EMERGENCE AND GROWTH OF CORN AND SOYBEAN UNDER SALINE STRESS

Flávio Favaro Blanco[1]*; Marcos Vinícius Folegatti[2]; Hans Raj Gheyi[3]; Pedro Dantas Fernandes[3]

[1]*Embrapa Meio Norte - Av. Duque de Caxias, 5650 - 64006-220 - Teresina, PI - Brasil*
[2]*USP/ESALQ - Depto. de Engenharia Rural, C.P. 9 - 13418-900 - Piracicaba, SP - Brasil.*
[3]*UFCG/CTRN - Unidade Acadêmica de Engenharia Agrícola, C.P. 10.087 - 58109-970 - Campina Grande, PB - Brasil.*
Corresponding author <flavio@cpamn.embrapa.br>

ABSTRACT: Emergence and seedling growth may be severely affected by salinity, mainly for sensitive crops. The objective of the present study was to verify the tolerance of corn and soybean to the irrigation water salinity (EC_i) during the emergence and initial development stages. Seeds of corn, hybrid 'AG-6690', and soybean, cv. 'Conquista', were sown in pots containing material from a sandy-loam soil and irrigated with water of increasing salinity levels, from 0.3 to 5.9 dS m^{-1}, giving nine levels of EC_i obtained by the addition of an equivalent proportion of sodium and calcium chloride, except for $EC_i = 0.3$ dS m^{-1} (tap water). Emergence of corn was not affected by salinity but seedling development was reduced for EC_i above 1.5 dS m^{-1}. Emergence and growth of soybean were reduced by water salinity and the crop was more tolerant during the emergence ($EC_i = 2.7$ dS m^{-1}) than in the initial development ($EC_i = 1.0$ dS m^{-1}) stage. Salinity of soil solution (EC_s) was linearly correlated to EC_i and affected the growth of corn and soybean for EC_s higher than 3 and 2 dS m^{-1}, respectively.
Key words: *Zea mays*, *Glycine max*, salinity tolerance, soil solution

EMERGÊNCIA E CRESCIMENTO DO MILHO E DA SOJA SOB ESTRESSE SALINO

RESUMO: A emergência e o crescimento inicial podem ser severamente afetados pela salinidade, principalmente para culturas sensíveis. O objetivo do presente estudo foi verificar a tolerância do milho e da soja à salinidade da água de irrigação (CE_i) nas fases de emergência e desenvolvimento inicial das plantas. Sementes de milho, híbrido 'AG-6690', e soja, cv. 'Conquista', foram semeadas em vasos contendo material de solo franco-arenoso e irrigadas com água de níveis crescentes de salinidade, variando de 0,3 a 5,9 dS m^{-1}, totalizando nove níveis de CE_i obtidos pela adição de cloreto de sódio e de cálcio em proporções equivalentes, exceto para $CE_i = 0,3$ dS m^{-1} (água de torneira). A emergência do milho não foi afetada pela salinidade da água, mas o desenvolvimento das plantas foi reduzido para CE_i acima de 1,5 dS m^{-1}. A emergência e o crescimento da soja foram reduzidos pela salinidade, sendo mais tolerante na fase de emergência ($CE_i = 2,7$ dS m^{-1}) do que no desenvolvimento inicial das plantas ($CE_i = 1.0$ dS m^{-1}). A salinidade da solução do solo (CE_s) foi linearmente correlacionada à CE_i e afetou o crescimento do milho e da soja para CE_s acima de 3 e 2 dS m^{-1}, respectivamente.
Palavras-chave: *Zea mays*, *Glycine max*, tolerância, solução do solo

INTRODUCTION

Soybean (*Glycine max* L.) and corn (*Zea mays* L.) occupy, respectively, the second and third positions among the most cultivated crops in Brazil, with productions of 49 and 42 million tons in the year 2004; the sum of the areas harvested of these crops is close to 35 million hectares in the country (IBGE, 2005). The utilization of irrigation for corn and soybean production, mainly in the winter season, has increased substantially along years in Brazil (SEAGRO, 2005; Gomes, 2005; Moreira et al., 2000), but few studies have been carried out on the tolerance of these crops

to salinity. Azevedo Neto & Tabosa (2000) verified a significant reduction of dry matter of shoot for salinity levels above 9.6 dS m^{-1} in nutrient solution for a sensitive cultivar and over 12 dS m^{-1} for a tolerant cultivar of corn, indicating that there are differences of salinity tolerance among cultivars.

One of the primary effects of salt stress is that it delays germination and emergence; most crops are tolerant during germination but the young developing seedlings are susceptible to injury during emergence from the soil and during early development (Maas & Grattan, 1999). Data reported by Essa (2002) showed that reduction of 8% in germination percentage and of

4% in plant height and in dry weight, at 45 days after planting of soybean cv. 'Lee', occurred for unitary increase of soil salinity (EC_e) above 0.5 dS m^{-1}. The reduction of soybean growth under saline conditions can be attributed to N deficiency, once the number of nodules and their size are severely affected by the increasing salinity of the growing media (Singleton & Bohlool, 1984), and to the reduction of the hydraulic conductivity of the root system (osmotic effect), with reduction of water delivery to the shoot (Joly, 1989).

