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Tomato growth and dry matter partitioning as a function of the irrigation water quality[1]

Crescimento do tomateiro e partição de matéria seca em função da qualidade da água de irrigação

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Abstract - In this study, the growth and dry matter partitioning of processing tomato cv IPA 6 were evaluated under irrigation with waters of different electrical conductivities (ECw) and sodium proportions in a completely randomized 5x2 factorial design. Seedlings were transplanted to rhizotrons and irrigated daily, being the dry masses of stem, branches, inflorescences and fruits determined at the end of the crop season. The soil was removed from the rhizotrons at 15 cm depth intervals, washed and sieved to determine the dry mass of roots at each soil layer. Shoot dry mass was reduced by 6.9% for each unit increase of salinity. Root dry mass decreased in the 30-45 cm layer and increased in the 0-15 cm layer due to the accumulation of salts in the deeper layer promoted by the leaching. Salinity and sodium proportions did not affect root growth, which increased after transplanting, reaching its maximum of 50 cm day^{-1} during the period between 30 and 40 days after transplanting. Dry matter partitioning was practically unaffected by salinity and sodium proportions.

Index terms: *Lycopersicon esculentum*; salinity; sodium

Resumo - Neste estudo, foram avaliados o crescimento e a partição de matéria seca do tomateiro industrial cv IPA 6, cultivado sob irrigação com águas de diferentes condutividades elétricas (ECw) e proporções de sódio, em um delineamento fatorial 5x2, inteiramente casualizado. As mudas foram transplantadas para rizotrons e irrigadas diariamente, sendo as matérias secas da haste, ramos, inflorescências e frutos determinadas no final do ciclo da cultura. O solo foi retirado dos rizotrons em intervalos de 15 cm de profundidade, lavado e peneirado para determinação da matéria seca das raízes em cada camada do solo. A matéria seca da parte aérea foi reduzida em 6,9% por incremento unitário da salinidade. A matéria seca das raízes diminuiu na camada de 30-45 cm de profundidade e aumentou na camada de 0-15 cm devido ao acúmulo de sais na camada mais profunda promovido pela lixiviação. A salinidade e as proporções de sódio não tiveram efeito no crescimento da raiz, que aumentou após o transplantio, atingindo o seu máximo de 50 cm dia^{-1} no período entre 30 e 40 dias após o transplantio. A partição de matéria seca praticamente não foi afetada pela salinidade e proporções de sódio.

Termos para indexação: *Lycopersicon esculentum*, salinidade, sódio

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Introduction

Tomato (*Lycopersicon esculentum* Mill.) is produced in large quantity in Brazil and it is highly accepted by consumers. In spite of the large amounts produced in the Southeast, it is also cultivated in the Northeastern region of Brazil, where the low rainfall turns the irrigation unavoidable to obtain satisfactory yields. Therefore, in absence of good quality water, saline waters are frequently used for irrigation in this region and many studies have demonstrated that the use of saline water in tomatoes may be harmful as it is moderately sensitive to salinity (MAAS; HOFFMAN, 1977).

The ability of a tomato genotype to resist decrease in dry matter production under salinity remains an important criterion for the assessment of salt tolerance (AGONG et al., 2003). The experiments aiming to determine the biomass production of tomato under salt stress are frequently conducted for short period of time, during early growing stages. Borsani et al. (2001) verified high reduction in tomato root growth when seedlings were exposed to salinity for two days. Results obtained by Rodriguez et al. (1997) show that salinity reduced dry mass partitioned to shoot in contrast to root for plants exposed to salt stress during 13 days. Total dry mass reduction by NaCl salinity was also found by Aranda et al. (2001) at 63 days after saline water irrigation started.

Sensitivity to soil salinity varies along plant development and many crops are tolerant during seed germination, but the young developing seedlings are susceptible to injury during emergence and during early juvenile development; once established, plants generally become increasingly tolerant during later stages of growth (MAAS, 1996). Similar results were obtained for corn (MAAS et al., 1983), wheat (MAAS; POSS, 1989a), cowpea (MAAS; POSS, 1989b) and cucumber (BLANCO; FOLEGATTI, 2000). Therefore, determining the biomass production along plant development is suitable to evaluate the crop tolerance to salinity and the results will represent the integration of the tolerance during all stages of growth.

