Studia Universitatis “Vasile Goldiş”, Seria Ştiinţele Vieţii
Vol. 21, issue 4, 2011, pp. 813-819
©2011 Vasile Goldis University Press (www.studiauniversitatis.ro)

REUSE OF SALINE AQUACULTURE EFFLUENT FOR ENERGY PLANT PRODUCTION

Réka Hegedűs*[1,2], Dénes Gál[1], Ferenc Pekár[1], Mária Oncsik Bíróné[1] and Gyula Lakatos[2]
[1]Research Institute for Fisheries, Aquaculture and Irrigation, Szarvas, Hungary
[2]Department of Applied Ecology, University of Debrecen, Debrecen, Hungary

ABSTRACT

Sodium and other elements of salts are persistent in recycled water. To obtain the basic information required before using halophyte tamarisk (*Tamarix tetranda* Pall) and “energy willow” (*Salix viminalis* L. Sp. Klon Marzecinski KLV 1052) to phytoremediation, we investigated the effects of saline effluent irrigation on the growth, survival, Na partitioning and the ability of uptake of Mg, Ca and the main macroelements, like N, P and K by plants. In the vegetation period the sodification effect was negligible according to the soil parameters. The highest sodium uptake by the plants was observed at the low-salt treatment (TDS: 369±57 mg/L).

Keywords: effluent, energy plant, irrigation, salt, phytoremediation

INTRODUCTION

The growth of the aquaculture industry has been associated with negative environmental impacts from the discharge of untreated effluent into the adjacent receiving water bodies. It is well known that discharge of effluents, treated or non-treated, into the environment, particularly natural water bodies such as lakes, rivers can cause severe degradation of these waters. The degradation is often related to the presence of organic and inorganic nutrients, which can cause problems such as eutrophication and algal blooms. The utilization of saline geothermal water in aquaculture, results in higher salt content in the effluent.

Sodium and other elements of salts are persistent in recycled water and are among the most difficult components to remove from water usually requiring the use of expensive cation exchange resins or reverse osmosis membranes (Toze, 2006). Salinization is one of the most serious problems confronting sustainable agriculture in irrigated production systems meanly in semi-arid and arid regions (Ravindran et al., 2007). Plant growth is directly affected by high levels of sodium and other salts, the absorption of salts can result in ion toxicity and nutrient imbalances (Marschner, 1986). However, the salinity is not inimical to all plants for example the plant species (halophytes), which grow naturally on the coastal and inland saline areas.

The presence of sodium ions in halophytes has been reported to be partitioned in the cell vacuole to minimize cytotoxicity and Na^+ and Cl^- are energetically efficiency osmolytes for osmotic adjustment (Pantoja et al., 1989; Blumwald et al., 2000). Gorham et al., (1987) observed that vascular halophytes accumulated high levels of sodium and other salts in their above ground tissues. Inorganic constituents such as sodium and chloride gradually declined in the natural saline soil with corresponding increase in the cultivated halophytes and two halophytes of them could remove 504 and 474 kg of sodium chloride from the saline land from 1 ha in 4 month time (Ravindran et al., 2007). Salix can also be used to purify municipal waste, such as waste water, landfill leachate, and sewage sludge (Börjesson, 1999).

Aquaculture effluents can often contain significant concentrations of organic and inorganic nutrients for example nitrogen and phosporus and these could be valuable plant nutrients (Ghate et al., 1997; Brown et al., 1999; Brown and Glenn, 1999; McIntosh and Fitzsimmoms, 2003; Miranda et al., 2008). There is potential for these nutrients present in recycled water to be used as a fertiliser source when the water is recycled as an irrigation source for agriculture. Using recycled water also reduces the pressures on the environment by reducing the use of environmental waters.

Energy plants can contribute the reduction of greenhouse gas emissions, they are renewable energy sources and with net energy gain per area unit is sufficiently high (Scholz and Ellerbrock, 2002). The biodiversity is estimated to be slightly increased with energy plants, and they can remove a significant fraction of the nutrients from the dosed effluent water and provide an economic return to the grower (Börjesson, 1999).