The method usually employed to represent the tolerance of crops to salinity is the piecewise linear response model (Maas & Hoffman, 1977):

$$Yr = \begin{cases} 1 & 0 \le c \le c_t \\ 1 - s\left(c - c_t\right) & c_t < c \le c_0 \\ 0 & c > c_0 \end{cases} \quad (1)$$

where Yr is the relative yield, c is the mean salinity expressed as electrical conductivity of the solution in the root zone during the cultivation period (dS m^{-1}), c_t is the threshold salinity (dS m^{-1}), c_0 is the salinity beyond which the yield is zero (dS m^{-1}) and s is the absolute value of the slope of the response function between c_t and c_0.

Several experiments have been conducted along the years to quantify this type of response of the crops to salinity (Steppuhn et al., 2005; Khan et al., 2003; El-Haddad & Noaman, 2001). Van Genuchten (1983) developed a software capable to make the adjustment of this model to data obtained in groups of experiments, which is particularly interesting for experiments repeated along years or seasons.

The objective of the present study was to determine the tolerance of corn and soybean to salinity of the irrigation water and of the soil solution during the emergence and seedling initial growth.

MATERIAL AND METHODS

The experiment was carried out in Piracicaba (22°42'S and 47°37'W), SP, Brazil, in a greenhouse covered with polyethylene film with anti-aphid screens in the laterals. Seeds of corn and soybean were sown in pots, 0.35 m diameter at the top, containing 60 kg of a soil material collected from the 0-0.30 m layer of a sandy-loam Typic Hapludox. Perforations were made at the bottom of the pots and a gravel layer of 0.03 m, covered with a polypropylene sheet, was displaced at the bottom to allow the drainage of the excess water. The pots were spaced 0.50 × 1.00 m.

The corn hybrid 'AG-6690' and of the soybean, cv. 'Conquista', were sown at a distance of 0.15 m and 0.075 m, in a single line, using four and three seeds in each sowing position, respectively. In this way, 12 seeds of corn and 15 of soybean were sown in each vase at a depth of 2 cm (Figure 1).

The treatments were composed of nine levels of electrical conductivity of the irrigation water (EC_i = 0.3, 1.0, 1.7, 2.4, 3.1, 3.8, 4.5, 5.2 and 5.9 dS m^{-1}), which were obtained by the addition of NaCl and $CaCl_2$ in the equivalent proportion of 1:1 (concentration of NaCl+$CaCl_2$ of 0.00, 0.39, 0.82, 1.29, 1.80, 2.35, 2.94, 3.27 and 4.24 g L^{-1}, respectively). Each vase was irrigated with the respective saline solution before planting in order to obtain levels of soil salinity. The experimental design consisted of completely randomized blocks, with a single factor (EC_i) and with three replicates, totaling 27 pots for each crop.

Two tensiometers at 0.15 and 0.30 m depth and one soil solution extractor at 0.15 m depth were installed in each vase for irrigation control and monitoring of the electrical conductivity of the soil solution (EC_s). Irrigations were accomplished by treatment whenever the mean matric potential of both tensiometers approached –30 kPa, the water in each treatment being applied manually, without leaf wetting. The volume of water applied was calculated based on the water retention curve of the soil, allowing for a leaching fraction of at least 0.20 to avoid excessive build up of EC_s.

Soil solution was collected at the beginning of the experimental period and after each irrigation, when the electrical conductivity of the solution (EC_s) was measured. Vacuum of about -70 kPa was applied to solution extractors after irrigation, when the soil matric potential was close to field capacity (about -6 kPa) and soil solution was taken from the extractor 24 h after vacuum application. The concentrations of NO_3^-, K^+ and Na^+ in soil solution were also determined in the first sampling taken six days after sowing, using cardy-ion meters.
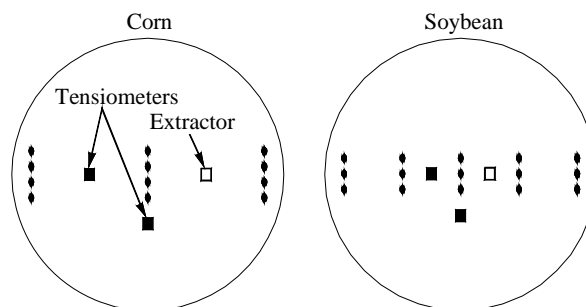

Figure 1 - Schematic representation of the planting positions of corn (with four seeds in each position) and soybean (three seeds per position) and the locations of tensiometers and soil solution extractor.

The study was conducted during two growing seasons in order to obtain more precise results, once salinity tolerance may be affected by meteorological conditions and also by other factors, such as the salt accumulation in the soil profile along various cropping seasons. The first growing season was from 04/26/2003 to 05/19/2003 and the second from 05/23/2003 to 07/01/2003. The smaller time of the first cultivation (23 days) in relation to the second (39 days) was due to the symptoms of phosphorus deficiency exhibited by the corn seedlings beginning from the 20th DAS (day after sowing), which did not appear in the second cultivation period, in which 20 g of monoammonium phosphate and 3.3 g KCl were applied to each vase, after diluting in the water used in the first irrigation.

During the first growing season, water was not applied immediately after sowing, because the soil was sufficiently wet due to the application of saline water for the salinization of the soil before planting. During the second season, 5 L of water were applied to each vase after sowing. Only one irrigation (5 L per vase) was added in the first growing period, at 10 DAS, and in the second growing period, besides the irrigation applied after sowing, 5 L of water were also applied at 25 DAS to each vase, giving a leaching fraction of about 0.35, in an attempt to maintain an uniform EC_s in the soil profile.

