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Studies on the role of root morphology attribution in salt tolerance of blue-panicgrass (*Panicum antidotale* Retz.) using artificial neural networks (ANN)

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ABSTRACT

The root is the organ of a plant that firstly is affected by salinity and may play a significant role in stress tolerance. There is limited information on the role of root morphological traits in different soil layers of salinity tolerance in halophytes. This experiment aimed at investigating the importance of root morphology attributes in salt tolerance of blue panicgrass (*Panicum antidotale* Retz.) using artificial neural networks (ANN). In a column experiment, blue panicgrass plants were exposed to four salinity levels of irrigation water (0, 86, 189 and 345 mM NaCl). The root dry weight decreased by 26, 54 and 54% at 86, 189 and 345 mM compared to the control, respectively. Salinity had no significant effect on root penetration, while it significantly decreased the length, diameter, volume, weight, number and area of plant root system. The ANN model used for predicting plant salt tolerance resulted in R^2 and RMSE values of 0.95 and 0.013, respectively. According to sensitivity analysis, the root penetration in different soil layers was the most important root morphology attribute affecting salt tolerance of blue panicgrass. The role of length, diameter, volume, weight, number and area of root on salt tolerance of plant was dependent on the soil depth. For the weight, area and number of roots, the greatest sensitivity coefficient was related to the depth of 60-80 cm, while the length and diameter of roots at 0-20 cm showed the greatest sensitivity coefficient. The results showed that root penetration was the most effective factor in salinity tolerance of blue panicgrass. Although, it should be considered the most effective soil depth for each root trait.

Key words : Bio saline systems, modelling, root penetration, sodium chloride, soil depth

INTRODUCTION

In arid and semi-arid regions of the world, scarce of freshwater (Abdel-Ghani, 2009), increasing soil and water salinity (Kafi and Khan, 2008), population growth and industrialization of societies (FAO, 2010) are as main factors and may degrade the quality of the agricultural lands. These conditions cause serious problems for individuals and of the whole community in saline areas. Therefore, to continue economical agriculture-systems in these regions, domestication of more salt-tolerant species could be considered for carrying on production (Kafi *et al.*, 2010). Blue panicgrass (*Panicum antidotale* L.) as xero-halophytic native plant is a suitable candidate for bio-saline production systems (Halvorson and Guertin, 2003; Kafi and Khan, 2008).

There are different mechanisms for salinity tolerance in plant organs, tissue and cell levels (Munns and Tester, 2008). The roots are the first plant organ that exposed to salinity and play a significant role in the stress tolerance (Munns *et al.,* 2006). Number, weight, area, volume, diameter and length of the roots are considered the common morphological parameters to show root characteristics (Bohm, 1979). Although, root dry weight is suitable criterion for root studies

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in response to environmental conditions, yet is not appropriate parameter to justify the activity or absorbed water and minerals, because while the capillary roots may be most active part of the root, but form only small part of the root biomass (Dittmer, 1949). Soil layer with the greatest root biomass cannot be the same layer that has more water and nutrients absorption (Russel, 1977). Roots area or surface appears to be one of the main characteristics in studies of root uptake of water and nutrients (Dittmer, 1949; Steingrobe *et al.*, 2001). Root diameter measurement can help in understanding interactions between roots and soil micro pores and also the potential of root penetration (Wiersum, 1957). Root length can be considered as the most commonly used parameter, because researchers believe that the length of roots per unit of soil volume is the best feature to evaluate soil water and nutrient uptake by the plant (Taylor and Klepper, 1975).

Artificial neural network (ANN) is a mathematical tool, which tries to represent low-level intelligence in natural organisms. It has a flexible structure, and is capable of making a non-linear correlation between input and output spaces (Gorzalczany, 2002). Neural networks are one of the most dynamic research fields that attracted many scientists from different scientific disciplines (Norouzi *et al.,* 2009). Due to the ability of this tool in simulating very complex and uncertain processes in science that are abundant in agriculture, extensive background and capable use of it provide and found a large number of research in this area (Caudill and Butler, 1992). Using artificial neural networks and selecting the appropriate weights and proper activation functions can be linear and non-linear processes to be simulated.

It follows from the above that improvement carbohydrate production with saline water and in salt-affected soils condition would require the recognition role of morphological root traits with regard to salinity tolerance. This experiment was conducted to evaluate the growth response of blue panicgrass to salinity levels of irrigation water, and investigate the importance of root morphology attribution in salt tolerance of blue panicgrass using artificial neural networks (ANN).

