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Use of foliage and root characters for the evaluation of salinity tolerance at seedling stage in maize

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The aim of this research was to evaluate the salinity tolerance in maize at the seedling stage quantifying the influence of traits related to it. Eight accessions/lines were probed in two treatments (0 and 100 mM NaCl). We recorded several growth characters and the electrolyte leakage (cell membrane stability). The direct effects on shoot dry mass were different in both treatments. In salt, the leaf length had larger direct effect on shoot dry mass (0.58), whereas in the treatment without salt, it was smaller (0.22). Important differences between saline and non saline conditions were found for shoot length (0.13 and 0. 41, respectively) and for root length (0.08 and 0.34, respectively). The results confirm the importance of the root length, in the identification of behavior of corn seedlings under high saline growth media. However, leaf length, could also be used to identify tolerance to salinity. This trait is easy to determine and would be useful in breeding programs where there is a great amount of material to assess.

Key words: *Zea mays*; seedling growth; phenotypic correlations; path analysis; salinity.

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El objetivo de este trabajo fue evaluar la tolerancia a la salinidad en el maíz en el estado de plántula cuantificando la influencia que muestran distintos caracteres sobre la tolerancia. Ocho introducciones / líneas se probaron en dos tratamientos (0 y 100 mM de NaCl). Se midieron varios caracteres de crecimiento y estabilidad de la membrana celular (pérdida de electrolitos). Los efectos directos sobre el peso seco aéreo fueron diferentes en ambos tratamientos. En sal, el largo de hoja tuvo mayor efecto directo (0,58), mientras que en el tratamiento sin sal, fue menor (0,22). Se encontraron diferencias importantes entre los dos tratamientos (con y sin sal) para largo de plántula (0,13 y 0,41 respectivamente) y largo de raíz (0,08 y 0,34, respectivamente). Los resultados obtenidos confirman la importancia del largo de raíz, en la identificación de la tolerancia a salinidad. Además, se ha encontrado que el carácter largo de hoja también podría ser utilizado para identificar la tolerancia a la salinidad. Este carácter es fácil de medir y sería de utilidad en programas de mejoramiento donde la cantidad de material a evaluar es grande.

Palabras Clave: *Zea mays*; crecimiento de plántula; correlaciones fenotípicas; coeficientes de paso; salinidad.

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INTRODUCTION

Saline soils are a factor affecting current and future agricultural productivity. About 7% of the world's total land area is affected (FAOSTAT. 2006. http: /www.fao.org/corp/statistics/es/) and it constitutes a restriction to the increased demand for food all over the world. The development of salt tolerant crop plants could become an increasingly important breeding objective. Salt tolerance of plants is a complex phenomenon that involves physiological, biochemical, and molecular processes as well as morphological changes (Flowers & Flowers, 2005).

Three primary types of stress are produced in plants because of salinity: osmotic stress, specific ion toxicities (e.g. Na^+ and Cl^-) and ionic imbalance (e.g. Na^+ *versus* K^+; Na^+ *versus* Ca^{2+}) (Munns et al., 2002; Flowers & Flowers, 2005). Reduction in growth and yield are undoubtedly the most physiological conspicuous responses of plants to the excess of salt in the soils. The limitation in the crop production is primarily caused by a reduction in the expansion and photosynthetic capacity in leaves (Banziger & Araus, 2007). This will determine a lower production and transport of assimilates to growing tissues that may limit growth. In that respect, the reduction of shoot growth is the primary response of a plant to salinity stress. Munns et al. (1995) define the concept of two-phase growth response to salinity. In the first phase, the osmotic phase, the salt outside the root causes a rapid growth reduction due to difficulty in the absorption of water. The second phase or ionic phase, which takes more time to develop, results from an internal accumulation of salts in transpiring leaves, causing toxic concentrations in the old leaves and premature senescence.

Tolerance mechanisms may be classified into two categories: osmotic stress tolerance associated with the first phase of growth reduction and ionic stress or specific salt effects tolerance related to the second phase of growth reduction (Munns et al., 1995; Munns, 2005). The mechanisms in the ionic phase are associated with the ability of plants to control salt transportation. Two different strategies regulate salt transportation: the exclusion of Na^+ from leaves by accumulation in roots and the intrinsic tolerance of tissue, which requires compartmentalization of Na^+ and Cl^- at cellular and intracellular levels.

