers to ensure NaCl stress in the root medium at a given concentration, but to avoid anoxia by water logging. Varying osmotic potentials in the root medium temporarily may facilitate water uptake and, hence, strengthen the effect of NaCl stress while reducing those of water stress, thus allowing focus on the salt-specific impacts. To improve fruit quality, runners were removed at emergence. Fruits were harvested at the optimum stage of physiological maturity, when 90% of the fruit surface had reached a fully red color. At the end of each experiment, 5 plants were randomly collected from each treatment to measure the fresh mass (FM) and dry mass (DM) of leaves, petioles, crowns and roots. The number of flowers and fruits per plant was recorded weekly from the appearance of the first flower until the end of the experiments. At the end of the experiment, all plants from each treatment were sampled to measure leaf area and weight. The leaf area was measured using a leaf area-meter (Li-Cor, Moldel Li- 1300, USA) by the subtraction of necrotic leaf area from total area of the leaf.

Plant growth

According to Chen *et al.* (1997), leaf area ratio (LAR) was defined as the amount of leaf area per unit of plant dry mass. The specific leaf area (SLA) is the amount of leaf area per unit of leaf dry mass. Net assimilation rate (NAR) of the plants was calculated as the net increment in plant dry mass per unit of mean leaf area during the experiment. Relative growth rate of plants (RGR) was calculated by multiplying LAR and NAR. Fruit fresh weight per plant, fruit number per plant, and individual fruit fresh weight were calculated.

Analyses of macro and micro nutrition contents

Oven-dried materials of both shoot and root of each replication were used. Dried samples (0.5 g) of each replication were ground and ashed at 550°C in a porcelain crucible for 6 h, separately. The white ash was taken up in 2 M hot HCl, filtered into a 50 mL volumetric flask, and finally made up to 50 mL with distilled water. Na^+ and K^+ were determined by flame photometer (Model: PEP, Germany). Calcium and Mg^{2+}, Fe, Mn, Zn and Cu were analyzed with atomic absorption spectrophotometer (GBC Avanta ver.1.33).

Statistic

Experimental data were analyzed with the SAS 9.1 statistical program. All data sets were tested for a normal distribution and the variance homogeneity ($P < 0.05$). In case of homogeneous sample variances, means were compared by Duncan tests.

Tab. 1. Composition of modified Hoagland solution (pH 6.5) for soilless culture of plant

	$mg.L^{-1}$		$mg.L^{1}$
Ca	150	$CuSO_4, 5H_2O$	0.07
Mg	50	N	180
K	270	PO_4	65
Fe	5	SO_4	67
$MnSO_4, 4H_2O$	1	$(NH_4)6MoO_{24}, 6H_2O$	0.06
$ZnSO_4, 7H_2O$	0.2	B	0.08

Results

Plant growth and water content of organs

A two-way ANOVA showed a significant individual effect of salinity and substrate and their interaction on total leaf area of strawberry cv. 'Camarosa' (Fig. 1). Among

Tab. 2. Fruit yield and growth parameters of strawberry cv. 'Camarosa' as affected by NaCl salinity and different substrate (M)