MATERIALS AND METHODS

Experimental Site and Soil Properties

This experiment was conducted in the field of Soilless Culture Research Center, Isfahan University of Technology, Iran (32°51′ 33′ ′N, 51°31′ 45′ ′E, Altitude=1602 m) from 26 June to the middle of September 2010. The air temperature ranged from 24 to 37°C during the day and 16-23°C during the night. Relative humidity fluctuated from 45 to 60% at day/night. Plastic tubes, 90 mm in diameter and 140 cm deep were filled with 14 kg soil taken from a field and mixed with washed river sand. Then each filled tube located inside the black PVC cylinder for stability prevented both the penetration of light and greening the root. The PVC cylinders were placed in spaces that were designed on the table. This medium was designed such that the surface of PVC cylinders was equal with the soil surface. To avoid warming the bed level around the table was entirely covered with heavy-duty textiles. Collected soil was air-dried and sieved through a 2 mm mesh. The soil used in experiment contained 71% sand, 21% silt, 8% clay (sandy loam texture), alkaline pH (7.75), 0.62% organic carbon, 0.06% total nitrogen (N), 41 ppm available (Olsen) phosphorus (P), 228 ppm available potassium (K) and electrical conductivity (1 : 1) of 3.10 dS/m.

Plant Material

The seeds of blue panicgrass (*Panicum antidotale* L.) were obtained from the Agricultural and Natural Resource Research Center of Sabzevar, Khorasan Razavi, north-east of Iran. The germination tests of seeds were performed in the sterilized Petri dishes. Results showed that germination percentage of seeds was 95.

MATERIALS AND METHODS

The tubes were irrigated to reach the field capacity (i. e. 100% available water) to supply uniform moisture conditions before sowing. On 26 June 2010, blue panicgrass seeds were sown in the pots at the rate of 10 seeds per pot at 1-2 cm depth. Emergence was

completed on 30 June and seedlings were thinned to one healthy plant per PVC cylinder at the second leave fully expanded.

The treatments were 0, 86, 189 and 345 mM NaCl solution (Table 1). The NaCl concentration was gradually increased until it reached the desired concentration (345 mM). Different levels of NaCl solutions were added as irrigation water after thinning every other day. Complete compound fertilizer [growth 20 : 20 : 20+trace element corresponding to N : P_2O_5 : K_2O : + (Mg, Fe, Zn, Cu, Mn and B), respectively] as solution was applied at the rate of 2 l/ha in three times with water irrigation.

Four harvests were performed at different phonological stages consisting : (h_1) beginning of tillering, (h_2) stem elongation, (h_3) panicle emergence and (h_4) seed ripening, respectively, that occurred after 18, 35, 45 and 65 days from sowing date.

Table 1. Description of NaCl solution used in the study

Treatment	Concentration (mM)	Electrical conductivity (dS/m)	Osmotic potential (MPa)
1	0	0	0
2	86	9.09	0.39
3	189	20.01	0.80
4	345	30.60	1.52

Measurements

In order to measure the root properties, plastic tubes were removed and root depth was recorded of each plant, firstly. Then, each pot was divided into 200 mm parts. Each part was transferred into the water and soil and roots floated in water for 20 min. The contents of each container were poured into the sieve and washed with well water and plunged within the distilled water. The prepared root samples were transferred to 4°C to reduce the microorganisms activity and prepare other samples. Then root parameters such as number, average area (cm^{-2}), average length (m), diameter (mm) and volume (cm^{-3}) were determined by using scanners and computer software Delta T-scan for different layers of soil depths between 0-140 cm that each layer was 200 mm, respectively. Root samples were dried for 48 h at 70ºC and weighed.

Salt tolerance as relative biomass production in saline to non-saline condition was considered as a salinity tolerance criteria.

Statistical Analysis

The trial for end harvest stage was arranged as a randomized complete block design with three replications. Statistical analysis was carried out using SAS *v.* 9.1 with the PROC ANOVA (SAS Institute, 2000). Data were first tested for normality with the Kolmogrov-Smirnov test, and then were analyzed using two-way analysis of variance (F-test). Significant test results were followed by LSD test for identification of important contrasts at 0.05 probability levels, respectively.

Artificial Neural Network Modelling

In this study, multilayer perceptron (MLP) with back-propagation learning rule was employed. The MLP network [also termed feed-forward back-propagation (BP) network] (Fig. 1) is a common architecture, probably the most popular network in engineering problems in the case of non-linear mapping that requires relatively little memory and is generally fast, is called the 'universal approximator' (Haykin, 1994; Lawrence, 1994).

The learning process was performed using the well known BP algorithm, the standard BP algorithm based on the delta learning rule (Rumelhart and McClelland, 1986). Two main processes were performed in a BP algorithm, with a forward pass and a backward pass. In the forward pass, an output pattern was presented to the network and its effect propagated through the network, layer by layer. For each neuron, the input value was calculated by the following Equation (1) (Haykin, 1994) :