Even though growth is affected, plants may respond in several ways in order to minimize its effects. In the osmotic phase, expansion of leaf area could be positive since it allows maintaining a larger surface for photosynthesis. However, this would be feasible in situations where there is no water stress (Munns & Tester, 2008). Furthermore, keeping a high Shoot Dry Mass/Root Dry Mass relation and a high growth rhythm may contribute to reduce the accumulation of salt in leaves and consequently improve the ionic stress tolerance (Munns et al., 2002).

Crops differ in their response in saline soils; maize is a moderately sensitive crop and the most sensitive of cereals (Maas & Hoffman, 1977).

A wide variety of physiological, morphological and molecular traits have been suggested for use in improving the salinity tolerance of crops. Response to salinity in maize at seedling stage may persist through the mature plant (Ashraf & Mc Neilly, 1987; Ashraf & Mc Neilly, 1990; Maiti et al., 1996), and this could provide a screening for selection of enhanced salinity tolerance in maize. When a large number of genotypes are screened, identification of traits that can be analyzed with rapid and low-cost techniques becomes necessary. Several seedling traits were employed to identify tolerance to salinity in maize. The lengths of root of seedlings grown in control and saline solutions have been broadly used; when the seedlings were exposed to salinity the root growth was rapidly reduced (Rao & McNeilly, 1999; Khan & McNeilly, 2005). However, Eker et al. (2006) pointed out that under salt stress, measurement of shoot growth may be a more effective and useful traits than root growth to identify salinity tolerance. The increase of leaf area was inhibited by salinity, although it was not a reliable indicator of salt tolerance (Cicek & Cakirlar, 2002). Unfortunately, it has not been possible to relate the seedling response, either tolerant or sensitive, with a definite physiological process. This clearly points out the complexity of salt tolerance.

Other traits associated with salt tolerance are reflected at cellular level, because the plasma membrane is the primary site of salt injury. Salt tolerance, evaluated by measuring cell membrane stability has shown changes in the structure or composition of the membrane in genotypes with different response under salinity conditions. Salt sensitive cultivars show greater increase in the cell permeability compared to salt tolerant cultivars. This trait could be reflected in the behaviour of the whole plant and could be a useful feature in a breeding program for developing salt tolerance genotypes (Mansour & Salama, 2004; Mansour et al., 2005; Collado et al., 2010).

The path analysis methodology has been frequently used by plant breeders to assist in identifying traits that are useful as selection criteria to improve crop yield. The path coefficient (Li, 1975) is a standardized partial regression coefficient which measures the direct influence of a predictor variable on the response variable. The method allows the partition of the correlation coefficients into direct and indirect effects, applied to a causal diagram built according to logical basis. The analysis allows a critical examination of specific factors that produce a given correlation and can be successfully employed in formulating an effective selection strategy.

The aim of this research was to evaluate the salinity tolerance in maize at the seedling stage quantifying the influence of traits related to it.

MATERIALS AND METHODS

Plant materials and growth conditions

Eight accessions Flint type were used, of which, five were populations and three inbred lines. These genotypes were selected from the results obtained in a previous trial where 31 different genotypes of maize were evaluated in two treatments (0 and 150 mM NaCl) applied from germination. After 12 days the seedlings were harvested and different traits were measured. The genotypes selected were those that showed a contrasting response compared to saline stress. Among selected populations, three showed tolerant response (BBC473; BBC480 and 26A) and two susceptible (F7 and BBC483). The inbred lines F564 and SC75 were tolerant while AD3 was salt sensitive (Collado et al., 2009).