RGR ($g.kg^{-1}.day^{-1}$)	NAR ($g.m^{-2}.day^{-1}$)	LAR ($M^2.kg^{-1}$)	SLA ($m^2.kg^{-1}$)	Root volume (mm)	Total dry weight (g/plant)	Fruit yield (g/plant)	NaCl mM
0.84±0.09	2.9±0.28	6.3±0.44	17.6±1.9	9.4±1.09	18.8±1.6	303±25.2	0
0.79±0.05	1.7±0.16	5.1±0.34	15.5±0.5	11.2±1.3	15.9±1.1	220±27.7	30
1.2±0.15	1.4±0.1	4.5±0.45	14.8±1	9.2±1	9.7±0.65	176±18.2	60
0.84±0.08	1±0.12	4.1±0.36	12.3±0.9	10.5±0.88	5.1±0.39	167±18.2	90
RGR ($g.kg^{-1}.day^{-1}$)	NAR ($g.m^{-2}.day^{-1}$)	LAR ($M^2.kg^{-1}$)	SLA ($m^2.kg^{-1}$)	Root volume (mm)	Total dry weight (g/plant)	Fruit yield (g/plant)	Substrate
0.84±0.08	1.7±0.21	5.1±0.41	14.8±1	9.9±1.2	14.6±1.3	236±31.4	M1
0.94±0.12	1.6±0.21	5.3±0.58	16.1±1.1	8±0.95	12.4±1.1	190±27.3	M2
0.96±0.11	1.7±0.31	5.5±0.35	15.1±1	12.6±0.86	12.9±0.9	189±22.2	M3
0.98±0.13	1.9±0.35	5±0.39	14.1±0.8	9.7±0.95	16.2±1.4	250±32.5	M4

All data indicated Mean ± SE (n=12)

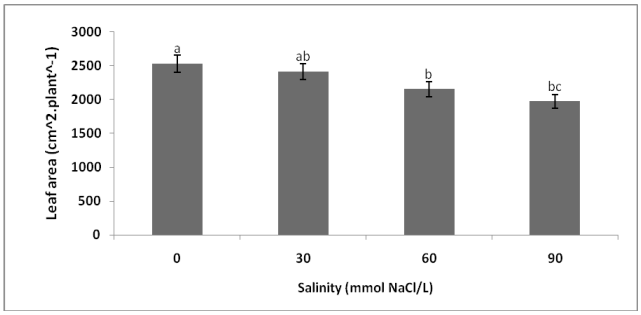

Fig. 1. Influence of NaCl stress on leaf area of strawberry cv. 'Camarosa'. Different letters indicate significances by Duncan tests at $p<0.05$. Bars in each column indicate mean ± SE (n=12)

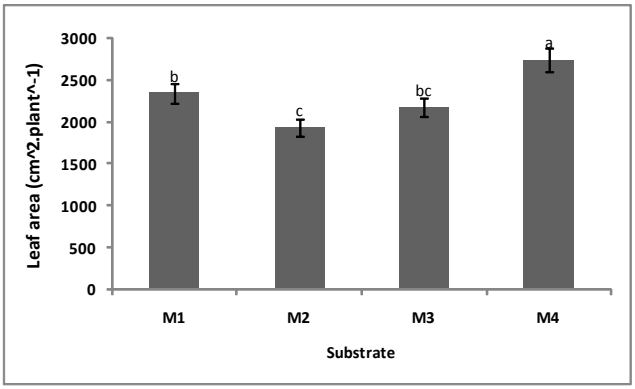

Fig. 2. Influence of different substrate on leaf area of strawberry cv. 'Camarosa'. Different letters indicate significances by Duncan tests at $p<0.05$. Bars in each column indicate mean ± SE (n=12)

the different substrates, the highest leaf area was found in M4 (70% Coco peat+30% Perlite) (Fig. 2). Total dry weight accumulation of plants was not inhibited at low salinities, but it was significantly inhibited at 60 mM NaCl. The highest dry weight was found in substrate M4 and the lowest in substrate M2 (Coco peat 100%) (Tab. 2). Type of substrate significantly affected other organ DMs of plants (Tab. 2). With the exception of stem DM, the highest DM in all organs found with substrate M4 followed by M1 (Fig. 2). Root volume was only affected by substrate which was the highest in substrate M3 (Tab. 2). With the exception of crowns, the presence of NaCl in the rhizosphere significantly reduced leaf area and DM of plant organs (Tab. 2). The number of dead leaves rose significantly due to salinity in this cultivar (data not shown). Typical symptoms of excessive Na^+ and Cl^-, resulting from a high level of these toxic ions in the root medium appeared in leaves. Young and nearly completely expanded leaves were characterized by a bowl-shaped appearance typical of Na^+ stress, while old leaves showed red to brown necrosis at the leaf margin starting with tip burning, which expanded towards the leaf center during ageing. In the final case, the necroses covered the entire blade surface and leaves died at the highest Na^+ and Cl^- concentrations in the root medium.