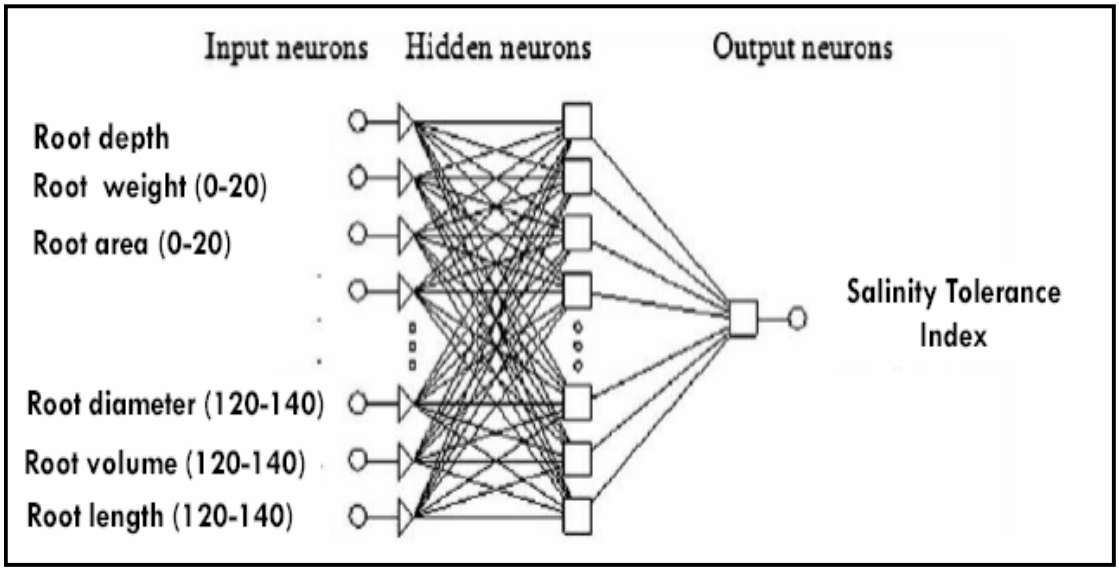

Fig. 1. Multilayer perceptron neural network for the estimation of salinity tolerance of blue panicgrass (*Panicum antidotale* Retz.) in artificial neural network (ANN) modelling.

$$net_i^n = \sum_{j=1}^{m} W_{ji}^n . O_j^{n-1} \quad (1)$$

Where, net^n_i is the input value of *i*th neuron in *n*th layer; W_{ji}^n is the connection weight between *i*th neuron in *n*th layer and *j*th neuron in the (n-1)th layer; O_j^{n-1} is the output of *j*th neuron in the (n-1)th layer; n is the number of neurons in the (n-1)th layer.

In each neuron, the value calculated from Equation (1) was transferred by an activation function.

The common function for this purpose is the sigmoid function, given by Equation (2).

$$Sig\ (net_i^n)=1/[1+Exp(-net_i^n)] \quad ...(2)$$

The output of each neuron was computed and propagated through the next layer until the last layer. Then, the final computed output of the network was prepared to compare with the target output. In this regard, an appropriate objective function such as the sum of square error (SSE) or the root mean square error (RMSE) was calculated following Equations (3) and (4) (Degroot, 1986) :

$$SSE = \sum_{i=1}^{n_p} \sum_{j=1}^{n_o} (T_{pj} - O_{pj})^2 \quad (3)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n_p} \sum_{j=1}^{n_o} (T_{pj} - O_{pj})^2}{n_p . n_o}} \quad (4)$$

Where, T_{pj} is the *j*th element of the target output related to the *p*th pattern;/O_{pj} is the computed output of *j*th neuron related to the pth pattern;/n_p is the number of patterns; n_o is the number of neurons in the output layer.

After calculating the objective function, the second step of the BP algorithm i. e. the backward process was started by back propagation of the network error to the previous layers. Using the gradient-descent technique, the weights were adjusted to reduce the network error by performing Equation (5) (Rumelhart and McClelland, 1986) :

$$\Delta w_{ji}^n|_{(m+1)} = \eta \frac{\partial(E)}{\partial w_{ji}^n} + \alpha \Delta w_{ji}^n|_{(m)} \quad (5)$$

Where, ΔW_{ji}^n is the weight increment at the (m-1) *th* interation (Epoch); η is the learning rate, and α is the momentum term ($0 \leq \eta, \alpha \leq 1$).

This process was continued until the allowable network error was obtained. For designing the ANN, the measured morphological root data were used. The number of available data collected for this study was 36. The data sets were shuffled; 22 of them were used for the learning process,

seven sets were used for testing, and the remaining seven sets were used for verification, respectively. The data sets for learning, testing and verification processes were selected randomly at different points on the morphological root traits to avoid bias in estimations. In this study, ANN models were performed using MATLAB software package (MATLAB, 2008). The number of neurons in input and output layers depends on the independent and dependent variables, respectively. The network was designed with 43 parameters as input pattern and the salinity tolerance index as the output parameter. The number of hidden layers, number of neurons in the hidden layers, and the number of interations were selected by calibration through several test runs and trial and error (Marquardt Levenberg learning rule). Various activation functions were tested for MLP neural networks and the tansigmoid function presented the best results.

Sensitivity Analysis

In order to identify the most important morphological root trait affecting salt tolerance of blue panicgrass, sensitivity analysis was performed using the StatSoft method (StatSoft Inc., 2004). A sensitivity ratio was calculated by dividing the total network error when the variable was treated as being not variable by the total network error when the actual values of the variable were used. A ratio greater than 1.0 implied, indicated that the variable made an important contribution to the variability in root morphological components. Variables with higher sensitivity ratio are more important (StatSoft Inc., 2004; Miao *et al.,* 2006).