Two environments were used: non saline treatment where no NaCl solution was added and the other treatment receiving 100mM NaCl. Seeds of the different genotypes were surface sterilized in 1% sodium hypochlorite solution for 5 minutes before experimentation, then rinsed with distilled water. The caryopses were germinated in Petri dishes with moistened filter paper in a dark incubator at 26 ºC during five days. In the sixth day of germination, three uniformly germinated seedlings were transferred to pots containing "perlite". These pots were put into trays containing half-strength Hoagland´s nutrient solution and seven days later started the salt additions. The final concentration was reached by a gradual increment of 25mM NaCl every two days (Rao & McNeilly, 1999; Cicek & Cakirlar, 2002; Khan & McNeilly, 2005). The solutions were renewed every three days. The experiment was carried out in a controlled environment room at 25 ºC, with 16h day length. All conditions were maintained constant during the growth period. A completely randomized block design with four replicates was adopted.

Growth analysis

After 14 days of salt treatment at 100mM ClNa, the seedlings were harvested. The shoot, radicle and third leaf (SL, RL and LL, respectively) lengths and the width of the third leaf (LW) were recorded. Measurement of leaf area (LA) was made in the third leaf according to Zhang & Brandle (1997). Shoot and radicle were separated and the samples were dried for two days until constant weight, for dry mass determination (SD and RD respectively). The total dry mass (TD) was calculated as the sum of SD and RD.

Electrolyte leakage measurement

The cell membrane stability was estimated on the third leaf with a conductometer (Consort C931) and expressed in total of solids (mg/l of solution) (TS). A piece of leaf was cut, weighted and washed with distilled water to remove the solution from tissue, then the samples were immersed in 10 ml of distilled water and placed for incubation for 24 h (Mansour & Salama, 2004; Mansour et al., 2005). After incubation samples were equilibrated to room temperature. Then, the conductivity of the medium was recorded (TS1). The samples were autoclaved for 15 min to kill all tissues, and after cooled to room temperature, the conductivity of the solutions was read again (TS2).

Statistical analysis

The data was subjected to the analysis of variance. The phenotypic and genotypic correlations among the different traits were estimated in both treatments (Sokal & Rohlf, 1995). The Mantel test (Mantel, 1967; Rohlf, 1998) was used to verify the congruence between the matrices of phenotypic and genotypic correlations obtained for each environment.

Path coefficient analysis was used to partition the correlation coefficients among variables into direct and indirect effects (Li, 1975).

To apply the method of path coefficients, it is necessary to work within a logical cause-effect diagram construct with the traits considered. In the diagram adopted TD is the dependent variable, RD and SD are the first degree variables; LL, SL and RL are the second degree variables; and TS is the third degree variable (Fig. 1). This scheme was constructed for salt and control treatments with the correlation coefficients that were statistically significant ($p < 0.05$).

The phenotypic correlation coefficients were partitioned into direct and indirect effects according to the following set of linear equations:

Shoot dry mass:

$r_{AD} = P_{AD} + r_{AB} P_{BD} + r_{AC} P_{CD}$

$r_{BD} = r_{AB} P_{AD} + P_{BD} + r_{BC} P_{CD}$

$r_{CD} = r_{CA} P_{AD} + r_{BC} P_{BD} + P_{CD}$

Root dry mass:

$r_{AE} = P_{AE} + r_{AB} P_{BE} + r_{AC} P_{CE}$

$r_{BE} = r_{BA} P_{AE} + P_{BE} + r_{BC} P_{CE}$

$r_{CE} = r_{CA} P_{AE} + r_{BC} P_{BE} + P_{CE}$

Total dry mass:

$r_{DF} = P_{DF} + r_{DE} P_{EF}$

$r_{EF} = r_{ED} P_{DF} + P_{EF}$

Where:

(*A*): leaf length, (B): shoot length, (C): root length, (D): shoot dry mass, (E): root dry mass and (F): total dry mass, *r* is the phenotypic linear correlation coefficient between two variables, *P* is the path coefficient measuring direct effects and *r P* is the measure of the indirect effect of one variable upon another (Li, 1975).

The magnitude of the path coefficients could be biased by the presence of multicollinearity among variables, preventing the appropriate interpretation of results. The presence of multicollinearity determines an overestimation of the direct effects of the independent variables on the response variable. To evaluate that was employed the procedure of Montgomery & Peck (1981). They propose the assessment of the matrix condition number (CN) which is the ratio between the highest and lowest eigenvalue; if CN< 100, multicollinearity is not a problem, 100<CN< 1000 the multicollinearity is moderate to strong and CN> 1000 is severe (Cruz, 2001).