The most reduced DM organ in this plant was by 62% for stem DM per plant following by Leaf leaf and root DM at 45% and 48%, respectively. The least DM effect was observed for petiole DM (Fig. 3). Total DM per plant was reduced by 63% at 90 mM NaCl. The root to shoot ratio of DM did not change under NaCl salinity and different substrate and their interaction, while NaCl stress significantly decreased root, leaf and stem DM (Fig. 3). In consequence, dry mass partitioning in NaCl-stressed plants was in favor of crown and petioles and at the expense of root, stem and leaf, whereas leaf, stem and root DM progressively declined with an increase in salinity (Fig. 4). A two-way ANOVA showed that only salinity affected SLA, LAR, NAR and RGR (Tab. 2). SLA and LAR significantly decreased at 60 and 90 mM NaCl (Tab. 2). Thus, this cultivar of strawberry developed leaf thickness with increasing salinity while leaf area per plant significantly decreased by increasing salinity (Fig. 1). The RGR of shoots was calculated at the flowering stage to determine the alteration of strawberry growth. NAR and RGR progressively declined with an increase in salinity (Tab. 2). In general, Plant growth was depressed by NaCl in the medium. Reduction of dry mass was most distinct for leaves, shoots, and roots. Shoot/root ratios was not influenced by salinity

Tab. 3. Impact of NaCl stress on macro and micronutrition content (mg.g^{-1}.DM) of strawberry cv. 'Camarosa' in shoots and roots.

Fe	Mn	Zn	CU	Ca	Mg	K/Na	K	Na	NaCl mM
				Shoot					
0.023±0.02	0.38±0.13	0.13±0.03	0.05±0.008	8.8±1.4	3.7±0.22	8.1±3.1	24.9±4.4	3.1±0.6	0
0.022±0.01	0.45±0.19	0.15±0.1	0.05±0.008	8.6±1.1	3.9±0.11	6.8±5.5	23.4±4.5	3.4±1.2	30
0.019±0.01	0.41±0.12	0.13±0.1	0.05±0.009	7.2±1.6	3.5±0.15	3.1±1.4	15.7±2.1	5.1±1.2	60
0.010±0.01	0.49±0.12	0.14±0.09	0.04±0.01	7.6±1.8	3±0.31	1.9±1.7	12.2±1.7	6.4±1.5	90
				Root					
0.12±0.04	0.077±0.06	0.010±0.01	0.020±0.003	1.8±0.54	0.9±0.38	5.4±1.63	31.1±4.1	3.2±0.6	0
0.11±0.06	0.087±0.08	0.032±0.07	0.020±0.004	2.3±0.34	1.1±0.28	4.1±1.5	27.4±3.9	4.7±1.4	30
0.09±0.04	0.089±0.05	0.027±0.06	0.018±0.005	2.7±0.69	0.9±0.33	3.2±0.76	18.3±2	5.8±1.7	60
0.07±0.07	0.074±0.04	0.027±0.06	0.017±0.004	2.8±0.71	1.1±0.28	2.3±0.75	13.8±1.5	6.8±2.3	90

All data indicated Mean ± SE (n=12)