The number of emerged plants was determined everyday after sowing, which was accomplished up to the 14th and 20th DAS, respectively, for the first and second growing seasons, because the low temperatures during the second season delayed germination (Figure 2).

The emergence percentage (PE) was calculated from the total number of plants emerged in each vase and the speed of emergence (SE) was calculated as suggested by Maguire (1962):

$$SE = \frac{E_1}{N_1} + \frac{E_2}{N_2} + \dots + \frac{E_n}{N_n} \tag{2}$$

where E_1, E_2 and E_n are the number of emerged plants, and N_1, N_2 and N_n are the number of days after sowing computed in the first, second and last countings, respectively. For the calculation of SE, the emergence period for each season corresponded to the day of maximum emergence for all pots, that is, the 13 DAS for the first season and 17 DAS for the second.

The seedlings of corn and soybean were collected from each vase at 10 and 20 DAS, respectively, for the first and second growing seasons, and only three seedlings of corn and five of soybean, that is, only one seedling in each sowing position were kept
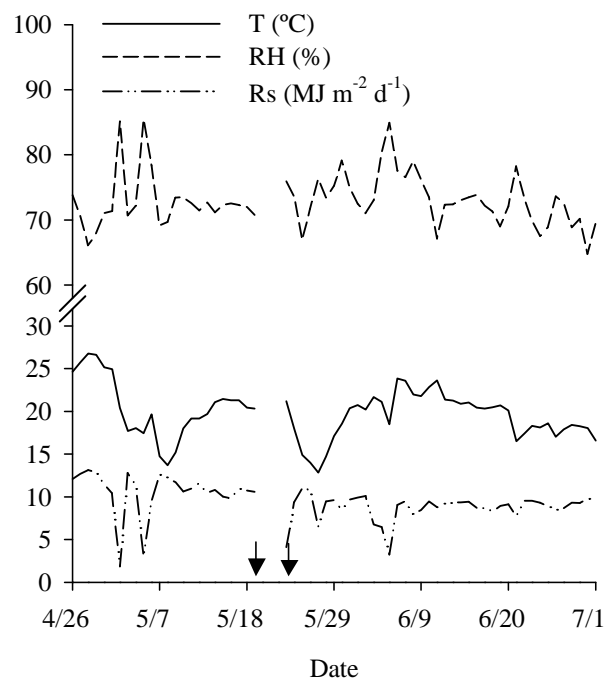

Figure 2 - Variations of temperature (T), relative humidity (RH) and global solar radiation (Rs) inside the greenhouse during the experimental period. The arrows indicate the end of the first growing season and the beginning of the second growing season.

in the pots. At the end of each cultivation period, the central seedlings of each vase (one seedling of corn and three seedlings of soybean) were collected. The seedlings were cut at the soil surface level and oven-dried at 60°C, and the mean dry weight per plant was evaluated. The dry weight of soybean was computed separately for stem and leaves in the last sampling for the two growing periods. The absolute (AGR) and relative (RGR) growth rates were determined as recommended by Benincasa (1988):

$$AGR = \frac{D_2 - D_1}{T_2 - T_1} \tag{3}$$

$$RGR = \frac{\ln(D_2) - \ln(D_1)}{T_2 - T_1} \tag{4}$$

where D_1 and D_2 are the mean dry weights (g) in the first and second collections, respectively, and T_1 and T_2 refer to time interval (days after sowing) of the collections for each growing period. The leaf weight ratio (LWR) was determined dividing the leaf dry weight by the total dry weight. Plant height was measured before cutting by measuring the distance between the soil surface and the growing point for soybean and, for corn, the leaves were extended upwards and the maximum distance between soil surface and leaf tip was measured.

The parameters s and c_t (equation 1) were estimated using the software SALT (Van Genuchten, 1983), which makes the adjustment of the regression model by the piecewise linear regression method. The adjustments of the PE and SE were performed only in relation to EC_i, once EC_s in the shallower layer of the soil may be assumed to be equal to the salinity of the water that infiltrates in the soil (Rhoades et al., 2000); thus, as seedlings were sown at 2 cm depth, the EC_i and EC_s are the same for the emergence stage. The dry weight of the seedlings was confronted with EC_i and with the mean values of EC_s determined for each growing season.

RESULTS AND DISCUSSION

The percentage of emergence (PE) and the speed of emergence (SE) of corn were not affected by the electrical conductivity of the irrigation water (EC_i), while for soybean, EC_i responded to both variables (Table 1). Effects of EC_i on PE and SE for soybean were practically the same and they were reduced for the second growing season for all levels of EC_i due to the higher salinity of the soil solution as a result of salt accumulation in the soil profile with the successive irrigations (Figure 2). Mean EC_i threshold (c_t) for relative values of PE and SE for soybean was about 2.7 dS m^{-1}, with a reduction of 20% for each unitary increase of EC_i above c_t; the emergence was completely inhibited when EC_i was close to 8.0 dS m^{-1}, determined by extrapolation (c_o = 7.9 dS m^{-1}).