RESULTS AND DISCUSSION

Variance analysis showed highly significant genotype differences for all the characters examined ($p < 0.01$), with exception of TS1 and TS which have shown differences at $p < 0.05$. These results demonstrated the presence of genetic variability among the tested genotypes. The salt application significantly decreased the growth in the morphological traits measured (LL, RL and SL) but increased the membrane stability traits (TS1 and TS) (Table 1). Consequently, these traits would be very useful in salinity tolerance improvement programs, especially root length which has shown a major growth reduction compared to the controls.

Table 1: Analysis of variance and means for treatments of: width leaf (WL, cm), leaf length (LL, cm), leaf area (LA, cm^2), shoot length (SL, cm), root length (RL, cm), shoot dry mass (SD, mg), root dry mass (RD, mg), total dry mass (TD, mg), total solid 1 (TS1, mg/l of solution), total solid 2 (TS2, mg/l of solution), total solid (TS, mg/l of solution) in maize seedling. T x G: Treatment x Genotype interaction.

Source *of variation*	*Mean squares*											
	df	WL	LL	LA (x10^5)	SL	RL	SD (x10^2)	RD (x10^2)	TD (x10^2)	TS1	TS2	TS
Treatment	1	0.01ns	159**	50.1ns	420**	3566**	27ns	62.5ns	173ns	627*	89ns	1193**
Genotype	7	0.57**	115**	120**	139**	155**	3606**	510**	6764**	381*	333**	94*
T x G	7	0.03ns	13ns	5.8ns	56ns	100**	139ns	31.1ns	228ns	271ns	182*	76*
Error	45	0.07	21.3	13.1	42ns	31	433	71.3	765	125	71	34
Mean												
Non-saline		2.05	43.5*	67.8	66.42*	48.2*	914.3	332.9	1250	33.42	32.41	65.83
Saline		2.04	40.06	61.7	60.39	32.6	897.9	313.4	1210	38.75*	35.72	74.5*

**,*, indicates differences significant at $p < 0.01$; 0.05 respectively, while ns, denotes not significantly differences.

Table 2. Phenotypic correlation coefficients between 11 traits measured in the non saline treatment (above diagonal) and saline treatment (below diagonal).

	LA	WL	LL	SL	RL	SD	RD	TD	TS1	TS2	TS
LA	1	0.92**	0.80**	0.64**	0.46*	0.87**	0.85**	0.88**	-0.41*	0.31	-0.23
WL	0.80**	1	0.53**	0.38*	0.42*	0.79**	0.79**	0.81**	-0.39*	0.37*	-0.13
LL	0.77**	0.26	1	0.83**	0.36	0.69**	0.65**	0.69**	-0.35	0.17	-0.33
SL	0.67**	0.22	0.87**	1	0.23	0.68**	0.56**	0.66**	-0.05	-0.23	-0.42*
RL	0.41*	0.22	0.40*	0.25	1	0.52**	0.59**	0.55**	-0.29	0.29	-0.06
SD	0.93**	0.74**	0.73**	0.65**	0.35*	1	0.89**	0.99**	-0.17	0.04	-0.23
RD	0.81**	0.71**	0.54**	0.47**	0.48**	0.80**	1	0.95**	-0.36	0.24	-0.25
TD	0.94**	0.77**	0.71**	0.63**	0.40**	0.98**	0.89**	1	-0.24	0.11	-0.24
TS1	-0.12	0.08	-0.28	-0.16	-0.42*	-0.09	-0.12	-0.11	1	0.79**	0.52**
TS2	0.11	0.07	0.12	-0.03	0.29	0.05	0.03	0.05	0.87**	1	0.1
TS	-0.04	0.29	-0.37*	-0.37*	-0.35*	-0.11	-0.2	0.14	0.59**	-0.12	1

*Significant at the 0.05 probability level, **Significant at the 0.01 probability level

Leaf area (LA, cm2), width leaf (WL, cm), leaf length (LL, cm), shoot length (SL, cm), root length (RL, cm), shoot dry mass (SD, mg), root dry mass (RD, mg), total dry mass (TD, mg), total solid 1 (TS1, mg/l of solution), total solid 2 (TS2, mg/l of solution), total solid (TS, mg/l of solution).