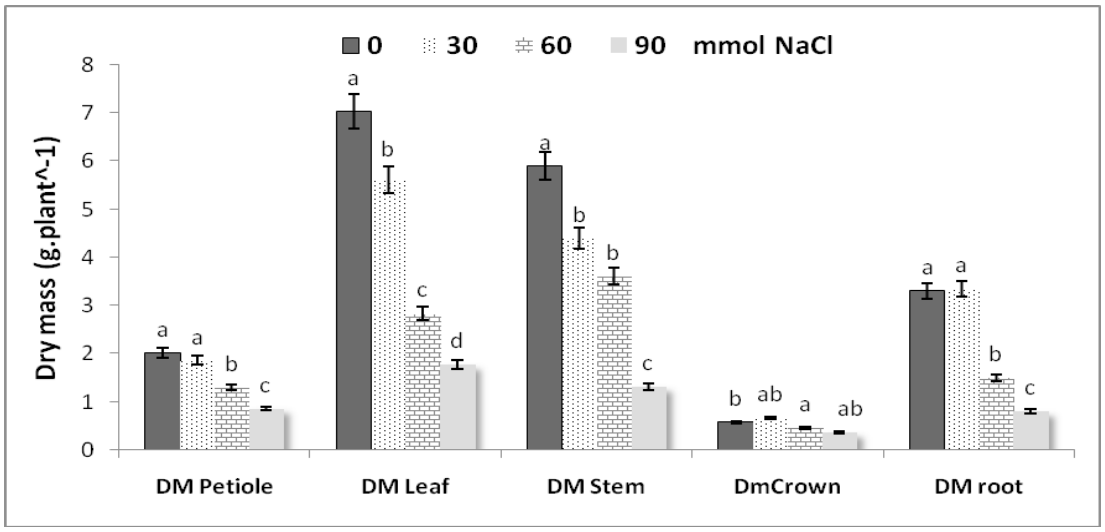

Fig. 3. Influence of NaCl stress on dry mass content (g.plant^{-1}) of strawberry organs. Different letters indicate significances by Duncan tests at p<0.05. Bars in each column indicate mean ± SE (n=12)

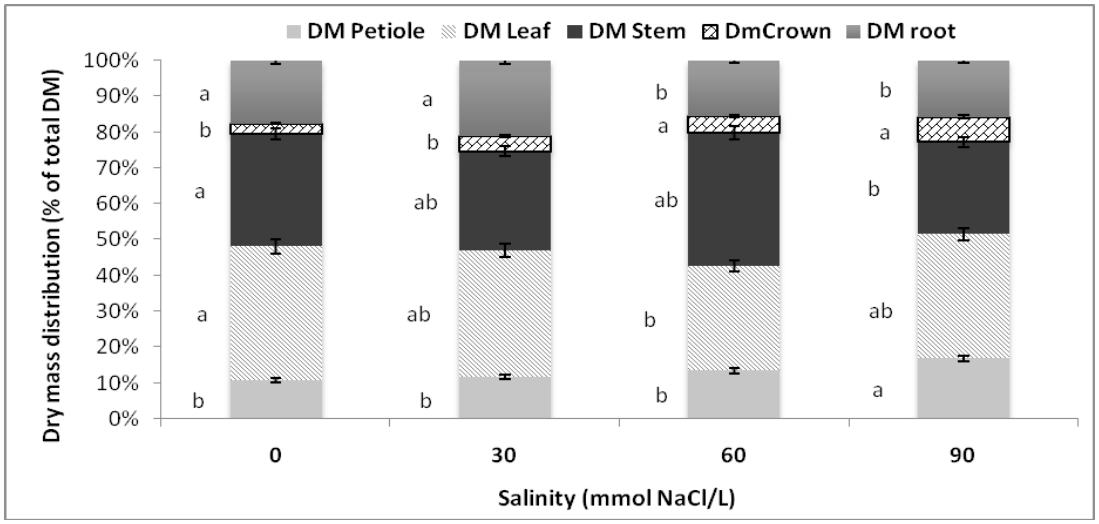

Fig. 4. Influence of NaCl stress on dry mass distribution (% of total DM) of strawberry organs. Different letters indicate significances by Duncan tests at p<0.05. Bars in each column indicate mean ± SE (n=12)

(Unpublished data). Control plants had more leaves per plant while stressed plants had less leaf area with greater thickness. Water content of plant organs was significantly influenced by the NaCl level in the root medium, while the water content of roots, stem, crowns and petioles rose under NaCl stress, it decreased significantly in leaves (Fig. 5).