The results for corn are in agreement with Maas (1984), who stated that corn may tolerate high salinity (up to 24 dS m^{-1}) in soil saturation extract (EC_e) at germination. In the present study, although the data refers to EC_i, EC_e was below the cited threshold value, once the highest electrical conductivity of the soil solution (EC_s) was 7.12 dS m^{-1} and it probably was higher than EC_e because only highly soluble salts were used.

The ability of a seed to germinate and emerge under salt stress indicates that it has a genetic potential for salt tolerance, at least at this stage in the life cycle, but this does not necessarily indicate that a seedling germinated under salt stress could continue under salt stress and that the plant could complete its life cycle (Essa, 2002).

Salinity affected the plant height (PH), total dry weight (TDW) and absolute growth rate (AGR) of corn in both growing periods (Table 2). Relative values of TDW and AGR were more sensible to EC_i than PH; the threshold EC_i for TDW and AGR was 1.5 dS m^{-1}, with reduction of 22% for unitary increase of EC_i above 1.5 dS m^{-1}, while c_t and s for PH were 1.9 dS m^{-1} and 13%, respectively (Table 3).

The absence of response of RGR shows that the growth obtained relative to the amount of tissue present was the same for all levels of EC_i, that is, the growth potential of corn 'AG6690'seedling under low and high salinity was the same. Otherwise, the growth speed was lower for high EC_i, once AGR was reduced for EC_i above 1.5 dS m^{-1}.

Dry weight of leaf (DWL) and stem (DWS) of soybean were affected by EC_i in the first growing period, as well as total dry weight (TDW), but PH, LWR and the physiological indexes were not sensitive to salinity (Table 4). During the second growing period, only LWR was not affected by salinity.

A little increase in DWL, DWS and TDW occurred for the EC_i of 1.0 dS m^{-1} in relation to tap wa-

Table 1 - Percentage (PE) and speed (SE) of emergence for corn and soybean seeds for different levels of electrical conductivity of the irrigation water (EC_i) and summary of the analysis of variance for each growing season.

EC_i	Season 1		Season 2	
	PE	SE	PE	SE
dS m^{-1}	%	seeds day^{-1}	%	seeds day^{-1}
	Corn			
0.3	97	2.2	83	1.3
1.0	92	1.9	81	1.2
1.7	89	1.9	92	1.3
2.4	83	1.7	78	1.1
3.1	86	1.8	83	1.2
3.8	67	1.5	86	1.1
4.5	89	1.8	89	1.2
5.2	72	1.4	86	1.1
5.9	58	1.1	78	1.0
F Test§	ns	ns	ns	ns
CV# (%)	19.3	26.4	16.3	17.6
	Soybean			
0.3	98	3.8	56	1.1
1.0	89	3.0	76	1.5
1.7	93	3.3	78	1.5
2.4	96	3.3	87	1.6
3.1	87	3.0	62	1.1
3.8	76	2.6	62	1.1
4.5	80	2.4	40	0.7
5.2	56	1.6	31	0.5
5.9	47	1.3	7	0.1
F Test§	**	**	**	**
CV# (%)	14.8	19.1	24.5	28.6

§ns non-significant; **significant at 0.01 by the test F; #CV - coefficient of variation

Table 2 - Means and F test for electrical conductivity of the soil solution (EC_s), plant height (PH), total dry weight (TDW) and absolute (AGR) and relative (RGR) growth rates of corn irrigated with waters of different salinities (EC_i).

EC_i	EC_s	PH	TDW	AGR	RGR
--- dS m^{-1} ---		cm	mg	mg d^{-1}	mg mg^{-1} d^{-1}
Growing season 1					
0.3	0.68	38.7	569	48	0.152
1.0	1.02	37.5	410	34	0.153
1.7	1.94	33.8	396	29	0.119
2.4	2.34	29.0	300	24	0.146
3.1	2.90	28.3	387	31	0.146
3.8	3.91	36.7	398	35	0.180
4.5	4.17	30.5	396	35	0.182
5.2	4.39	27.5	266	22	0.153
5.9	5.07	20.8	151	11	0.095
F Test§	**	*	**	*	ns
CV# (%)	13.9	17.8	27.2	36.5	30.0
Growing season 2					
0.3	0.87	100.7	12730	654	0.195
1.0	1.66	102.7	10970	562	0.190
1.7	3.51	102.0	12680	651	0.196
2.4	3.88	97.3	9750	501	0.193
3.1	4.27	83.3	5620	287	0.184
3.8	5.62	73.7	4270	218	0.186
4.5	6.07	72.7	5490	283	0.199
5.2	6.97	50.4	1270	63	0.126
5.9	7.12	47.3	1530	140	0.167
F Test§	**	**	**	**	ns
CV# (%)	14.1	11.2	41.6	41.7	34.3

§ ns non-significant; *, ** significant at 0.05 and 0.01 level by the test F, respectively; #CV - coefficient of variation.

Table 3 - Values of threshold salinity (c_t), slope (s) and salinity for zero yield (c_0) adjusted from the electrical conductivity of the irrigation water (EC_i) and soil solution (EC_s) by the model SALT (Van Genuchten, 1983), for traits (relative values) of corn and soybean.