RESULTS AND DISCUSSION

Effect of Salt Stress on Biomass Accumulation and Allocation

Shoot and root dry weight were significantly ($P<0.01$) decreased with increasing salinity (Table 2). Root dry weight was more sensitive to salinity than shoot dry weight (Table 3). Shoot dry weight was reduced by 6 and 43% at 189 and 345 mM, but increased by 11% at 86 mM salinity compared to control, respectively. Also, salinity stress caused reduction in root dry weight by 26, 54 and 54% at 86, 189 and 345 mM, respectively.

Table 2. Analysis of variance of biomass accumulation and allocation in root and shoot, morphological root traits of blue panicgrass (*Panicum antidotale* Retz.) in response to different salinity levels of irrigation water (0, 86, 189 and 345 mM NaCl solution)

Source	d. f.	Shoot weight	Root weight	Total biomass	R/TB	Root penetration	Root length	Root area	Root diameter	Root number	Root volume
Replication	2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Salinity	3	**	**	**	**	NS	**	*	*	**	**
C. V. (%)	-	15.1	22.1	11.9	15.6	6.65	11.2	11.9	14.0	11.9	11.6

R/TB–Root to total biomass ratio. NS : Not Significant.
*,**Significant at P=0.05 and P=0.01 levels, respectively.

Overall, salt stress strongly impaired biomass accumulation and significant ($P<0.01$) decrease in biomass accumulation was evident (Table 2). At the end of the experiment, biomass decreased by 48% in the severe saline stress (345 mM) as compared with the respective control condition (Table 3).

Similarly, assimilate allocation to root was affected by salinity levels significantly (Table 2). Highest assimilates were allocated to roots at control (46.6%) and lowest assimilates allocated at 345 mM (36.3%), respectively.

Effect of Salt Stress on Root Penetration and Root Length

Root penetration in the soil was reduced by increasing salinity but these reductions were not significant (Table 3). Also, root length significantly ($P<0.01$) reduced at all salinity treatments it was reduced by 9, 40 and 44% in 86, 189 and 345 mM NaCl solutions, respectively (Tables 2 and 3).

Table 3. Mean values of biomass accumulation and allocation in root and shoot, morphological root traits of blue panicgrass (*Panicum antidotale* Retz.) at different water salinity levels (0, 86, 189 and 345 mM NaCl solution)

Water salinity (mM NaCl)	Shoot weight (g/plant)	Root weight (g/plant)	Total biomass (g/plant)	R/TB (%)	Root penetration (cm)	Root length (m)	Root area (cm^2)	Root diameter (mm)	Root number	Root volume (cm^3)
0	3.46[a]	2.45[a]	5.91[a]	41.3[a]	137.0[a]	63.7[a]	872.0[a]	1.872[a]	244308[a]	46.6[a]
86	3.87[a](-11)	1.82[ab](26)	5.69[a](4)	32.3[ab](22)	133.3[a](2)	57.8[a](9)	560.0[ab](36)	1.662[ab](11)	253987[a](-25)	39.1[ab](16)
189	3.26[a](6)	1.12[b](54)	4.38[b](25)	25.7[b](38)	129.7[a](5)	45.1[b](40)	397.3[b](54)	1.425[b](24)	203238[ab](17)	31.9[bc](31)
345	1.96[b](43)	1.12[b](54)	3.08[c](48)	36.3[a](12)	120.0[a](12)	35.8[b](44)	324.5[b](62)	1.342[b](28)	163597[b](33)	29.8[c](36)
LSD (P=0.05)	0.950	0.721	1.14	10.6	17.28	11.4	326.0	0.441	51834	8.55

R–TB–Root to total biomass ratio.

Means within each column followed by the same superscript are not significantly different at $P<0.05$ based on LSD test.

Values in parentheses are percentage reductions compared with the water-treated control.

Effect of Salt Stress on Root Characteristics

The analysis of variance showed significant difference ($P<0.05$) for both area and diameter of roots among salinity treatments (Table 2). The lowest values for two traits were observed at 345 mM NaCl solutions (Table 3).

Salinity caused a significant ($P<0.01$) reduction in the number and volume of roots of blue panicgrass (Table 2). Root number and volume per plant progressively decreased with the rise in water salinity except at 86 mM NaCl solutions, which root number was increased 25%, compared to control (Table 3).

Artificial Neural Networks (ANN) Analysis of Salinity Tolerance of Blue Panicgrass Based on Root Morphological Traits

A feed-forward back-propagation Artificial Neural Network (ANN) approach (as illustrated in Fig.1) was utilized to estimate salt tolerance as root biomass accumulation in saline compared to non-saline condition with root morphological characters in different soil layers.