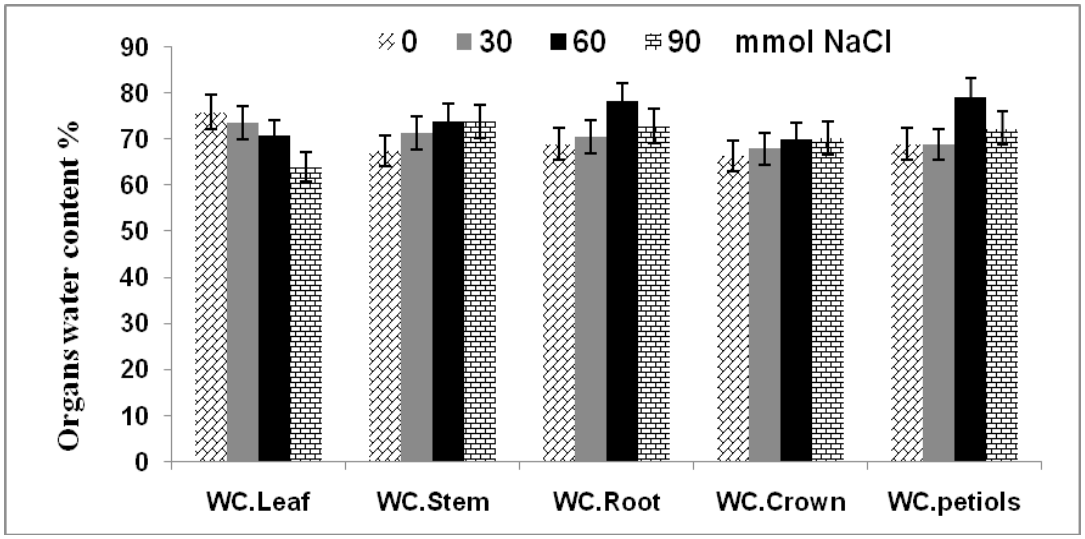

Fig. 5. Influence of NaCl stress on water content (%) of strawberry organs. Bars in each column indicate mean ± SE (n=12)