Inadequate information is available on the growth and survival of willow and tamarisk species (Tomar et al., 2003; Arndt et al., 2004) as a function of soil salinity, and the salt tolerance mechanisms and the whole-plants levels of salt accumulation are not yet adequately understood. In the phytoremediation function of the energy plants, and mainly the halophytes and salt tolerant should have a significant ability to bio-accumulate salts from the soil by means of uptake from the soil and accumulation in the plant biomass. To obtain the basic information required before using halophyte tamarisk (*Tamarix tetranda* Pall) and “energy willow” (*Salix viminalis* L. Sp. Klon Marzecinski KLV 1052) to phytoremediation, we investigated the effects of saline effluent irrigation on the growth, survival, Na partitioning and the ability of uptake of Mg, Ca and the main macro-elements, like N, P and K by plants.

MATERIALS AND METHODS

The field experiment was conducted at Lysimeter station of HAKI (Research Institute for Fisheries, Aquaculture and Irrigation), Szarvas in 2009. The treatment system consisted of one stabilisation pond and one fishpond, which were connected serially; the water of the fishpond was used for irrigation on the lysimeters. The plants were grown in field experiments in lysimeters containing calcareous chernozem soil. The rooted cuttings in the 16 lysimeters (1x1x1 m) were divided into three treatments: a control treatment irrigated with river water containing 246±51 mg/l of salts (TDS), a low-salt treatment (50% effluent) with water of 369±57 mg/L salt content and a high-salt treatment (100% effluent) with water containing 738±116 mg/L of salts. Each lysimeter received a total 370 mm of water during the experimental period, corresponding to the annual precipitation (520 mm in this year). Soil samples were collected at the beginning (before soil preparation) and at the end of the study (after harvest) to measure macronutrients concentrations and soil salinity by the Hungarian standard methods. Plant samples were collected from 10 points in the autumn season and were mixed and composed to 6 average samples. The fresh weight of vegetative parts (biomass) was recorded, then oven-dried at 105 ºC, for dry weight determination. Plant samples were ground into a fine powder using a laboratory mill and were analysed for total nitrogen by Kjeldahl apparatus, total P, Na, K, Mg, Ca were measured using ICP-OES after a microwave digestion. The data of experiments were compared statistically by LSD test and t-test, using SPSS software.

RESULTS AND DISCUSSIONS

Irrigation water

Among irrigation water quality parameters monitored, statistically significant differences at 5% level were found in conductivity (EC_W), chemical oxygen demand (COD_{Cr}), total inorganic nitrogen (TIN), total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS), total dissolved solids (TDS), calcium (Ca), potassium (K), sodium (Na) and hydrogen carbonate (HCO_3^-), and SAR (Sodium Absorption Ratio) (Table.1).

Table 1. Levels of selected water quality parameters measured from both river and effluent water during the experiment

Parameters	Unit	effluent		river water		Difference (E-R)
		average(n=9)	SD	average(n=8)	SD	
EC_w	dS/m	1	0.132	0.390	0.05	0.610*
COD_{Cr}	mg/L	131	53.2	26	20.2	105*
NH_4-N	mg/L	1.43	2.42	0.155	0.118	1.28 ^{ns}
NO_2-N	mg/L	1.03	1.04	0.017	0.012	1.01 ^{ns}
NO_3-N	mg/L	2.30	2.54	0.496	0.341	1.80 ^{ns}
TIN	mg/L	4.76	2.35	0.786	0.274	3.97*
ON	mg/L	4.56	4.06	1.32	2.15	3.24 ^{ns}
TN	mg/L	9.33	4.08	2.03	2.23	7.30*
PO_4-P	mg/L	0.565	0.448	0.139	0.034	0.426 ^{ns}
TP	mg/L	1.04	0.424	0.294	0.268	0.746*
TSS	mg/L	142	80.3	29	21.9	113*
TDS	mg/L	794	137	270	60	524*
Ca	mg/L	22.8	3.4	40.1	3.6	-17.3*
K	mg/L	6.25	0.70	4.38	0.96	1.87*
Mg	mg/L	10.6	1.8	9.11	1.02	1.49 ^{ns}
Na	mg/L	228	36.2	33.1	6.5	195*
Cl^-	mg/L	31.2	2.8	31.6	7.9	-0.4 ^{ns}
SO_4^{2-}	mg/L	10.7	4.99	21.8	10.8	-11.1 ^{ns}
HCO_3^-	mg/L	676	93	181	17	495*
SAR		9.91	1.76	0.87	0.78	9,04