ANN Modelling

The data on best structures having optimum parameters (ANN structure : 43-87-1; Transfer function; Tangentical Sigmoid or Tansig; iterations : 7000; number of hidden layer : 1 and number of hidden neurons : 87) of the final selected ANN models could be used to predict the salinity tolerance of blue panicgrass. Each trained model had 22 input nodes and one output node. The hidden-layer nodes were determined to be 85, also, the optimum iterations learning rates were determined as 7000. The ANN root-salinity tolerance model resulted in R^2 and RMSE values of 0.95 and 0.013 for salinity tolerance of blue panicgrass, respectively. To calculate coefficients of determination (R^2) predicted data plotted versus observed data (Fig. 2).

Sensitivity Analysis

Average root weight : The relative importance of average root weight attributes in different soil layers with using sensitivity analysis based on coefficients of sensitivity of the ANN models is shown in Table 4. The parts with high values made an important contribution to the variability in salinity tolerance index. Average root weight of 60-80 cm soil layer was identified as the most important factor for salinity tolerance. Other important parts for predicting salinity tolerance included root weights of 40-60 and 0-20 cm layer of the soil with relative

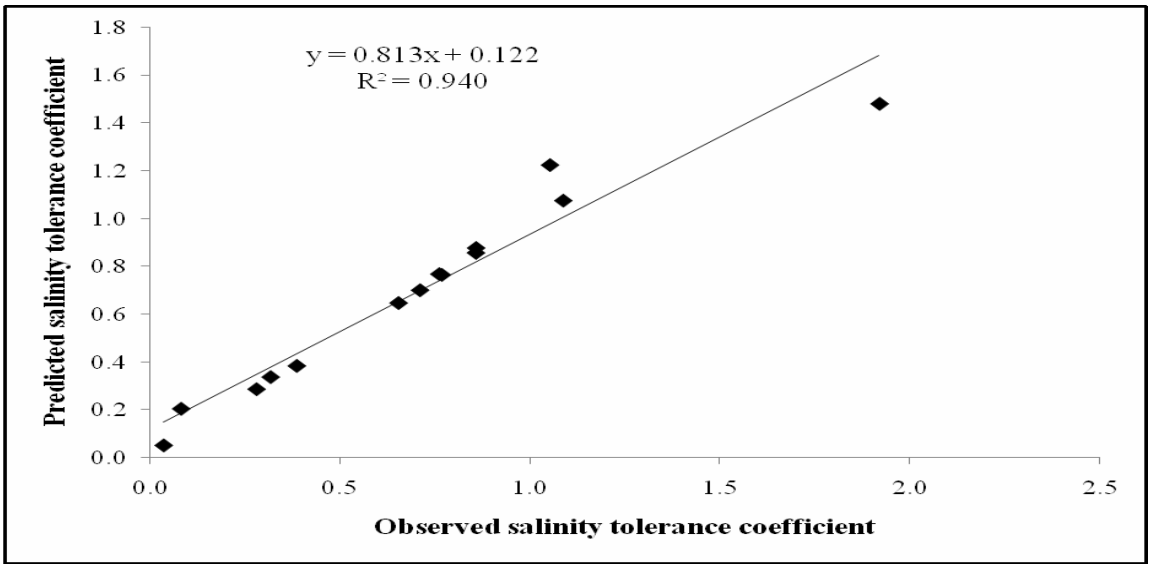

Fig. 2. Scatter plots displaying results of artificial neural network (ANN) predicted versus observed salinity tolerance for blue panicgrass plant (*Panicum antidotale* Retz.) from the validation data set.'s

coefficients of sensitivity in ranking as 2.01 and 1.99, respectively. Lowest relative coefficients of sensitivity belonged to root weight of 120-140 cm layer of the soil depth. Average dry weight of roots in 60-80 cm soil depth allocated almost 11% of the total root of each plant and had greater impact on the salinity tolerance. However, root dry weight in the 120-140 cm layer of the soil depth that was only about 3% of total dry weight was consistent with lower relative importance attribution in salinity tolerance (Table 5).

Average root area : Average root area of 60-80 cm layer of soil depth was identified as the most important part for salinity tolerance (Table 4), while its share was 12% of root area of each plant, respectively. Also, salinity tolerance showed the lowest sensitivity to root area of 120-140 cm layer that allocated 4% of plant root area. Other important parts for predicting salinity tolerance included root area of 20-40, 40-60 and 80-120 cm layers of soil depth with relative coefficients of sensitivity in ranking as 1.60, 1.54 and 1.53, respectively (Table 4).

Table 4. Sensitivity analysis based on StatSoft method, relative sensitivity coefficients of average weight, area, volume, number, length and diameter of plant root system in different layers of soil depth to salinity tolerance of blue panicgrass (*Panicum antidotale* Retz.)