The application of the Mantel test showed no significant differences (*r*= 0.98) between the phenotypic and genotypic correlations obtained for each environment. Consequently, the phenotypic correlations can be considered like a good estimate of the genotypic correlations. The results obtained are closely related to the nature of the assay used (in the laboratory under controlled conditions) where the similarity of phenotypic and genotypic correlations are high because environmental variances and covariances are minimal (Waitt & Levin, 1998).

The comparative analysis of the resulting correlation matrixes from both treatments employed (with and without salt) allows us to point out some peculiarities between seedlings growing in the two environments (Table 2).

In salt-free nutritive solution the trait WL had a positive and significant correlation with LL, SL and RL. This could suggest that, in seedlings developed without stress, a same group of genes could regulate the harmonic and balanced growth of the different parts of a seedling. However, in salinity, non significant correlations were found between these traits. Therefore, stress may have affected the regulating action of the genes, which seems to have caused alterations in growth patterns.

The trait TS1 shows the loss of electrolytes from membranes due to the damage caused by salinity effect. Although the correlations obtained between TS1 and the different traits have been negative, they were only significant for the RL trait within the salinity treatment. These results are reasonable if it is taken into account that the root is the first place where salt produces its effect, thus, it is more strongly damaged. This apparently evidences the importance of the Root Length variable in the identification of a tolerant response, as pointed out by various authors (Rao & McNeilly, 1999; Khan & McNeilly, 2005).

The TS trait measured in salinity has shown negative and significant correlations with three traits of seedling, such as: LL, SL and RL (-0.37; -0.37 and –0.35, respectively). On the other hand, in the controls, only the SL variable has shown a significant association (-0.42). This seems to indicate that salinity has equally affected the different parts of the seedling; damage in the membrane seems to have determined reductions in growth, especially in length, which are very similar in roots, leaves and shoots.

The cause-effect diagram has allowed distinguishing direct and indirect effects of the variables affected by salinity. To avoid overestimation of the direct effects produced by the presence of multicollinearity, the CN was estimated separately for three dependent variables (TD, RD and SD) in both treatments. The matrix condition number (CN) was higher than 1000 for TD from the first-order independent variables (RD and SD) and was lower than 100 for SD and RD when were used the second-order independent variables (LL, SL and RL) in both treatments. These results indicate that due to the presence of multicollinearity was necessary to correct the direct effect on the variable TD (Montgomery & Peck, 1981; Cruz, 2001).

Comparing the direct and indirect effects between both treatments, the most important differences have been observed for SD (Table 3). These results indicate that the salt stress has induced modifications in the distribution of resources, leading to the reduction of the negative effects of salinity.

Table 3. Direct and indirect effects of leaf length, shoot length and root length upon shoot dry mass of maize seedling grown under saline and non saline conditions.

Shoot Dry Mass		
	Environment	
Type of effect	Saline	Non saline
Effect of leaf length		
Direct effect	0.58	0.22
Indirect effect via shoot length	0.12	0.34
Indirect effect via root length	0.03	0.12
Total correlation (r_{CAD})	0.73	0.69
Effect of shoot length		
Direct effect	0.13	0.41
Indirect effect via leaf length	0.50	0.18
Indirect effect via root length	0.02	0.08
Total correlation (r_{BD})	0.66	0.68
Effect of root length		
Direct effect	0.08	0.34
Indirect effect via leaf length	0.23	0.08
Indirect effect via shoot length	0.03	0.09
Total correlation (r_{CD})	0.35	0.52
Coefficient of Determination (R^2)	0.53	0.61