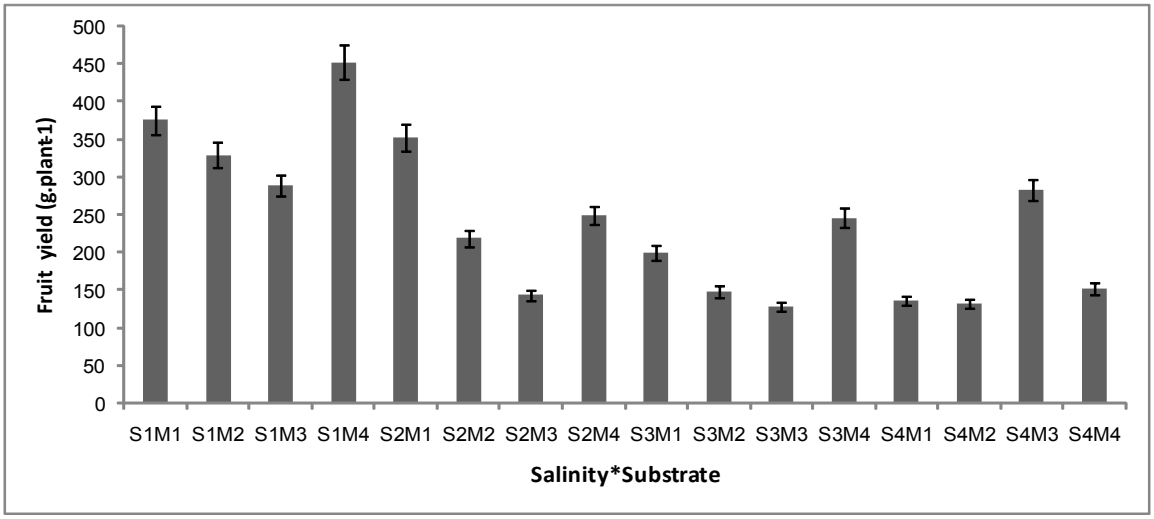

Fig. 6. Influence of salinity and substrate interaction on fruit yield (g.plant^{-1}) of strawberry cv. 'Camarosa'. Bars in each column indicate mean ± SE (n=3)

Macro and micro nutrient assimilation and distribution

A two-way ANOVA showed that only salinity affected macro- and microelement concentration in roots and shoots of strawberry cv. 'Camarosa' (Tab. 3). The presence of NaCl in the root medium resulted in an increase in total Na content in shoots and roots (Tab. 3). In general, cv. 'Camarosa' maintained a high level of Na^+ in shoots because of its larger DM in leaf, stem, petioles and crown (Fig. 3, Tab. 2 and 3). Na^+ content was relatively higher in root compared with shoots. contrary to Na^+ and K^+ which had the same changes trend in shoots and roots with increasing salinity, Ca^{2+} and Mg^{2+} concentrations decreased in shoot and increased in root with an increase in salinity. In general, ion content increased from root to shoot. Potassium content in control plants was higher than that of Na^+. The mineral composition analysis indicated that K^+ concentration decreased markedly with increasing NaCl concentration (Tab. 3), and the decrease was more pronounced in the shoot than in the root. 'Camarosa' plants were characterized by a significant decrease of K in shoots under NaCl stress. The K/Na ratio of the plant organs was high in control groups and, significantly decreased in shoot and root with an increase in salinity (Tab. 3). The highest Na/K ratio was found in roots at control, followed by shoot at this treatment. The K/Na ratios in the shoot and root of plant subjected to 90 mmol NaCl L^{-1} were only 1.9 ± 1.7 and 2.3 ± 0.75 mg.g^{-1}.dw^{-1} in shoot and root, 23% and 42% of control values, respectively. Distribution of other macronutrients between shoot and root varied with different mineral types. For example, the concentration of Ca^{2+} was significantly affected in shoot. Mg^{2+} content was not significantly affected in shoot and root (Tab. 3).

For all micro- and macroelements however, significant concentration changes related to different substrates were

not detected (unpublished results). Results showed a significant decline of Fe content of 40% and 49% in shoot and root due to NaCl salinity in 90 mmol NaCl L^{-1} (Tab. 3). It is worth noting that Fe content was distinctly higher in roots than shoots, indicating that Fe may be less movable than other micronutrients within the plants. For Zn, Cu and Mn however, significant concentration changes related to NaCl stress were not detected (Tab. 3).

Fruit yield

Fruit yield per plant was significantly affected by salinity, substrate, and their interaction (Tab. 2). Among the different substrates, the highest fruit yield (250 ± 32.5 $g.plant^{-1}$) was found in substrate M4 (70% Coco peat + 30% Perlite) followed by M1. In general, substrate M1 was the best substrate at 30 mmol NaCl L^{-1} salinity, M3 was the best substrate at 90 mmol NaCl L^{-1} salinity, M4 was the best substrate at 60 mmol NaCl L^{-1} salinity and control and M2 was not a good substrate for hydroponic strawberry production in grow bags (Fig. 6).