Therefore, the objective of this study was to evaluate the effects of salinity and sodium proportions of the irrigation water on growth and on dry matter partitioning of processing tomato.

Material and Methods

Plant material and growth conditions - Seeds of processing tomato (*Lycopersicon esculentum* Mill.), cultivar 'IPA 6', obtained from the market, were sown in expanded polystyrene tray (128 cells), using the commercial substrate Plantmax (Eucatex, São Paulo, Brazil), composed of vermiculite, perlite, pinus bark and peat. After sowing, each tray received 1 L of water of the corresponding treatment and the trays were piled for four days, when they were placed on suspended supports in a greenhouse. Irrigation was accomplished daily from the fifth day after sowing, using the water of the corresponding treatments. A total of 10 treatments having five salinity levels (electrical conductivity of the water - ECw = 1; 2; 3; 4; and 5 dS m^{-1}) and two equivalent proportions of Na:Ca:Mg (P1 = 1:1:0.5 and P2 = 7:1:0.5) in the irrigation water were used. Seedlings were transplanted to rhizotrons 21 days after sowing, and one seedling per rhizotron was planted. Details of the rhizotrons construction, soil characteristics, fertilizer application and irrigation management were presented earlier by Campos et al. (2006). The rhizotrons containing the seedlings were placed under plastic covering until fruit ripening. The waters used for irrigation of the tomato plants were prepared with tap water, which was either diluted with distilled water or salinized with NaCl, $CaCl_2.2H_2O$ and $MgCl_2.2H_2O$, after analysis to achieve the desired electrical conductivity and proportion of Na^+, Ca^{2+} and Mg^{2+}. The amounts of salts or distilled water added were determined in order to obtain the desired ECw of the respective treatment with an equivalence of 1:1:0.5 and 7:1:0.5 for Na:Ca:Mg, using the relationship $mmol_c\ L^{-1}$ = ECw x 10 (RHOADES et al., 1992).

The experiment was conducted in Campina Grande, PB (7°15'18" S, 35°52'28" W and altitude of 550 m), from May 29 to October 12, 2000. The temperature and relative humidity measured in a conventional weather station are shown in Figure 1.

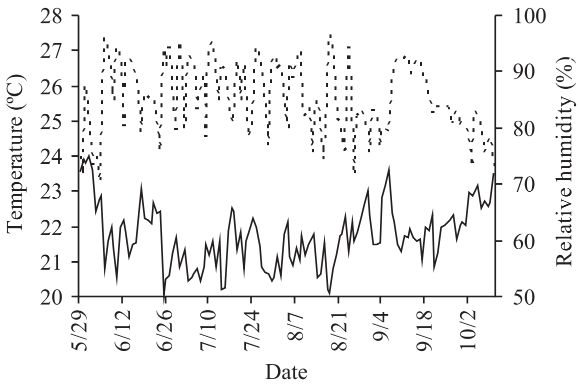

Figure 1 – Air temperature (solid line) and relative humidity (dashed line) during the experimental period. Data were obtained from a conventional weather station in Campina Grande

Growth analysis - Evaluation of root growth was performed at five days interval, starting from transplanting. A transparent plastic sheet was fixed onto the acrylic screen and the distribution of roots was drawn with a colored pen, using a different color for each observation. The acrylic plate was covered with a black polyethylene film which was removed only for tracing root distribution. The plastic was later placed on a millimeter paper, and the length of each root was measured. The lengths were then added and divided by five to calculate the daily root growth for the five days interval. Fruit harvest started on the 75th day after transplanting (DAT) and all fruits from each plant were dried to obtain their dry mass, and the dry mass of the leaves that fell during crop development.