Under salt growing media, the direct effects of LL (0.58) have been the ones that mostly explained the variability of SD, whereas in the treatment without salt, the direct effect of LL was much smaller (0.22). The other two variables have also shown important differences: 0.41 and 0.13 (non-salinity and salinity, respectively) for SL and 0.34 and 0.08 (non-salinity and salinity, respectively) for RL (Table 3). It can be seen again that in adverse situations like salinity, the increase in the length of the leaves allows the plant to maintain tissue with photosynthetic capacity, apart from reducing the rhythm of salt accumulation in tissue. The persistence of an intense growth rhythm is associated to a tolerance strategy, which determines a reduction in the accumulation of salt and which is related with tolerance in the ionic phase of growth reduction (Munns & Tester, 2008). The indirect effects of SL and RL via LL have been much different in both tests. It can be stated that in the test with salt, the values observed were higher. This seems to point out the importance of leaf development in the response to salinity (Table 3).

The direct effects in both treatments have shown the same patterns for the RD trait (Table 4). In the non–saline environment, the direct contributions were higher in the three variables, with predominance of RL (0.42) and LL (0.37) effects, while SL had a discrete effect (0.16). On the other hand, in salinity only the LL variable (0.34) showed a direct effect similar to the one obtained in the non-saline treatment, whereas great differences have been observed for the RL (0.32) and SL (0.08) variables. It can be seen that the variation in LL had a strong effect over the variation in RD in both situations, while the direct effect of RL in salt was smaller. This could indicate that part of the resources which would have been destined for the roots were sent to develop the leaves. In stress situations, the plant is capable of maintaining a high photosynthetic capacity which allows it to fulfill its metabolism normally. Munns et al. (2002) and Munns & Tester (2008) states that the ionic mechanism in response to salinity is associated to the accumulation of salt in old leaves, which allows to preserve photosynthetic capacity in new leaves. In accordance with that, the variation observed in LL in the test with salt seems to correspond with an increase of the photosynthetic capacity of tissue, in addition to maintaining root growth and the ability to accumulate water (Table 4).

Table 4. Direct and indirect effects of leaf length, shoot length and root length upon root dry mass of maize seedling grown under saline and non saline conditions.

Root Dry Mass	Environment	
Type of effect	Saline	Non saline
Effect of leaf length		
Direct effect	0.34	0.37
Indirect effect via shoot length	0.07	0.13
Indirect effect via root length	0.13	0.15
Total correlation (r_{AE})	0.54	0.65
Effect of shoot length		
Direct effect	0.08	0.16
Indirect effect via leaf length	0.34	0.30
Indirect effect via root length	0.08	0.10
Total correlation (r_{BE})	0.46	0.56
Effect of root length		
Direct effect	0.32	0.42
Indirect effect via leaf length	0.14	0.13
Indirect effect via shoot length	0.02	0.04
Total correlation (r_{CE})	0.48	0.59
Coefficient of Determination (R^2)	0.36	0.58

The estimate of determination coefficients (R^2) has also shown differences between both tests (Figure 1). In the salt-free test, the variables used in the diagram steadily explained the variability observed for SD and RD (R^2=0.61 and 0.58, respectively). Instead, in salinity the R^2 values were different for SD (0.53) and RD (0.36). The low value registered for RD seems to show that there were variables that were not taken into account in the cause-effect diagram proposed and they apparently have a strong effect in the explanation of RD variability (Figure 1).

The SD/RD ratio estimated for both treatments (not presented data) has shown that the average in the saline treatment was similar to the one obtained in the non salinity (2.91 and 2.86, respectively). Even though these relationships may show that, as a result of salt stress, shoot growth, particularly leaves, is maintained, it can be observed that the differences between both tests are apparently non significant. On the other hand, the estimate of the LL/LR relation based on our data has shown major differences (1.23 for the test with salt and 0.90 free-salt). This ratio would be important in the identification of tolerance.