Symbol(*) and ns denote statistical significance at the 5 % level, and statistically non-significant, respectively.

Levels of EC_w (t=12.87, $p<0.05$), TDS (t=10.294, $p<0.05$), K (4.536, $p<0.05$), Na (t=15.01, $p<0.05$), HCO_3^- (t=14.78, $p<0.05$) were higher in the effluent as compared to river water. These higher values compared to the river water were probably due to the application of geothermal water. This is a common practise in this climate to provide the optimal temperature for the African catfish production. Observed higher levels of TIN (t=4.758, $p<0.05$),TN (4.639, $p<0.05$), TP(t=4.389, $p<0.05$), TSS (t=4.065, $p<0.05$) COD_{Cr} (t=5.47, $p<0.05$) in the catfish effluent as compared to the river water may be attributed to the high fish stocking density and high feeding rates (wasted feed and faecal matter). Other studies (Ghate et al., 1997; Brown et al., 1999; Brown and Glenn, 1999; McIntosh and Fitzsimmoms, 2003; Miranda et al., 2008) have shown that aquaculture effluent presented high levels of both total nitrogen and ammonium nitrogen. The calcium (t=-10.16, $p<0.05$) chloride (t=-0.149, $p<0.05$) and sulphate (t=-2.77) content was higher in the river water than in the effluent. According to the Food and Agriculture Organization (FAO) water quality guidelines (Ayers and Westcot, 1985), the catfish effluent did present slight to moderate degree of restriction for irrigation regarding to salinity (EC_w=0.7-3.0 dS/m). This means the effluent may cause reduction in soil-water infiltration, and toxicity of sodium and chloride for sensitive plants. On the other hand, Magesan et al. (2000) noted that the organic and inorganic nutrients in treated effluent that had a high carbon to nitrogen ratio stimulated the soil organisms, which, in turn, decreased the hydraulic conductivity of irrigated soil.

Soil chemical characteristic

Changes in monitored soil chemical parameters from spring to autumn in each treatment are shown Table 2 and Table 3. According to the statistical analysis, there were no significant differences among the initial and the treated plots ($p<0.05$). After the treatment, the soil irrigated with effluent presented higher levels of Na, except for the 100% treatment of *Tamarix*, it decreased from 475 to 411 mg/kg. Regarding to soil salinity, SAR (Sodium Adsorption Ratio) decreased in the 50 % treatment this was a consequence of the high calcium content of applied river water (40.1±3.6 mg/L). While at the 100% treatment this value increased. In the case of *Tamarix* another change was monitored, that the SAR value increased at low-salt treatment, and decreased at high-salt treatment. It was probably caused by the halophytic characteristic of this plant such ability of higher sodium uptake. But in the first year the sodification effect was negligible by the average concentrations. The organic matter (OM), $CaCO_3$ and soil cohesion (K_A) levels were improved by the nutrients of the effluent water. According to our results the irrigation may be considered as a good alternative for pre-treated slightly saline catfish farm effluent utilisation, but requires regular monitoring of soil salinity to prevent soil salinisation.