Variable#	EC_i			EC_s		
	c_t	s	c_0	c_t	s	c_0
	------------------- dS m^{-1} -------------------					
Soybean						
PE	2.8	0.19	7.9	-	-	-
SE	2.6	0.20	7.7	-	-	-
PH	0.9	0.14	8.1	2.5	0.13	10.0
DWL	1.0	0.21	5.6	2.1	0.18	7.6
DWS	0.8	0.22	5.4	2.0	0.18	7.4
TDW	1.0	0.22	5.5	2.1	0.18	7.5
AGR	0.6	0.22	5.2	1.6	0.17	7.6
RGR	2.4	0.16	8.5	4.6	0.20	9.7
Corn						
PH	1.9	0.13	9.6	3.5	0.14	10.7
TDW	1.5	0.22	6.0	3.0	0.22	7.6
AGR	1.5	0.22	6.1	2.7	0.18	8.3

#PE=Percentage of emergence; SE=speed of emergence; PH=plant height; DWL=dry weight of leaves; DWS=dry weight of stem; TDW=total dry weight; AGR=absolute growth rate; RGR=relative growth rate.

(Silva et al., 2003; Agong et al., 2003, Kaya et al., 2003). The soybean variety 'Conquista' presented no ability in adjusting the photosynthetic capacity in high saline conditions; the LWR was not affected by salinity, thus the leaf area decreased with reduction of the DWL.

The mean reduction of DWL, DWS and TDW for soybean was of 22% for each unitary increase in EC_i above 1.0 dS m^{-1} and the EC_i of 5.5 dS m^{-1} resulted in no plant development (Table 3). The lower c_t and higher s for AGR (0.6 dS m^{-1} and 0.22, respectively) than for RGR (2.4 dS m^{-1} and 0.16, respectively) reveals that the growing speed of the plants was more affected by salinity than the growth potential. Therefore, soybean growth is delayed by salinity and high EC_i also affects the dry matter accumulation in relation to preexisting dry matter. The results of this study are in agreement with those of Moraes & Menezes (2003) and Wang & Shannon (1999), who reported that shoot growth of soybean is more affected by salinity than the PE.

The EC_s was linearly correlated to EC_i for both crops, being higher for the second than for the first growing period (Figure 3). When data of each variable were adjusted as a function of EC_s (Table 3) it

ter (0.3 dS m^{-1}) for both growing periods. Generally Na$^+$ is not essential for most plants, although their growth may be stimulated at low Na$^+$ concentrations because it might serve as an *osmoticum* in the vacuole, reducing plants need for K$^+$ (Marschner, 1995). Thus, for plants irrigated with water of 1.0 dS m^{-1}, the soybean seedlings may have accumulated Na$^+$ in their vacuoles, which partly could have compensated the lower K$^+$ uptake and promoted a higher growth than the plants irrigated with tap water.

Besides the ability of some plants to accumulate salts in cells in order to reduce the osmotic potential under saline stress (Munns, 2002), moderate and high levels of NaCl may lead to toxicity by Na$^+$ and Cl$^-$ (Tester & Davenport, 2003) and growth reduces according to the severity of the imposed stress

Table 4 - Means and results of test F for electrical conductivity of the soil solution (EC$_s$), plant height (PH), dry weight of leaves (DWL), stem (DWS) and total (TDW), absolute (AGR) and relative (RGR) growth rates and leaf weight ratio (LWR) of soybean irrigated with waters of different salinities (EC$_i$).

EC$_i$	EC$_s$	PH	DWL	DWS	TDW	AGR	RGR	LWR
-------- dS m^{-1} --------		cm	mg	----------------- mg d^{-1} -----------------			mg mg^{-1} d^{-1}	
Growing season 1								
0.3	1.1	18.7	307	137	444	29	0.098	0.69
1.0	1.4	19.3	333	133	466	33	0.113	0.71
1.7	1.8	18.3	286	125	411	26	0.094	0.70
2.4	2.2	18.7	273	123	396	25	0.093	0.69
3.1	3.4	17.7	271	112	383	25	0.094	0.71
3.8	3.8	17.8	289	126	415	29	0.115	0.70
4.5	4.0	16.0	249	103	352	24	0.107	0.71
5.2	4.6	17.3	240	104	344	18	0.097	0.70
5.9	4.9	14.2	199	84	283	24	0.096	0.70
F Test[§]	**	ns	**	**	**	ns	ns	ns
CV[#] (%)	15.8	12.8	24.4	21.7	22.8	16.4	16.9	2.2
Growing season 2								
0.3	0.8	45.0	2548	1592	4140	238	0.143	0.61
1.0	2.1	44.7	3102	1693	4796	236	0.145	0.65
1.7	2.9	38.6	2016	1117	3132	152	0.136	0.64
2.4	4.0	37.9	2040	1129	3169	157	0.149	0.65
3.1	5.3	31.2	1232	602	1834	86	0.118	0.67
3.8	5.8	30.1	1113	536	1649	95	0.126	0.68
4.5	6.4	20.9	567	325	892	31	0.086	0.65
5.2	6.6	14.3	333	132	465	-	-	0.71
5.9	7.1	17.0	270	140	410	-	-	0.66
F Test[§]	**	**	**	**	**	**	**	ns
CV[#] (%)	10.5	11.7	20.1	23.5	14.8	8.4	5.6	8.3

[§]ns Non-significant; **significant at 0.01 level by the test F; [#]CV - coefficient of variation.