At the end of the experimental period (on the 136th DAT) the plants were collected and the dry masses of the different plant parts were obtained after drying at 65 ºC for 72 h. The dry mass of the shoot (DMSH) was obtained by addition of the dry mass of its parts (leaves + stem + branches + inflorescences + flowers). For root dry mass determination, the soil was removed from the rhizotron in layers of 15 cm and the roots present in each layer (0-15, 15-30 and 30-45 cm) were washed over a sieve until it was completely clean. All fragments and whole roots were dried to obtain the dry mass of roots (DMR), and the total dry mass (TDM) of the plant was calculated by addition (DMSH + DMR). Dry mass partitioning was calculated by dividing the dry mass of each part of the plant by its TDM. Absolute (AGR) and relative (RGR) growth rates were determined according to Benincasa (1988), being the interval of measurements from zero to 136 DAT.

Statistical analysis - The experimental design was a completely randomized 5x2 factorial with three replicates per treatment, and the data were subjected to analysis of variance and test F. When statistically significant, the effects of water salinity (ECw) were evaluated by polynomial regression and the effects of the different proportions of sodium by comparison of means using the Tukey's test (GOMES, 2000).

Results and Discussion

The dry mass of leaves (DML), stem (DMS), branches (DMB), shoot (DMSH) and the total dry mass (TDM) were linearly affected by the electrical conductivity of the irrigation water (ECw), but the dry masses of the inflorescences (DMI), fruits (DMF) and roots (DMR) did not vary statistically with salinity. The increase of sodium proportions (Na:Ca:Mg) from 1:1:0.5 to 7:1:0.5 reduced the DMF by 14%, while DMSH and TDM were found to reduce by 10%. There was no significant interaction ECw x P for none of the variables studied (Table 1). These results led us to perform the regression curves and their respective

Table 1 - Mean values of dry masses of leaves (DML), stem (DMS), branches (DMB), inflorescences (DMI), fruits (DMF), root (DMR), shoot (DMSH) and total dry mass (TDM) of processing tomato, under different salinity levels (ECw) and sodium proportions (P1 = 1Na:1Ca:0.5Mg and P2 = 7Na:1Ca:0.5Mg) in the irrigation water, and summary of the ANOVA

ECw ($dS\ m^{-1}$)	DML (g)	DMS	DMB	DMI	DMF	DMR	DMSH	TDM
1	94	43	21.3	13.6	152	24	323	348
2	74	30	15.9	12.4	147	25	279	305
3	83	35	17.5	13.5	139	25	287	312
4	65	22	12.2	10.7	147	25	258	283
5	62	21	11.9	9.8	119	22	224	246
Test F	L**	L**	L**	ns	ns	ns	L**	L**
Na Prop[§]								
P1	77 a	33 a	15.8 a	12.6 a	151 a	26 a	289 a	315 a
P2	74 a	28 a	15.7 a	11.4 a	130 b	23 a	259 b	283 b
ECw x P	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	19.2	23.4	24.3	23.5	16.1	23.0	12.2	11.4

L represents linear effect by the regression analysis; ** Statistically significant by the test F ($P < 0.01$); ns Non-significant by Test F ($P < 0.05$); [§] Means followed by the same letter in the same column are not significantly different by the Tukey test ($P < 0.05$)

equations that are shown in Figure 2. This figure shows that there were reductions of 8.0; 12.8; 11.0; 6.9 and 6.5% in DML, DMS, DMB, DMSH and TDM for each unit increase of ECw above 1 dS m^{-1}, respectively.