Table 2. Soil chemical characteristics before (spring) and after (autumn) the treatment using effluent water

Time	Species/Treatment	pH	S.D.	K_A	S.D.	Total salt	OM	S.D.	NO_3-+NO_2	S.D.	$CaCO_3$	S.D.
Unit						%	%	%	mg/kg	mg/kg	%	%
spring	*Salix/50%*	7.33	0.064	34	2.12	<0,02	1.54	0.007	5.2	0.268	2.61	0.431
autumn	*Salix/50%*	7.41	0.028	32	1.06	<0,02	1.64	0.015	1.87	0.778	2.89	0.843
spring	*Salix/100%*	7.36	0.043	34	1.41	<0,02	1.51	0.141	5.82	2.7	2.61	0.332
autumn	*Salix/100%*	7.45	0.049	32	1.97	<0,02	1.74	0.133	2.05	0.261	2.78	0.312
spring	*Tamarix/50%*	7.36	0.057	34	1.41	<0,02	1.59	0.12	6.63	1.06	2.54	0.601
autumn	*Tamarix/50%*	7.45	0.064	33	0.07	<0,02	1.60	0.074	1.71	0.24	2.94	0.468
spring	*Tamarix/100%*	7.38	0.035	34	0.00	<0,02	1.47	0.035	3.84	0.014	2.59	0.728
autumn	*Tamarix/100%*	7.47	0.071	32	1.13	<0,02	1.57	0.022	2.14	0.204	3.00	0.499

Table 3. Soil chemical characteristics before (spring) and after (autumn) the treatment using effluent water

Time	Species/Treatment	Ca	S.D.	Mg	S.D.	Na	S.D.	SAR	S.D.
Unit		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
spring	*Salix/50%*	13850	2050	5730	452	422	107	0.76	0.214
autumn	*Salix/50%*	18150	1343	5620	1244	470	81.3	0.69	0.179
spring	*Salix/100%*	14300	848	5515	870	380	204	0.68	0.359
autumn	*Salix/100%*	17000	3394	5455	2072	484	13.4	0.84	0.336
spring	*Tamarix/50%*	13350	1909	5275	389	326	53	0.61	0.116
autumn	*Tamarix/50%*	11660	5430	3670	1329	454	28.3	0.97	0.154
spring	*Tamarix/100%*	14650	2333	5870	481	475	175	0.84	0.336
autumn	*Tamarix/100%*	15600	1131	4595	926	411	62.9	0.75	0.157

Element composition of above-ground plant parts

In the case of nitrogen (N) there was not significant deviation among the species (Fig.1). The uptake of N was higher in the leaves than in the stems, but there were not any significant differences. The N content of the willow was found in higher amount than in the tamarisk at the leaves. Among the low-salt treatment (50%) and high-salt treatment (100%) there were significant different ($p<0.05$) in the *Tamarix* leaves. Between the control and the low-salt and high-salt treatment were found significant different at the stem of *Tamarix* ($p<0.05$). The uptake of *Tamarix* was higher in the high-salt treatment.

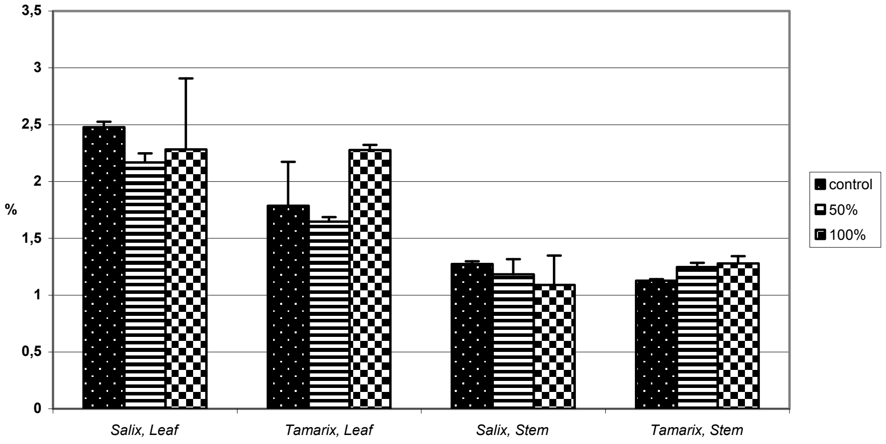

Figure 1. N concentration in the above-ground plant parts in dry weight (%)