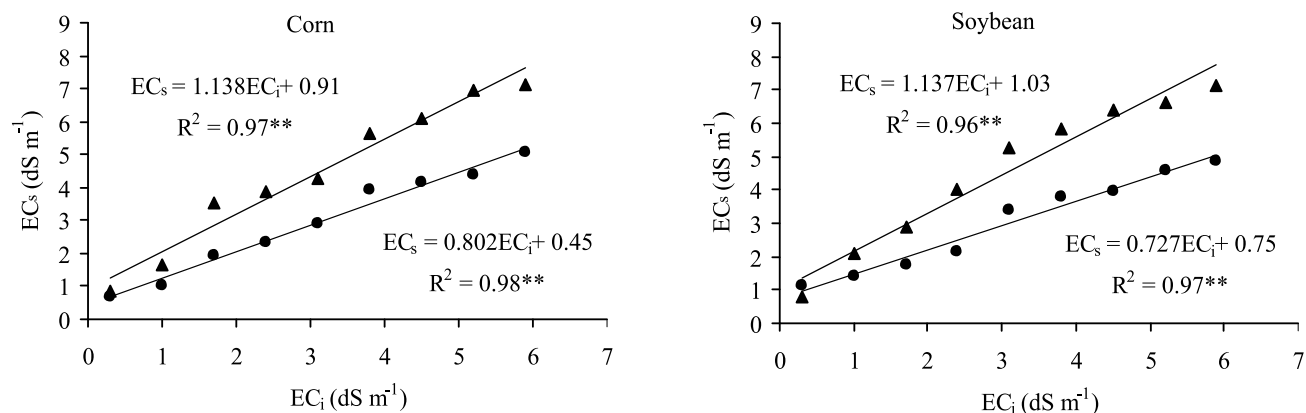

Figure 3 - Mean electrical conductivity of soil solution (EC$_s$) in the first (●) and second (▲) growing periods of corn and soybean, as a function of electrical conductivity of the irrigation water (EC$_i$).

was observed that the salinity threshold was about two times higher than c$_t$ for data adjusted to EC$_i$, as a result of the concentration factor (the concentration of salts in soil after successive irrigations).

Willadino et al. (1994) tested eight cultivars of corn in relation to salinity and all of them survived and had heights above 1.5 m when grown in saline soil with electrical conductivity of the saturation extract (EC$_e$)

of 9.9 dS m^{-1}. Considering that the EC$_e$ is generally lower than EC$_s$ (Blanco, 2004; Eymar et al., 2001; Rieu et al., 1998), the results of total dry weight of corn in relation to EC$_s$ (Table 3) allow us to conclude that seedling development at EC$_e$ of 9.9 dS m^{-1} is not possible, agreeing with Maas & Hoffman (1977), who reported that at EC$_e$ of 10 dS m^{-1} was corn growth ceases.

In the emergence stage the soybean 'Conquista' was less sensible to salinity of the irrigation water than in the seedling growth stage. Waters up to 2.8 dS m^{-1} may be used for germination without reduction of the stand, but after emergence EC$_i$ above 1.0 dS m^{-1} should be avoided, which lead to severe damage for plant growth. Although little reductions of emergence of corn 'AG6690' were observed for the mean data, it was not sensitive to salinity; on the other hand, irrigation with water of EC$_i$ above 1.5 dS m^{-1} is deleterious for seedling growth with severe reduction of plant development.

The optimal concentrations of NO$_3^-$ and K$^+$ in the early half of the season for most crops are 220-330 and 20-60 mg L^{-1}, respectively (Burt et al., 1998; Tisdale et al., 1993). At the beginning of each growing period, the concentrations of NO$_3^-$ and K$^+$ in soil solution were in this range for most treatments (Table 5). The concentration of Na$^+$ in soil solution increased linearly with EC$_i$ and the concentration for each treatment was, on average, 73% higher in the second growing period in comparison to the first (Figure 4). The increase in concentration of K$^+$ with EC$_i$ could be attributed to the replacement of K$^+$ from the exchange complex by Na$^+$, which allowed higher K$^+$ in soil solution.

The results of this study show that the response of corn and soybean to salinity is quite different. While soybean is more tolerant to salinity than corn

Table 5 - Concentration of NO$_3^-$, K$^+$ and Na$^+$ in soil solution at the beginning of each growing period of corn and soybean, for each electrical conductivity of the irrigation water (EC$_i$).

EC$_i$	NO$_3^-$	K$^+$	Na$^+$	NO$_3^-$	K$^+$	Na$^+$
dS m^{-1}	-------------------- mg L^{-1} --------------------					
	Growing season 1			Growing season 2		
	Corn					
0.3	217	34	37	228	32	45
1.0	230	71	76	177	79	93
1.7	177	98	167	193	96	247
2.4	186	78	183	200	120	330
3.1	83	103	223	110	125	445
3.8	185	103	325	280	125	605
4.5	240	160	387	280	150	583
5.2	170	133	433	215	145	860
5.9	183	133	647	270	130	950
F Test[§]	ns	*	**	ns	ns	**
CV[#] (%)	39.0	34.8	23.4	53.5	31.8	26.2
	Soybean					
0.3	145	50	30	177	47	38
1.0	207	96	74	120	100	120
1.7	144	75	105	165	83	200
2.4	112	50	147	220	73	290
3.1	147	107	250	235	127	485
3.8	167	167	293	247	180	513
4.5	133	114	327	247	177	733
5.2	106	102	487	345	170	675
5.9	150	88	505	290	140	830
F Test[§]	ns	**	**	ns	*	**
CV[#] (%)	45.0	31.4	28.2	30.5	37.0	24.0