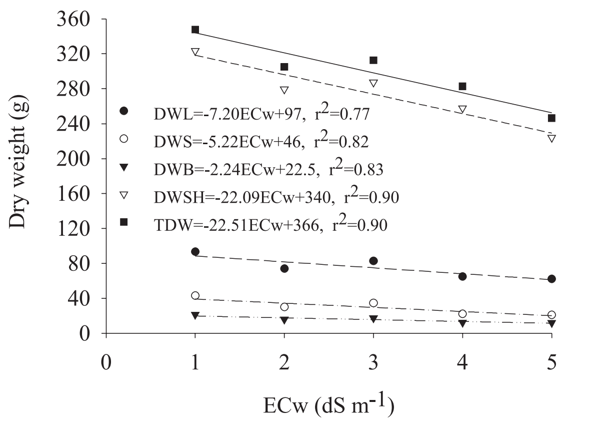

Figure 2– Regression curves and their equations for the effects of the electrical conductivity of the irrigation water (ECw) on dry masses of leaves (DML), stem (DMS), branches (DMB), shoot (DMSH) and total dry mass (TDM) of processing tomato

There was no significant reduction of DMF with increasing ECw (Table 1). This was unexpected because the reduction of fruit yield is a common response of tomato to salinity (CUARTERO; MUÑOZ, 1999). Increase of dry matter percentage of fruits is generally observed under saline conditions for various crops and, in the present study, the dry matter percentage of fruits increased from 4.0 to 6.2% for ECw of 1 and 5 dS m^{-1}, respectively (Figure 3). Thus, while salinity promoted fruit yield decrease of 11.0% (CAMPOS et al., 2006), the dry matter percentage of the fruits increased 12.8% for each unitary increase of ECw above 1 dS m^{-1}, which compensated the reduction of fruit yield in terms of dry matter production of fruits. Therefore, the dry matter partitioning to fruits is a useful tool for understanding the physiological effects of a given factor of stress. Determination the yield of fresh fruits is required when the objective is to evaluate the effects of the stress to serve as guideline for commercial producers.

Root/shoot ratio (R/S), root length (RL), root growth (RG) and relative growth rate (RGR) were not affected by ECw and sodium proportions (Table 2). These results agreed with Agong et al. (2003), that found no reduction of root dry mass of tomato for electrical conductivity of the nutrient solution up to 21 or 29 dS m^{-1}, depending on the genotype, while shoot dry mass decreased even at the lower salinity level (13 dS m^{-1}).

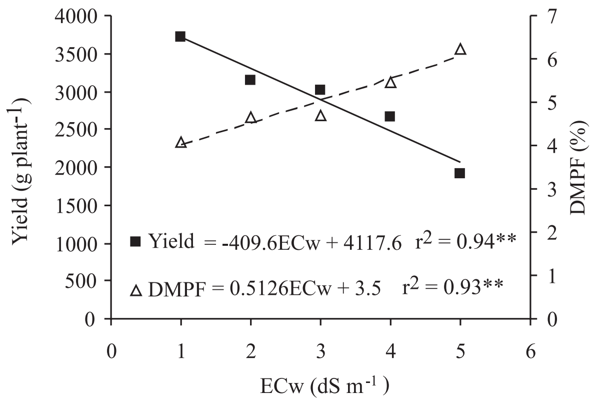

Figure 3 – Regression curves and their equations for the effects of the electrical conductivity of the irrigation water (ECw) on fresh fruit yield and on dry matter percentage of the fruits (DMPF) of processing tomato

Absolute growth rate (AGR) was found to be reduced by 10% when Na:Ca:Mg proportion increased from 1:1:0.5 to 7:1:0.5 (Table 2), and by 6.5% (AGR = -0.1645ECw + 2.7, r^2 = 0.90) for each unit increase of ECw above 1 dS m^{-1}. Reduction of AGR with salinity has also been observed for other crops, like passion fruit (SOARES, 2001) and sorghum (SILVA et al., 2003). On the other hand, dry mass accumulation in relation to the preexisting dry mass, expressed as the RGR, was not affected by salinity and sodium proportions.