The phosphorus (P) uptake by leaves were significantly higher ($p<0.05$) in the control than in the treated plants (Figure 2.). The P concentrations of *Salix* stem were significantly higher ($p<0.05$) in the control than the treated plants. Brown et al. (1999) also found that the lysimeters in lowest salinity treatment removed significantly more total and soluble reactive phosphorus than in higher salt treatment. According to their results the percentage of the applied total phosphorus removed by the plant shoot was greater at the lowest (0.5 ppt) and the middle salinity (10 ppt) than at the highest salinity (35 ppt) treatment. Salinity had an inhibitory effect on total phosphorus in the plant shoot (Brown et al., 1999). Although the P uptake of the *Tamarix* leaves was significantly ($p<0.05$) higher in the high-salt treatment than the smaller salt treatments (control and 50%), in the case of stem was observed that a significant different between the low-salt and high-salt treatment ($p<0.05$).

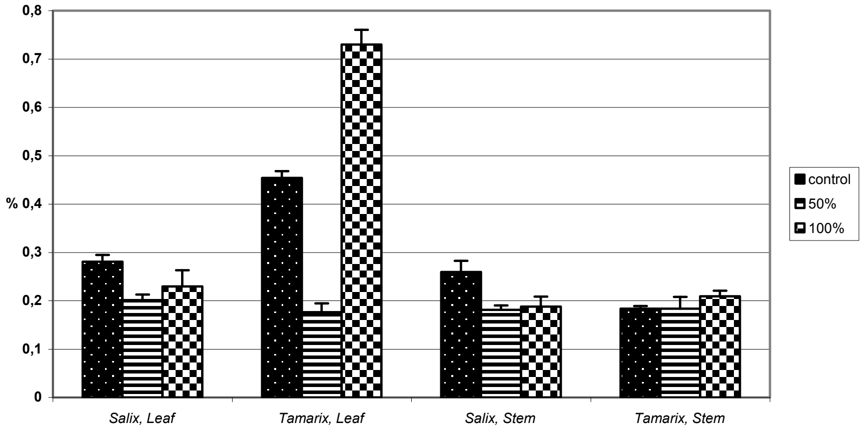

Figure 2. P concentration in the above-ground plant parts in dry weight (%)

The potassium (K) contents were remarkably higher in the leaves both of two species (Fig. 3). Imada et al. (2009) reported that, in salt-tolerance *Populus alba* L., the K accumulation in tree biomass decreased with increasing salinity and the K partitioned in the leaves decreased in the high – salt treatment. According to our measuring the K levels of *Tamarix* leaves were significantly higher in the high-salt treated plants than in the control and the low-salt treatment ($p<0.05$). The content of the K was lower in the stem of both species, and in the *Salix* leaves there were significant differences between the control and the low-salt treatment and the high-salt treatment and the low-salt treatment.

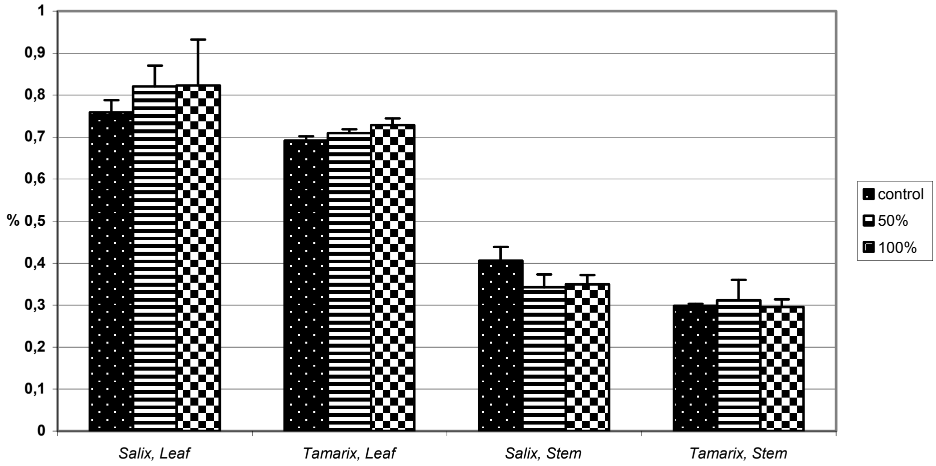

Figure 3. K concentration in the above-ground plant parts in dry weight (%)