[§]ns, *, **Non-significant and significant at 0.05 and 0.01 of probability by the test F, respectively; [#]CV - coefficient of variation
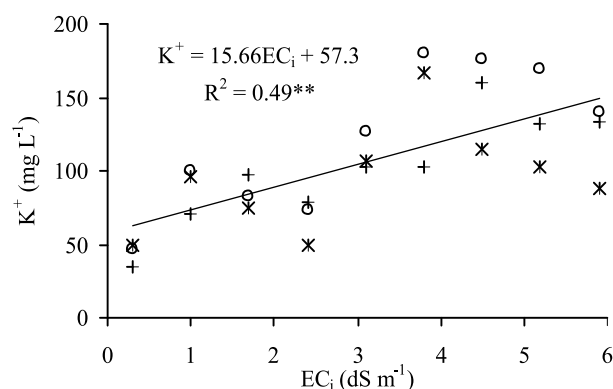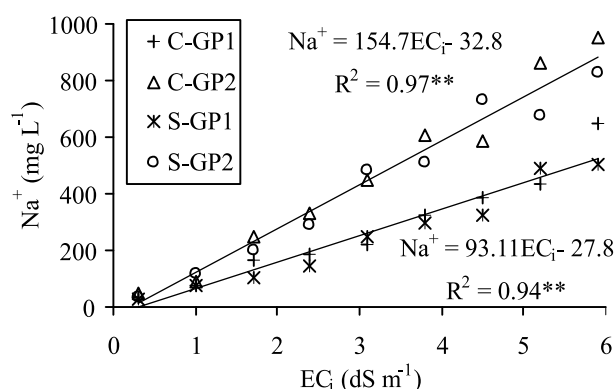

Figure 4 - Concentration of Na$^+$ and K$^+$ in the soil solution for corn (C) and soybean (S) in the first (GP1) and second (GP2) growing periods, as a function of electrical conductivity of the irrigation water (EC$_i$).

from the seedling stage to maturity (Ayers, & Westcot, 1985), the tolerance of corn overcame soybean from planting to seedling development stages. Therefore, an irrigation management strategy should be taken to maximize yield in the corn-soybean crop rotation when using saline water. Saline water could be used to produce soybean, being applied after crop establishment, and during the germination of corn, but a reduction of soil salinity is required to obtain satisfactory production of corn. Thus, corn-soybean crop rotation is advantageous because it allows farmers to use poor quality water and/or reuse the drainage water for irrigation of these crops, but the irrigation management must to be accomplished to avoid high soil salinity during the germination stage for soybean and latter stages of corn development.

CONCLUSIONS

Electrical conductivity of the irrigation water up to 5.9 dS m^{-1} does not reduce the emergence percentage and speed of emergence of corn 'AG6690', but reduces the emergence percentage and speed of emergence of soybean 'Conquista', with reduction of 20% for unitary increase irrigation water salinity above 2.7 dS m^{-1};

Growth of corn and soybean seedlings reduces with irrigation water salinity above 1.5 and 1.0 dS m^{-1} and with electrical conductivity of soil solution above 3.0 and 2.0 dS m^{-1}, respectively;

Corn is capable of maintaining the same growth rate in relation to the preexisting dry matter even under high saline conditions, while the relative growth rate of soybean is reduced for irrigation water salinity and soil solution salinity above 2.4 dS m^{-1} and 4.6 dS m^{-1}, respectively.

REFERENCES

AGONG, S.G.; KINGETSU, M.; YOSHIDA, Y.; YAZAWA, S.; MASUDA, M. Response of tomato genotypes to induced salt stress. **African Crop Science Journal**, v.11, p.133-142, 2003.

AYERS, R.S.; WESTCOT, D.W. **Water quality for agriculture.** Rome: FAO, 1985. 174p. (Irrigation and Drainage Paper, 29 rev.1).

AZEVEDO NETO, A.D.; TABOSA, J.N. Estresse salino em plântulas de milho: Parte I análise do crescimento. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.4, p.159-164, 2000.

BLANCO, F.F. Tolerância do tomateiro à salinidade sob fertirrigação e calibração de medidores de íons específicos para determinação de nutrientes na solução do solo e na planta. Piracicaba: USP/ESALQ, 2004. 115p. (Tese - Doutorado).

BENINCASA, M.M.P. **Análise de crescimento de plantas** (noções básicas). Jaboticabal: FUNEP, 1988. 41p.

BURT, C.; O'CONNOR, K.; RUEHR, T. **Fertigation.** San Luis Obispo: The Irrigation Training & Research Center, 1998. 295p.

EL-HADDAD, E-S.H.; NOAMAN, M.M. Leaching requirement and salinity threshold for the yield and agronomic characteristics of halophytes under salt stress. **Journal of Arid Environments**, v.49, p.865-874, 2001.

ESSA, T.A. Effect of salinity stress on growth and nutrient composition of three soybean (*Glycine max* L. Merrill) cultivars. **Journal of Agronomy & Crop Science**, v.188, p.86-93, 2002.

EYMAR, E.; OKI, L.R.; LIETH, J.H. Continuous measurements of electrical conductivity in growing media using a modified suction probe: initial calibration and potential usefulness. **Plant and Soil**, v.230, p.67-75, 2001.