Soil depth (cm)	Sensitivity coefficient					
	Average weight (g)	Average area (cm^2)	Average volume (cm^3)	Average number	Average length (mm)	Average diameter (mm)
0-20	1.992	1.417	1.421	1.527	2.795	2.923
20-40	1.836	1.607	1.898	1.716	1.535	1.547
40-60	2.008	1.543	2.490	1.486	1.629	1.887
60-80	2.160	2.466	1.823	2.408	1.530	2.174
80-100	1.876	1.534	2.107	1.702	2.798	1.380
100-120	1.676	1.400	1.444	1.483	2.795	2.409
120-140	1.330	1.468	1.451	1.452	1.442	1.527

Table 5. Summary statistics of average root weight and root number of blue panicgrass (*Panicum antidotale* Retz.) under different irrigation water salinity (0, 86, 189 and 345 mM NaCl solution) and growth stages (h_1 : beginning of tillering, h_2 : stem elongation, h_3 : panicle emergence and h_4 : seed ripening, respectively) in PVC cylinders experiment (n=48)

Character	Soil depth (cm)						
	0-20	20-40	40-60	60-80	80-100	100-120	120-140
				Average root weight (g)			
Min.	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Max.	0.778	0.924	0.433	0.419	0.365	0.343	0.162
Mean±S. E.	0.276±0.03	0.227±0.03	0.158±0.02	0.114±0.02	0.114±0.01	0.111±0.02	0.034±0.01
				Average root area (mm^2)			
Min.	161	0.00	0.00	0.00	0.00	0.00	0.00
Max.	17616	55159	12871	18632	8628	105516	8917
Mean±S. E.	6828±630	6398±1121	4618±469	4196±544	3217±410	5853±2189	1227±285
				Average root volume (cm^3/plant)			
Min.	0.20	0.00	0.00	0.00	0.00	0.00	0.00
Max.	11.0	12.5	7.51	7.36	6.81	6.58	4.32
Mean±S. E.	5.13±0.39	4.42±0.41	3.38±0.31	3.17±0.33	2.77±0.32	2.47±0.33	1.16±0.24
				Average root length (mm)			
Min.	283	0.00	0.00	0.00	0.00	0.00	0.00
Max.	16976	15803	14122	21526	9803	14169	9100
Mean±S. E.	6931±610	6155±506	5312±552	5103±612	3863±460	3814±556	1079±263
				Average root diameter (mm)			
Min.	0.929	0.00	0.00	0.00	0.00	0.00	0.00
Max.	3.297	1.886	2.097	2.980	2.243	2.449	3.392
Mean±S. E.	1.85±0.08	1.44±0.05	1.32±0.07	1.20±0.09	0.976±0.10	1.14±0.13	0.732±0.13
				Average root number (No.×100)			
Min.	2221	0.000	0.000	0.000	0.000	0.000	0.000
Max.	600	555	552	550	431	484	409
Mean±S. E.	278±19	282±19	228±21	214±21	172±19	161±22	56±12

Average root volume : Most important root volume of soil layers related to salinity tolerance observed in 40-60 cm (Table 4), on the other hand, salinity tolerance of blue panicgrass showed the lowest sensitivity to root volume at 0-20 layer. Other less important soil layers root volume included 80-100, 20-40 and 60-80 cm, respectively. Despite the large amount of plant root volume at 0-20 cm layer (about 23%), the attribution to salt tolerance was low, while the 40-60 cm layer by 15% of plant root volume had the most influence on blue panicgrass salinity tolerance (Tables 4 and 5).

Average root number : Average root number of 60-80 cm soil layer was identified as the most important soil layer to salinity tolerance (Table 4), and salinity tolerance of blue panicgrass showed the lowest sensitivity to average root number of 120-140 cm layer of soil depth. Other important layers for predicting salinity tolerance included root number of 20-40 and 80-100 cm layers, respectively. Although, average root number of 20-40 cm soil layer allocated 20% of total root number and had most value among different soil layers, but root number of 60-80 cm by 15% and 120-140 cm layer of soil depth by only 4% of the total number of plant roots, approximately, had the highest and the lowest relative importance to salinity tolerance (Tables 4 and 5).

Average root length : Average root length of 0-20, 80-100 and 100-120 cm layers of soil depth by 21, 12 and 12% of the total root length of each plant, respectively, were the most important parts for salinity tolerance (Tables 4 and 5), however, salinity tolerance of blue panic showed the lowest sensitivity to average root length of 120-140 cm layer (Table 4)., while the lowest root length of each plant was (about 4%) observed in this layer (Table 5).

Average root diameter : Average root diameter of 0-20 cm soil depth was identified as the most important soil layer regarding blue panicgrass salinity tolerance (Table 4). However, salinity tolerance of blue panic showed the lowest sensitivity to average root diameter at 80-100 cm soil layer. Other important parts for predicting salinity tolerance included root diameter of 100-120 and 60-80 cm layers, respectively. The difference between average root diameter at 0-20 cm and 80-100 cm layer of soil depth that had the most and the least attribute to salt tolerance was 0.9 mm or 47%, respectively (Table 5).

Although, the importance of plant root system and growth pattern is as significant or even more than the shoot characters regarding environmental stress tolerance, but it usually ignored in most studies due to difficulties and time consuming processing (Gregory, 2006; Taiz and Zeiger, 2008). Root systems grown in PVC cylinders are used to preliminary studies such as morphology, physiology, biochemical and ecological aspects of some of the plant roots. In this method, researchers can study separate environmental factors that may have unpredicted interaction with other components in natural or farm conditions (Bohm, 1979).