The highest calcium (Ca) concentrations were observed in the leaves and the Ca uptake by *Salix* was higher than the *Tamarix* (Fig. 4). There was no statistically significant difference at the 5% level in values of Ca between the control and the treated *Salix l*eaves and *Tamarix* stems. Nevertheless the Ca concentration of *Tamarix* leaf was significantly higher in the high-salt treatment than the control ($p<0.05$). Though the Ca content was significantly higher in the river water (in control treatment) than the in the aquaculture effluent (salt-treatment). According to Imada et al. (2009), the concentration of Ca in the above-ground parts of *Populus* were remarkably lower in the high-salt treatment than in the low-salt treatment.

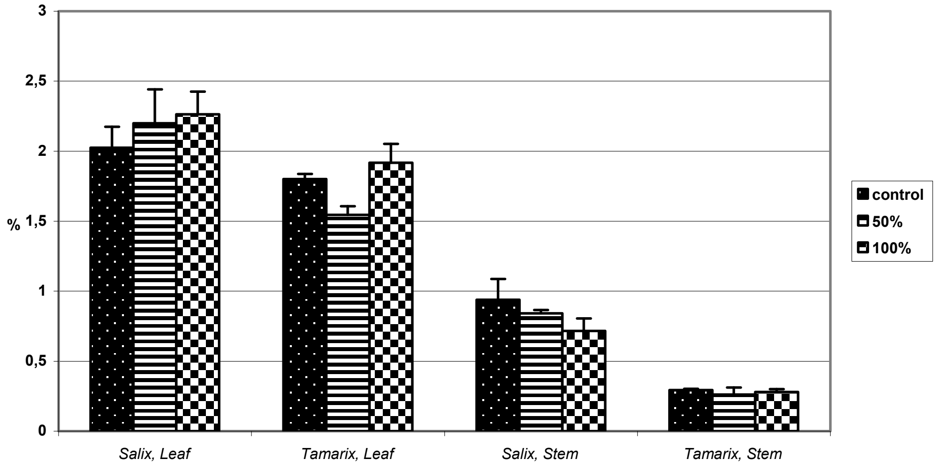

Figure 4. Ca concentration in the above-ground plant parts in dry weight (%)

The magnesium (Mg) uptake by *Tamarix* was higher than by the *Salix* (Fig. 5.). The amount of this element was higher in the leaves than the stems. There were statistically significant differences between the Mg concentration of the *Tamarix* leaves and stems between the low-salt treatment and the high-salt treatment ($p<0.05$). Imada et al. (2009) reported the concentration of Mg in the leaves were higher in the low-salt treatment than in the high-salt treatment, we found that the values of low-salt treatment were remarkably lower than in the high-salt treatment, and it was lower as compared to the control.