GOMES, C. **Centro-Oeste concentra plantios de soja no inverno.** Londrina: Embrapa Soja, 2005. Available at: <http://www.cnpso.embrapa.br/alerta/ver_alerta.php?cod_pagina_sa=80&cultura=1> Access 3 Dec. 2005.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE. **Banco de dados agregados.** Rio de Janeiro. Available in: <http://www.sidra.ibge.gov.br> Accessed 5 Dec. 2005.

JOLY, R.J. Effects of sodium chloride on the hydraulic conductivity of soybean root systems. **Plant Physiology**, v.91, p.1262-1265, 1989.

KAYA, M.D.; IPEK, A.; ÖZTÜRK, A. Effects of different soil salinity levels on germination and seedling growth of safflower (*Carthamus tinctorius* L.). **Turkish Journal of Agriculture and Forestry**, v.27, p.221-227, 2003.

KHAN, A.A.; RAO, S.A.; MCNEILLY, T. Assessment of salinity tolerance based upon seedling root growth response functions in corn (*Zea mays* L.). **Euphytica**, v.131, p.81-89, 2003.

MAAS E.V. Crop tolerance. **California Agriculture**, v.38, p.20-21, 1984.

MAAS, E.V.; GRATTAN, S.R. Crop yields as affected by salinity. In: SKAGGS, R.W.; VAN SCHILFGAARDE, J. (Ed.). **Agricultural drainage.** Madison: ASA/CSSA/SSSA, 1999. cap.3, p.55-108.

MAAS, E.V.; HOFFMAN, G.J. Crop salt tolerance – current assessment. **Journal of Irrigation and Drainage Division**, v.103, p.115-134, 1977.

MAGUIRE, J.D. Speed of germination aid in selection and evaluation for seedling emergence and vigor. **Crop Science**, v.2, p.176-177, 1962.

MARSCHNER, H. **Mineral nutrition of higher plants.** 2.ed. London: Academic Press, 1995. 889p.

MORAES, G.A.F.; MENEZES, N.L. Desempenho de sementes de soja sob condições diferentes de potencial osmótico. **Ciência Rural**, v.33, p.219-226, 2003.

MOREIRA, J.A.A.; STONE, L.F.; SILVEIRA, P.M.; GUIMARÃES, C.M. **Manejo da irrigação do milho no sistema plantio direto:** tensão da água no solo. Santo Antônio de Goiás: Embrapa Arroz e Feijão, 2000. 2p. (Pesquisa em Foco, 36).

MUNNS, R. Comparative physiology of salt and water stress. **Plant, Cell and Environment**, v.25, p.239-250, 2002.

RHOADES, J.D.; KANDIAH, A.; MARSHALI, A.M. **Uso de águas salinas para produção agrícola.** Trad. de H.R. GUEYI, J.R. SOUZA e J.E. QUEIROZ. Campina Grande: UFPB, 2000. 117p. (FAO. Estudos de Irrigação e Drenagem, 48).

RIEU, M.; VAZ, R.; CABRERA, F.; MORENO, F. Modelling the concentration or dilution of saline soil-water systems. **European Journal of Soil Science**, v.49, p.53-63, 1998.

SECRETARIA DA AGRICULTURA, PECUÁRIA E ABASTECIMENTO DO ESTADO DO TOCANTINS - SEAGRO. **Comparativo da produção anual de grãos**. Palmas. Available at: <http://www.seagro.to.gov.br/v_menu.php?id=131> Accessed 3 Dec. 2005.

SILVA, J.V.; LACERDA, C.F.; COSTA, P.H.A.; ENÉAS FILHO, J.; GOMES FILHO, E.; PRISCO, J.T. Physiological responses of NaCl stressed cowpea plants grown in nutrient solution supplemented with CaCl$_2$. **Brazilian Journal of Plant Physiology**, v.15, p.99-105, 2003.

SINGLETON, P.W.; BOHLOOL, B.B. Effect of salinity on nodule formation by soybean. **Plant Physiology**, v.74, p.72-76, 1984.

STEPPUHN, H.; GENUCHTEN, M.T.; GRIEVE, C.M. Root-zone salinity: I. Selecting a product-yield index and response function for crop tolerance. **Crop Science**, v.45, p.209-220, 2005.

TESTER, M.; DAVENPORT, R. Na+ tolerance and Na+ transport in higher plants. **Annals of Botany**, v.91, p.503-527, 2003.

TISDALE, S.L.; NELSON, W.L.; BEATON, J.D.; HAVLIN, J.L. **Soil fertility and fertilizers.** 5.ed. New York: Macmillan Publishing, 1993. 634p.

VAN GENUCHTEN, M.Th. **Analyzing crop salt tolerance data:** model description and user's manual. Riverside: USSL, 1983. 50p. (Research Report, 120).

WANG, D.; SHANNON, M.C. Emergence and seedling growth of soybean cultivars and maturity groups under salinity. **Plant and Soil**, v.214, p.117-124, 1999.

WILLADINO, L.; CÂMARA, T.R.; TABOSA, J.N.; ANDRADE, A.G.; GOMES, R.V.; SOUZA, A.J. Avaliação de cultivares de milho em solo salino do semi-árido de Pernambuco. **Pesquisa Agropecuária Brasileira**, v.29, p.1059-1065, 1994.