Water salinity induced significant reduction in root and shoot biomass accumulation. Shoot growth was less affected by salinity levels than root growth (Table 3). Our results disagree with Cordovilla *et al.* (1995) and Essa (2002), who stated that roots seemed to be more tolerant to salinity than shoots. The salt concentration in the soil solution reduced leaf growth and decreased stomatal conductance and thereby photosynthesis (Munns, 1993). As well as, Loveloke and Ball (2000) stated reduced carbon fixation could be responsible for less biomass accumulation, as could change in biomass allocation between leaf, stem and root, which could alter the balance of photosynthesis and respiration. However, it seems that change to allocation of assimilate to each part of plant in blue panicgrass had more reduction in the share of root than shoot (Table 2).

Shoot dry weight was increased by 11% at 86 mM NaCl solutions compared to non-saline treatment (Table 2). Flowers and Colmer (2008) reported that halophytes such as *Thellungiella halophyla* and *Suaeda maritime* showed optimal growth at low saline conditions. Blue panicgrass also showed the same reaction to salinity, therefore, it could classify as a halophyte plant.s

Root penetration was less affected by salinity and observed only 12% reduction at 345 mM NaCl solutions compared to control. On the other hand, in mild salinity stress (86 mM NaCl) root number was increased by 25% but other morphological root traits decreased (Table 2). With increasing salinity, root area was more sensitive than other characteristics and reduced by 54% at 189 mM NaCl compared to control. However, at 345 mM NaCl solutions, area, length, volume, number and diameter root of each plant had the highest reduction relative to non-saline condition, respectively. These observations showed that there was a great range of diversity in response of each root morphology attribute to salinity tolerance.

Artificial neural networks were used as desired instrument to identify most important root attributes for tolerating salinity. Then, the sensitivity coefficients of each root character were measured. Root penetration in the soil was the most important factor regarding salinity tolerance of blue panicgrass and root length and diameter were followed by root depth. Also, layer of soil depth or time of formation of morphological traits was effective in association with salinity tolerance. For example, the root length of 0-20 and 80-120 cm layers of soil depth were more important compared to other layers. However, it appears that 60-80 cm layer of soil depth plays a major role in salinity tolerance.

The results demonstrated that biomass accumulation in shoot of blue panicgrass as a euhalophyte plant increased in mild salinity stress, despite root dry matter was decreased. The ANN model has the potential to be useful as approach to investigate most important root attribute related to salinity tolerance and can improve other studies in this field. Based on sensitivity analysis, root penetration is the most effective trait in salinity tolerance of blue panicgrass (Fig. 3). Also, for the weight, area and number of roots, the greatest sensitivity coefficient was obtained at depth of 60-80 cm, while the length and diameter of roots at 0-20 cm had the greatest sensitivity coefficient that should be considered in bio saline production of blue panicgrass in arid and semi-arid regions.

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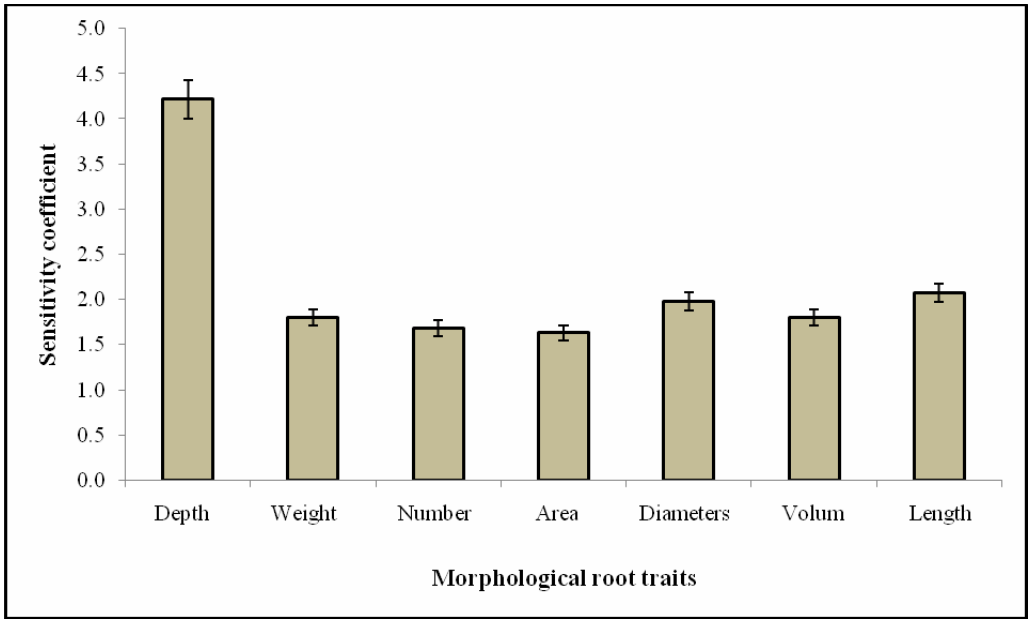

Fig. 3. Histogram displaying results of sensitivity analysis, means of relative sensitivity coefficients of morphological root traits in different layers of soil depth (from 0-140 cm with 200 mm part), for the salinity tolerance of blue panicgrass (*Panicum antidotale* Retz.).