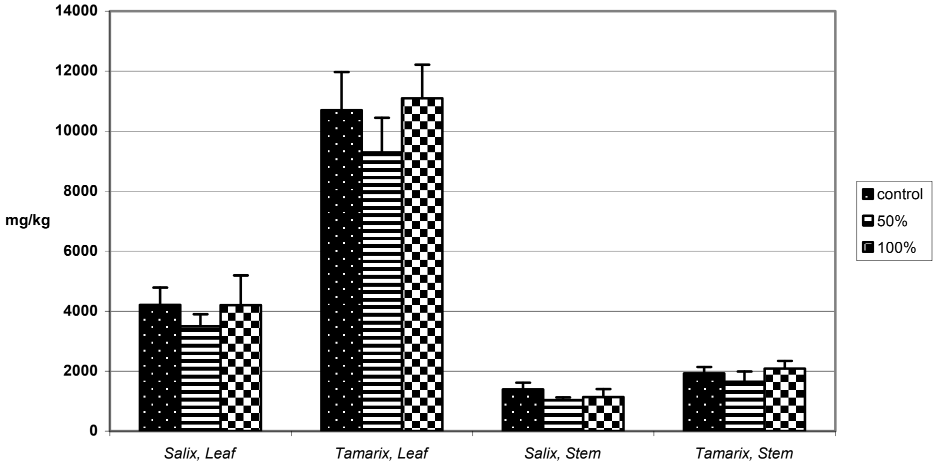

Figure 5. Mg concentration in the above-ground plant parts in dry weight (mg/kg)

The sodium (Na) accumulation in the above-ground tissues after 1 year of the treatment is higher in the *Tamarix* than in the *Salix* (Fig. 6). The Na concentration of the leaves of the *Tamarix* was higher than the levels of the willow. Imada et al. (2009) reported that the rooted cuttings of *Populus alba* L. in all treatments partitioned most of the Na uptake in their roots, but in the high-salt treatment, the Na partitioned in the roots appears to have been transported into above-ground plant parts. The partitioning of Na to the roots enabled the trees to maintain low levels of Na transport into above-ground parts, indicating this is an important mechanism for salt tolerance. We found that the highest Na uptake by *Tamarix* (leaves and stems) was at the low-salt treatment ($p<0.05$). Furthermore the Na concentration of *Salix* stem was significantly smaller in the high-salt treatment and in the low-salt treatment than in the control ($p<0.05$). Tomar et al. (2003) observed high Na concentration at leaves of *Tamarix articulate*, which was 3.56%. According to Arndt et al. (2004) *Tamarix* leaves contained the greatest concentration of mineral salts and had a constant and low K:Na ratio compared to the other species. *Tamarix* species can take up large amounts of mineral salts and excretes the accumulated salts through specialized salt glands in the leaves, besides Na can also be retained in the basal parts of the plants, where it exchanged against K in transfer cells of the xylem parenchyma.

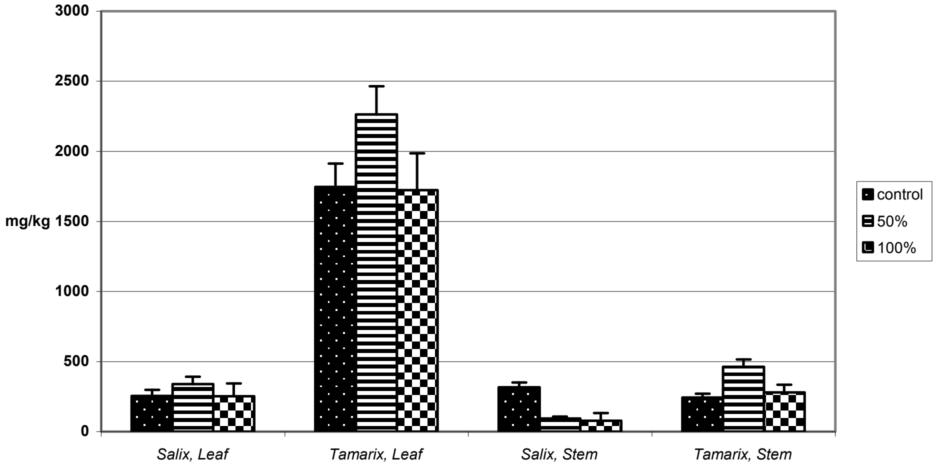

Figure 6. Na concentration in the above-ground plant parts in dry weight (mg/kg)

CONCLUSIONS

According to our experiments the irrigation may be considered as a good alternative for pre-treated salinity catfish farm effluent use, but requires regular monitoring of soil salinity to prevent soil salinization. In the first year the sodification effect was negligible according to the soil parameters. The results of the first year experiments showed that the Na and Mg uptake by tamarisk was higher. We conclude that using salinity aquaculture effluent to irrigate halophytes can be a viable strategy for disposal of effluent. Salt-tolerant and halophyte species may provide effective phytoremediation since they grow to large sizes, allowing the larger amount of biomass to accumulate more salts. Other benefits of effluent reuse are: protection of water resources, prevention of river pollution, recovery of water and nutrients for agriculture, savings in clear water use and effluent treatment cost and producing biomass for renewable energy generation simultaneously. The results of our research may contribute to elaborate an environmental-friendly, locally applicable wastewater treatment technology.