Greenway e Munns (1980) verified that at 50 mM of NaCl, growth of beans decreased and Na^+ concentrations in leaves increased only when Na/Ca (in mM) exceeded 17; they assumed that an increase in membrane permeability due to the high Na/Ca ratio in the root medium is the primary cause of the reduced growth of crops under salinity. Hence, in the present work, reductions of dry mass with sodium proportions can be attributed to the high Na/Ca ratio in the root environment, once Na/Ca in the irrigation water (in mM basis) was of 2.0 for P1 and 14.0 for P2. Furthermore, the effects of Ca^{2+} on the reduction of Na^+ toxicity only occurs for high concentrations of Ca^{2+} in the soil solution, generally above 10 to 20 mM Ca^{2+} (TESTER; DAVENPORT, 2003; SONG; FUJIYAMA, 1996). In the present study, the maximum Ca^{2+} concentration in the irrigation water was 10 mM Ca^{2+} for treatment of P1 of 5 dS m^{-1}, therefore it is little probable that there was some effect of Ca^{2+} in reducing toxicity of Na^+.

In spite of the negative effect of salt on the tomato roots (CUARTERO; MUÑOZ, 1999), root growth in cv. 'IPA 6' appears to be less affected by salinity than shoot growth. It has being demonstrated that abscissic acid originating

Table 2 - Mean values of root/shoot ratio (R/S), root length (RL), root growth rate (RG), absolute growth rate (AGR) and relative growth rate (RGR) of processing tomato, under different salinity levels (ECw) and sodium proportions (P1 = 1Na:1Ca:0.5Mg and P2 = 7Na:1Ca:0.5Mg) in the irrigation water, and summary of ANOVA

ECw ($dS\ m^{-1}$)	R/S ($g\ g^{-1}$)	RL (cm)	RG ($cm\ 5day^{-1}$)	AGR ($g\ day^{-1}$)	RGR ($mg\ g^{-1}\ day^{-1}$)
1	0.074	1269	60.4	2.54	39
2	0.091	1280	61.5	2.23	39
3	0.087	1460	69.5	2.29	40
4	0.099	1388	66.1	2.07	39
5	0.100	1410	67.1	1.80	40
Test F	ns	ns	ns	L**	ns
Na Prop§					
P1	0.089	1375	65.5	2.30 a	39
P2	0.091	1348	64.4	2.07 b	39
Test F	ns	ns	ns	*	ns
ECw x P	ns	ns	ns	ns	ns
CV (%)	14.0	21.9	21.9	11.4	2.2

L represents linear effect by the regression analysis; * Statistically significant ($P < 0.05$); ** Statistically significant ($P < 0.01$); ns Non-significant by Test F ($P < 0.05$); § Means followed by the same letter in the same column are not significantly different by the Tukey test ($P < 0.05$)

from the shoots plays a more important role in the control of plant growth than that originating from roots (CHEN et al., 2003). In addition, the reduction of K^+ concentration due to NaCl increase is markedly more accentuated in shoot than in root (CARVAJAL et al., 2000), which leads to a cation imbalance with consequent changes in physiological activities.

Root growth as a function of ECw and of sodium proportions averaged about 5 cm day^{-1} during the first ten days after transplanting (DAT), increased rapidly to reach its maximum of 50 cm day^{-1} between 30 and 40 DAT, and decreased thereafter to finally reach a rate between 2-10 cm day^{-1} after flowering, which occurred at 72 DAT (Figure 4).

The proportion of roots in each soil layer varied with salinity but not with sodium proportions (Table 3). Increasing salinity led to higher density of roots in the 0-15 cm layer and comparatively low in the 30-45 cm layer, probably due to the leaching of salts to the deeper layer, as leaching fraction was applied in all irrigations. Under field and drip irrigation conditions, Singh et al. (1989) found 55% of the roots in 0-15 cm, 32% in 15-35 cm and 12% in 35-55 cm in the beginning of the fruit ripening period (100 days after planting). In the present study, the larger percentage of roots in the 30-45 cm than in the 15-30 cm depth was probably due to the depth of the rhizotron, which impeded the root penetration to greater depth, once roots of tomato in field may be found at depths beyond 0.45 m (LORENZ; MAYNARD, 1988), even when plants are drip fertigated (HEBBAR et al., 2004).