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REFERENCES

Abdel-Ghani, A. H. (2009). Response of wheat varieties from semi-arid regions of Jordan to salt stress. *J. Agron. Crop Sci.* **195** : 55-65.

Bohm, W. (1979). *Method of Studying Root Systems.* Springer-Verlag, New York.

Caudill, M. and Butler, C. (1992). *Understanding Neutral Networks : Computer Explorations.* The MIT Press, Cambridge, MA.

Cordovilla, M. P., Ocaña, A., Ligero, F. and Lluch, C. (1995). Salinity effects on growth analysis and nutrient composition in four grain legumes-rhizobium symbiosis. *J. Plant Nutr.* **18** : 1595-1609.

Degroot, M. (1986). *Probability and Statistics.* Addison-Wesley Press, Reading, MA.

Dittmer, H. J. (1949). Root hair variation in plant species. *Amer. J. Bot.* **36** : 152-55.

Essa, T. A. (2002). Effect of salinity stress on growth and nutrient composition of three soybean [*Glycine max* (L.) Merrill] cultivars. *J. Agron. Crop Sci.* **188** : 86-93.

FAO (2010). Country Profiles. *Website : www.fao.org/countryprofiles/index.asp?lang= en&iso3=FIN.*

Flowers, T. J. and Colmer, T. D. (2008). Salinity tolerance in halophytes. *New Phytologist* **179** : 945-63.

Gorzalczany, M. B. (2002). *Computational Intelligence Systems and Applications.* Physica-Verlag Company, Heidelberg, Germany.

Gregory, P. J. (2006). *Plant Roots, Growth, Activity and Interaction with Soil.* Blackwell Publishing Ltd.

Halvorson, W. L. and Guertin, P. (2003). Fact sheet for *Panicum antidotale* Retz. Funded by U. S. Geological Survey National Park Service. pp. 1-21.

Haykin, S. (1994). *Neural Networks : A Comprehensive Foundation.* MacMillan, New York, NY.

Kafi, M., Asadi, H. and Ganjeali, A. (2010). Possible utilization of high-salinity waters and application of low amounts of water for production of the halophyte Kochia scoparia as an alternative fodder in saline agroecosystems. *Agric. Water Manage.* **97** : 139-47.

Kafi, M. and Khan, M. A. (2008). *Crop and Forage Production Using Saline Waters.* Daya Publishers, New Delhi, India.

Lawrence, J. (1994). *Introduction to Neural Networks.* California Scientific Software Press, Nevada, CA.

Loveloke, C. E. and Ball, M. C. (2000) Influence of salinity on photosynthesis of halophytes. In : *Salinity : Environment-Plants-Molecules,* A. Lauchli and U. Luttge (eds.).

MATLAB (2008). *Neural Network TOOLBOX.* Mathworks Inc., Natick, MA, USA.

Miao, Y., Mulla, D. J. and Robert, P. C. (2006). Identifying important factors influencing corn yield and grain quality variability using artificial neural networks. *Precise Agric.* **7** : 117-35.

Munns, R., James, R. A. and Läuchli, A. (2006). Approaches to increasing the salt tolerance of wheat and other cereals. *J. Exp. Bot.* **57** : 1025-43.

Munns, R. and Tester, M. (2008). Mechanisms of salinity tolerance. *Ann. Rev. Plant Biol.* **59** : 651-81.

Norouzi, M., Ayoubi, S., Jalalian, H., Khademi, A. and Dehghani, A. (2009). Predicting rainfed wheat quality and quantity by artificial neural network using terrain and soil characteristics. *Acta Agric. Scandin. Section B–Plant Soil Science.* pp. 1-12.

Rumelhart, D. E. and McClelland, J. L. (1986). Parallel recognition in modern computers. Explorations in the Microstructure of Cognition. MIT Press.

Russel, R. S. (1977). *Plant Root Systems : Their Function and Interaction with the Soil.* McGraw-Hill, London.

SAS Institute (2000). *SAS/STAT User's Guide, Release 8.* SAS Institute, Cary, NC.

StatSoft Inc. (2004). Electronic statistics textbook (Tulsa, OK, USA). *http://www.statsoft.com/textbook/stathome.html.*

Steingrobe, B., Schmid, H., Gutser, R. and Claassen, N. (2001). Root production and root mortality of winter wheat grown on sandy and loamy soils in different farming systems. *Bio. Fertil. Soil* **33** : 331-39.

Taiz, L. and Zeiger, E. (2008). *Plant Physiology, 5th edn.* Sinauer Associates, Sunderland, MA.

Taylor, H. M. and Klepper, B. (1975). Water uptake by cotton root systems : An examination of assumptions in the single root model. *Soil Sci.* **120** : 57-67.

Wiersum, L. K. (1957). The relationship of the size and structural rigidity of pores to their penetration of roots. *Plant and Soil* **9** : 75-85.