REFERENCES

Arndt SK, Arampatsis C, Foetzki A, Li X, Zeng F, Zhang X, Contrasting patterns of leaf solute accumulation and salt adaptation in four phreatophytic desert plants in hyperarid desert with saline groundwater. Journal of Arid Environments, 59, 259-270, 2004.

Ayers RS, Westcot DW, Water Quality for Agriculture, FAO, Rome, 1985.

Blumwald E, Gilad SA, Maris PA, Sodium transport in plant cells, Biochimica et Biophysica Acta, 1465, 140-151, 2000.

Börjesson P, Environmental effects of energy crop cultivation in Sweden-I: Identification and quantification. Biomass and Bioenergy, 16, 137-154, 1999.

Brown JJ, Glenn EP, Reuse of highly saline aquaculture effluent to irrigate a potential forage halophyte, *Sueda esteroa.* Aquacultural Engineering, 20, 91-111, 1999.

Brown JJ, Glenn EP, Fitzsimmons KM, Smith SE, Halophytes for the treatment of saline aquaculture effluent. Aquaculture, 175, 255-268, 1999.

Ghate SR, Burtle GJ, Vellidis G, Newton GL, Effectiveness of grass strips to filter catfish (*Ictalurus punctatus*) pond effluent. Aquacultural Engineering, 16, 149-159, 1997.

Gorham J, Hardy C, Wyn Jones RG, Joppa LR, Law CN, Chromosomal location of the K/Na discriminating characters in the D genome of wheat. Theoretical Applied Genetics, 74, 584-588, 1987.

Imada S, Yamanaka N, Tamai S, Effects of salinity on growth, Na partitioning, and Na dynamics of a salt-tolerant tree, *Populus alba* L. Journal of Arid Environments, 73, 245-251, 2009.

Magesan GN, Williamson JC, Yeates GW, Loyd-Jones ARH, Wastewater C:N ratio effects on soil hydraulic conductivity and potential mechanisms for recovery. Bioresource Technology, 71, 21-27, 2000.

Marschner H, Mineral Nutrition of Higher Plants. Academic Press, London, 674 pp, 1986.

McIntosh D, Fitzsimmons K, Characterisation of effluent from an inland, low-salinity shrimp farm: what contribution could this water make if used for irrigation. Aquacultural Engineering, 27,147-156, 2003.

Miranda FR, Lima RN, Crisostomo LA, Santana MGS, Reuse of inland low-salinity shrimp farm effluent for melon irrigation. Aquacultural Engineering, 39, 1-5, 2008.

Pantoja O, Dainty J, Blumwald E, Ion channels in vacuoles from halophytes and glyophytes. Federation of European Biochemical Societies, 255, 92-96, 1989.

Ravindran KC, Venkatesan K, Balakrishnan V, Chellapan KP, Balasubramanian T, Restoration of saline land by halophytes for Indian soils. Soil Biology& Biochemistry, 39, 2661-2664, 2007.

Rusan MJM, Hinnawi S, Rousan L, Long term effect of wastewater irrigation of forage crops on soil and plant quality parameters. Desalination, 215, 143-152, 2007.

Scholcz V, Ellerbrock R, The growth productivity, and environmental impact of the cultivation of energy crops on sandy soil in Germany. Biomass and Bioenergy, 23, 81-92, 2002.

Tomar OS, Minhas PS, Sharma VK, Singh YP, Raj KG, Performance of 31 tree species and soil conditions in plantation established with saline irrigation. Forest Ecology and Management, 177, 333-346, 2003.

Toze S, Reuse of effluent water-benefits and risks. Agricultural Water Management, 80,147-159, 2006.