The increase and decrease in percentage of roots at 0-15 and at 30-45 cm layers was of 3.2 and 8.0%, respectively (Figure 5); therefore, the main response of tomato 'IPA 6' root growth under saline irrigation was the reduction of root growth in the more saline layer, which compensated the increase of roots in the less saline layer, thus maintaining the total root surface constant in relation to the non-saline condition.

Dry matter partitioning was practically unaffected by salinity and sodium proportions. Only DMS was affected by salinity ($DMS = -0.98ECw + 12.9$, $r^2 = 0.70$), while the proportion of the other organs of the plant in relation to the TDM remained constant (Table 4).

Fruits represented 47% of the TDM and 52% of the DMSH, which is close to 52% found by Ehret e Ho (1986). Adams et al. (2001) found that 44; 61; 62 and 29% of the dry matter was partitioned to fruits at constant temperatures of 14; 18; 22 and 26 ºC during the whole season. The results above reveal that tomato 'IPA 6' has an ability to adjust to the varying salt levels via shifts in the shoot:root dry matter biomass balance, and this ability is likely to be critical for the superior performance of some tomato genotypes under saline stress (AGONG et al., 2003).

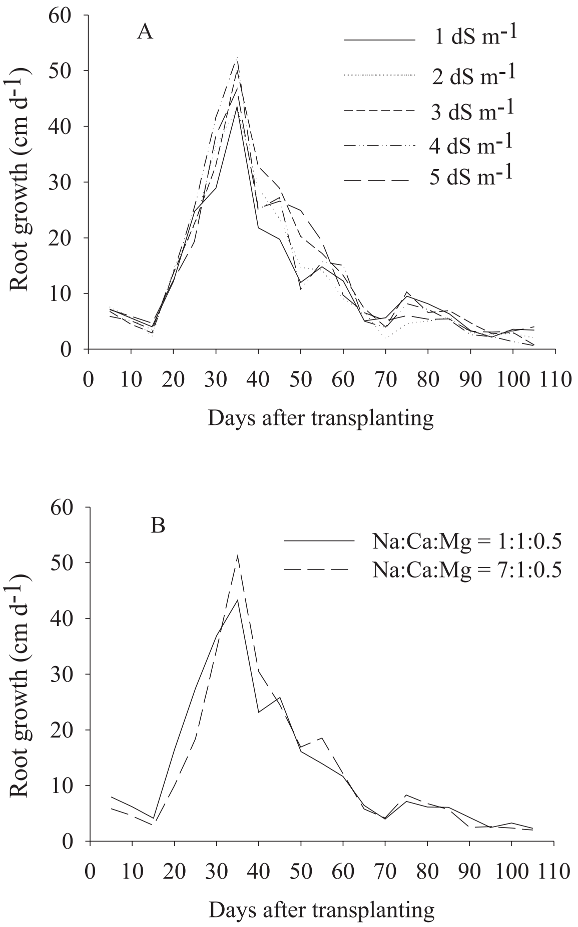

Figure 4 – Root growth of processing tomato for each level of ECw (A) and sodium proportions (B) of the irrigation water

It is important to point out that the plants are affected by salinity not only because the reduction of osmotic potential of the soil solution, but also due to the toxicity of some salts that accumulate in leaves due to the transpiration process. Sodium and chloride are the most important ions that cause toxicity in sensitive crops and the water used in the present work had high concentrations of these ions. According to classification of Ayers e Westcot (1999), water with sodium adsorption ratio (SAR) above 3 and 9 $(mmol_c\ L^{-1})^{0.5}$ may result in moderate and severe toxic effects for sensitive plants, respectively, and Cl^- concentration above 10 $mmol_c\ L^{-1}$ is extremely harmful. The SAR of the waters applied in the present study ranged from 3 to 20 $mmol_c\ L^{-1}$**,** while concentration of Cl^- was above 10 $mmol_c\ L^{-1}$ for all treatments, except for treatment of 1 dS m^{-1} and proportion P1 of sodium, which had 6 $mmol_c\ L^{-1}$ of Cl^-**.** Consequently, symptoms of Na^+ and Cl^- toxicity were observed on plants irrigated even with moderate salinity and sodium proportion (P1), but none of the plants died and all of them produced fruits. The low concentration of Ca^{2+} in the irrigation water at low and moderate ECw levels probably contributed to intensify the Cl^- toxicity, inasmuch as Cl^- toxicity increases for low Ca^{2+} concentration in the external solution (GRATTAN; GRIEVE, 1999).