Discussion

The leaves of 'Camarosa' showed a significant decrease of Fe content of 40% and 49% in shoot and root tissue, respectively, due to NaCl salinity at 90 mM NaCl (Tab. 3), while Mn, Zn and Cu were in these tissues was not significantly influenced, indicating that Fe may be less mobile than other micronutrients. Results of the present study also indicate that the strawberry cv. 'Camarosa' is a relatively salt-sensitive plant. Little inhibition in growth was recorded in media containing up to 30 mm NaCl, but 60 mm NaCl was inhibitory to plant growth. Root growth was significantly promoted in the low salinity treatments. The immediate response of salt stress is reduction in the rate of leaf surface expansion leading to cessation of expansion as salt concentration increases (Wang and Nil, 2000). Salt stress also results in a considerable decrease in the fresh and dry weights of leaves, stems, and roots (Chartzoulakis and Klapaki, 2000). Most likely salt toxicity was responsible for the occurrence of these leaf necroses. In contrast to leaves, water content rose in other organs, especially the perennial organs, roots and crowns, which ensure plant development (Munns, 2002). Deleterious effects of salinity are thought to result from low water potentials, ion toxicities, nutrient deficiencies, or a combination of these factors. Nutrient deficiencies can occur in plants when high concentrations of Na^+ in the soil reduce the amounts of available K^+, Mg^{2+} and Ca^{2+} (Epstein, 1972) or when Na^+ displaces membrane-bound Ca^{2+} (Cramer *et al.,* 1985). However, in the present experiments, the effects of water stress were reduced by leaching the root medium between the salt applications, so that it improved the water relations of the plants compared to plants continuously exposed to stable NaCl levels in the root medium. In addition, Na^+ may have a direct toxic effect, such as when it interferes with the function of potassium as a cofactor in various reactions. Many of the deleterious effects of Na^+, however, seem to be related to the structural and functional integrity of membranes (Kurth *et al.,* 1986). The results indicated that Na^+ content in shoots and roots increased with salinity. The Ca^{2+} and Mg^{2+} contents were reduced in shoots of 'Camarosa' plants grown at relatively high salinity agreeing with results found for other cultivars (Awang and Atherton, 1995a, b; Awang *et al.*, 1993; D'Anna *et al.,* 2003; Keutgen and Pawelzik, 2009).

'Camarosa' plants maintained a high level of Na+ in shoots and roots, mainly because of a large proportion of DM in roots and shoot (Tab. 3). Keutgen and Pawelzik (2009) reported that growth of 'Camarosa' was reduced at 40 mg NaCl. Shoot Na^+ content increased from 3.2 ± 0.6 to 6.8 ± 2.3 $mg.g^{-1}$ and shoot Na^+ content increased from 3.1 ± 0.6 to 6.4 ± 1.5 $mg.g^{-1}$ DM in treatments with 40 mm NaCl. Potassium content of the shoot decreased over this NaCl range from 11.8±1.5 to 27.4±3.9 $mg.g^{1-}$ DM. Greenway (1968) reported that Na^+ increased and K^+ content decreased in leaves when *Atriplex nummularia* was exposed to salinities ranging from 0 to 1% NaCl. High NaCl uptake competes with the uptake of other nutrient ions, especially K^+, leading to K^+ deficiency. Increasing NaCl induces an increase in Na^+ and Cl- and a decrease in Ca^{2+}, K^+, and Mg^{2+} levels in a number of plants (Khan, 2001; Khan *et al.,* 1999, 2000). Salinity enhanced the content of Na^+, Ca^{2+}, and Cl^- in *Vicia faba* and the ratio of K/Na decreased (Gadallah, 1999). It has been reported a significant increase in Na^+ content in shoot and root (Tab. 3) without any significant alteration of the endogenous level of K^+ and Fe in leaves (Parida *et al.,* 2004). Decreases of Ca^{2+} and Mg^{2+} content of leaves have also been reported upon salt accumulation in mangrove (*Bruguieraa parviflora*), suggesting increasing membrane stability and decreased chlorophyll content, respectively (Parida *et al.,* 2004). Since these data indicate that strawberry cv. 'Camarosa' is salt sensitive however, it could be altered by using suitable substrate Substrate M1 (Coco peat only) was the best substrate at 30 mM NaCl, M3 (70% Coco chip + 30% Perlite) was the best substrate at 90 mM NaCl , M4 (70% Coco peat + 30% Perlite) was the best substrate at 60 mM NaCl and control, and M2 (Coco chip only) was not a good substrate for hydroponic strawberry production in grow bag (Fig. 6). Because of the Na^+ content of shoots and roots under NaCl salinity (Tab. 3), the roots capacity to accumulate Na^+ for protecting the leaves from these toxic ions is reported, although a distinct reduction in roots and shoots DM was an important indicator for its sensitivity to NaCl salinity. Since there was no significant effect of different substrates and interaction between substrate and salinity on Na^+ content, it is concluded that salinity is the only factor that disturbed ion balances. Frequently, plants exposed to NaCl inevitably absorb a large amount of Na^+, which subsequently causes a decrease in the content of K^+ (Gomez *et al.,* 1996; Hasegawa *et al.,*