The direct and indirect effects on SD and RD, as stated above, have been different in both treatments. Contrarily, when the effects of SD and RD on the TD are calculated, it can be observed that there are no differences in both treatments. This could be showing that although the growth patterns were different, the shoot and root relation is maintained under both growth conditions (Table 5). Munns et al. (2002) and Munns & Tester (2008) indicate that intense growth rhythms, especially in leaves, could moderate the harmful effects caused by salt. The same authors point out that a high SD/RD relation apparently would be associated with tolerance to ionic stress, since it seems to delay the accumulation of salt in shoots. Accordingly, our results showed that the increase in leaf growth improved plant behavior in salt. This response of the maize plant could be related with osmotic tolerance phase, which develops immediately once it has been exposed to stress. The intense leaf growth, expressed in a high LL/LR ratio seems to protect leaves from a toxic salt accumulation and appears to be related to tolerance in the ionic phase of growth reduction.

Table 5. Direct and indirect effects of shoot dry mass and root dry mass upon total dry mass of maize seedling grown under saline and non saline conditions.

Total Dry Mass	Environment	
Type of effect	Saline	Non saline
Effect of shoot dry mass		
Direct effect	0.54	0.52
Indirect effect via root dry mass	0.34	0.42
Total correlation (r_{DF})	0.99	0.99
Effect of root dry mass		
Direct effect	0.38	0.43
Indirect effect via shoot dry mass	0.48	0.51
Total correlation (r_{EF})	0.94	0.98
Coefficient of Determination (R^2)	0.88	0.85

CONCLUSION

Characters which can be rapidly identified, such as root length, are commonly used in improvement programs for salinity tolerance. The results obtained in our research evidence the importance of the root length trait in the identification of behavior under saline conditions. However, we have found that traits related with shoot growth, particularly leaf length, could be also used so as to identify tolerance to salinity. This character is easy to determine and would be useful in programs where there is a great amount of material to assess.

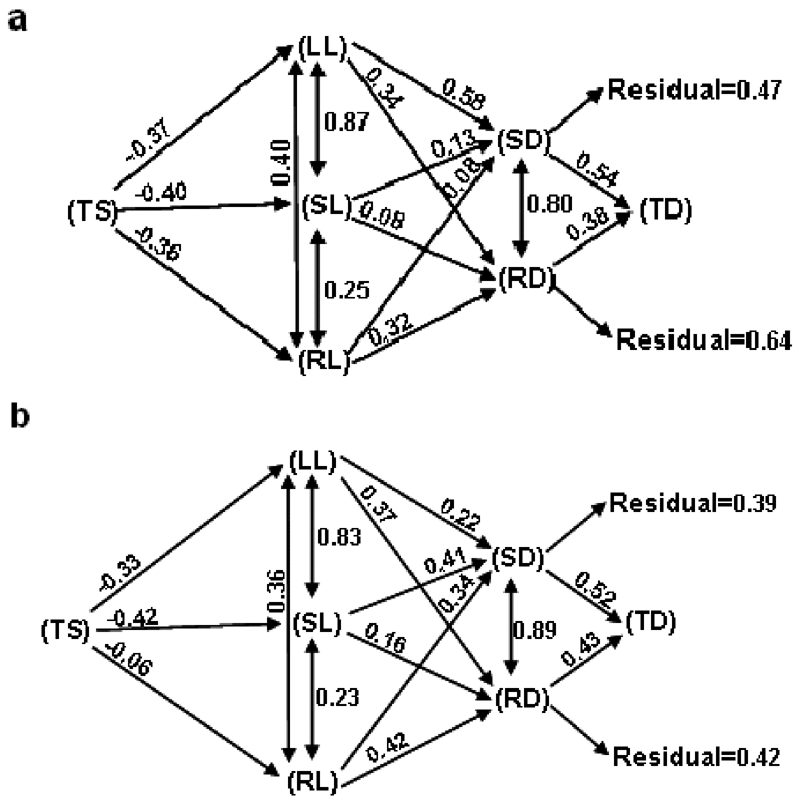

Figure 1. Path diagram describing the relationship between total dry mass (TD) and the factors total solid (TS), leaf length (LL), shoot length (SL), root length (RL), shoot dry mass (SD) and root dry mass (RD) in maize seedling growing in saline (a) and non saline environments (b). Residuals and path coefficients are shown with single-headed arrows and correlation coefficients with double-headed arrows.

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