Table 3 – Mean values of percentage of roots of processing tomato in each soil layer, under different salinity levels (ECw) and sodium proportions (P1 = 1Na:1Ca:0.5Mg and P2 = 7Na:1Ca:0.5Mg) in the irrigation water, and summary of ANOVA

ECw	Soil layer		
(dS m^{-1})	0-15 cm	15-30 cm	30-45 cm
	(%)		
1	62	15	23
2	66	12	22
3	67	14	19
4	72	13	15
5	69	14	17
Test F	L**	ns	L**
Na Prop			
P1	68	13	19
P2	66	14	20
Test F	ns	ns	ns
ECw x P	ns	ns	ns
CV (%)	14.6	11.8	14.1

L represents linear effect by the regression analysis; ** Statistically significant (P < 0.01); ns Non-significant by Test F (P < 0.05)

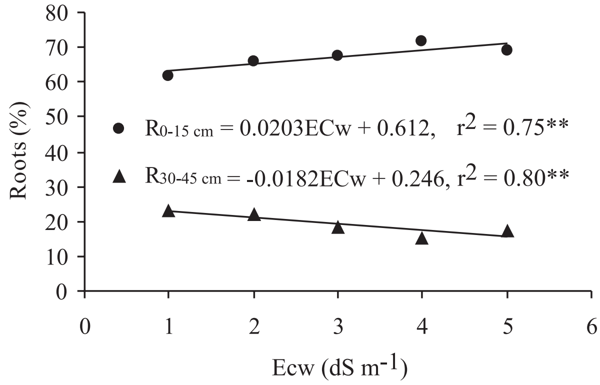

Figure 5 – Effect of the electrical conductivity of the irrigation water (ECw) on percentage of roots of processing tomato present at 0-15 cm and at 30-45 cm soil layers

Table 4 – Dry matter partitioning (percentages in relation to the total dry mass) of processing tomato, under different salinity levels (ECw) and sodium proportions (P1 = 1Na:1Ca:0.5Mg and P2 = 7Na:1Ca:0.5Mg) in the irrigation water, and summary of ANOVA

ECw	DML	DMS	DMB	DMI	DMF	DMR	DMSH
(dS m^{-1})				(%)			
1	26.9	12.4	6.1	3.9	43.6	7.0	93.0
2	24.3	9.9	5.2	4.1	48.1	8.4	91.6
3	26.5	11.1	5.6	4.3	44.4	8.1	91.9
4	23.0	7.9	4.3	3.8	52.1	8.8	91.2
5	25.3	8.5	4.9	4.0	48.3	9.1	90.9
Test F	ns	L**	ns	ns	ns	ns	ns
Na Prop							
P1	24.5	10.4	5.0	4.0	48.0	8.1	91.9
P2	26.2	9.9	5.6	4.0	46.0	8.3	91.7
Test F	ns	ns	ns	ns	ns	ns	ns
ECw x P	ns	ns	ns	ns	ns	ns	ns
CV (%)	12.2	22.3	21.3	18.1	11.6	12.6	2.4

L represents linear effect by the regression analysis; ** Statistically significant (P < 0.01); ns Non-significant by Test F (P < 0.05)

The effects of increasing ECw on IPA 6 tomato observed in this study was mainly the reduction in dry mass of the aerial parts (leaves, stem and branches) and promotion of an adaptation of the root system, which increased in density at the less saline soil layer and decreased at the more saline layer. As a result of this, the total dry mass of roots throughout the soil profile was maintained. Increasing the sodium proportions reduced shoot dry mass, mainly due to the reduction of fruit dry mass, and contributed to the delay in plant growth.

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