2000). In the present experiments, NaCl stress significantly reduced K content in shoots and roots. A similar response was found in different species of pepper (Chartzoulakis and Klapaki, 2000). An accumulation of K^+ under elevated NaCl suggests a more efficient K^+ uptake in strawberry compared to other plants. Jacoby (1999) proposed that K^+ accumulation represented plant adaptation to salinity. Not only Na^+ and K^+ contents, but also the Na/K ratio can be used as phyto-physiological parameters for screening less sensitive plants for NaCl stress (De Lacerda *et al.,* 2005; Raja Babu *et al.,* 2005). A low K/Na ratio indicates metabolic disorders such as a reduction of protein synthesis and enzyme activities (Brady *et al.,* 1984), as well as an increase in membrane permeability (Alam, 1999). Moreover, elevated K^+ levels act osmotically, preventing Na^+ influx into roots and shoots (Jacoby, 1999). K/Na ratio was significantly decreased with increase salinity to 60 mM NaCl, which reflected an adaptation to the lower salt stress. Ca^{2+} content of roots increased. According to Grattan and Grieve (1999), maintaining a sufficient Ca level in the root medium represents an important factor in controlling the severity of toxic ions. In the experiments, micronutrient concentrations were not significantly affected (Cu, Zn, Mn) or increased in shoot (Mn), while Fe decreased in root (Tab. 3). For horticultural and commercial practice, the fruit yield reduction due to NaCl salinity observed during the experiment and the different substrates had different effects on fruit yield. The reduction of fruit yield was due to a reduction of leaf area and total dry weight (Fig. 1, 2).

Conclusions

Obviously, plant growth was significantly reduced in cv. 'Camarosa' and this decrease was due to a reduction of leaf number and leaf area, in addition to an increase of necrotic leaf area. Apart from Na^+ and Cl^-, macro- and micronutrient contents were slightly influenced by NaCl stress. While micronutrient contents were not affected by substrate and any level of NaCl in the root medium, K^+, Ca^{2+} and Mn^{2+} contents were significantly higher in shoots at 60 and 90 mM NaCl than roots. However, K^+ content significantly decreased in shoot and root. In contrast to Mn, Cu and Cu, Fe content significantly decreased in shoots with increasing salinity. In the experiments, cv. 'Camarosa' was characterized by a large necrotic leaf area due to NaCl stress, which was accompanied by lower water content of the leaf (Fig. 5). These results are in line with those of Saied *et al.* (2005) and Turhan and Eris (2004). These authors is also reported a decrease of K^+ contents in roots and shoots, and a reduction of the P level in shoots of cv. 'Camarosa' cultivated in Perlite or Perlite-zeolite medium, but partly contradict those of Keutgen and Pawelzik (2009). These differences mainly resulted from the experimental conditions of different ionic compositions and root media, while the experimental substrate could have altered or intensified salinity stress effects on nutrient uptake of and distribution within the plants.

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