YIELD AND FRUIT QUALITY OF INDUSTRIAL TOMATO UNDER SALINE IRRIGATION

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ABSTRACT: Industrial tomato is the most important vegetable crop of the Brazilian agribusiness. Few researches have evaluated the tolerance of this crop to saline stress. In this study, the effects of five levels of salinity of the irrigation water (1, 2, 3, 4, and 5 dS m^{-1}) and two equivalent proportions of Na:Ca:Mg (1:1:0.5 and 7:1:0.5) were tested on yield and quality of fruits of industrial tomato, cultivar IPA 6. Seedlings were transplanted in rhizotrons and grown under plastic covering until fruit ripening. Volume of water for daily irrigations was determined by the difference between the applied and drained volume in the previous irrigation. Unitary increase of water salinity above 1 dS m^{-1} reduced the commercial and total yield by 11.9 and 11.0%, respectively, and increased the concentration of soluble solids and the titratable acidity of the fruits by 13.9 and 9.4%, respectively. The increase of the proportion of sodium reduced the total and marketable yield, the number of marketable fruits and pulp yield. Water of moderate salinity, with low concentration of sodium, can be used in the irrigation of the industrial tomato, without significant yield losses.
Key words: *Lycopersicon esculentum* Mill., salinity, pulp yield, water quality, sodium

RENDIMENTO E QUALIDADE DE FRUTO DO TOMATE TIPO INDUSTRIAL SOB IRRIGAÇÃO SALINA

RESUMO: O tomate para processamento industrial é a hortaliça mais importante da agroindústria brasileira. Poucas pesquisas têm sido desenvolvidas para avaliar a tolerância da cultura ao estresse salino. Neste estudo, foram testados os efeitos de cinco níveis de salinidade da água de irrigação (1, 2, 3, 4 e 5 dS m^{-1}) e duas proporções equivalentes de Na:Ca:Mg (1:1:0,5 e 7:1:0,5) sobre a produção e a qualidade dos frutos de tomateiro tipo industrial, cultivar IPA 6. As mudas foram transplantadas em rhizotrons e o cultivo foi conduzido sob cobertura plástica até a maturação dos frutos. O volume de água necessário para irrigações diárias foi determinado pela diferença entre o volume aplicado e o drenado na irrigação anterior. O aumento unitário da salinidade da água acima de 1 dS m^{-1} reduziu a produção comercial e total em 11,9 e 11,0%, respectivamente, e aumentou a concentração de sólidos solúveis e a acidez titulável dos frutos em 13,9 e 9,4%, respectivamente. O aumento da proporção de sódio resultou em redução da produção total e comercial, do número de frutos comerciais e do rendimento de polpa. Águas de salinidade moderada, com baixa concentração de sódio, podem ser utilizadas na irrigação do tomateiro industrial, sem perdas de rendimento no processamento.
Palavras-chave: *Lycopersicon esculentum* Mill., salinidade, rendimento de polpa, qualidade da água, sódio

INTRODUCTION

The cultivar 'IPA 6' of industrial tomato occupies large part of the areas planted with this crop in Brazil, especially in semi-arid areas subjected to salinity problems. However, studies about tomato tolerance to salinity are scarce, particularly for this cultivar. Giordano et al. (2000) report that the cultivar 'IPA 6' is resistant to *Fusarium* sp. and nematodes, and harvest can be completed at 120 days after planting, but ripening occurs along some weeks, which turns various harvestings needed.

According to Maas & Hoffman (1977), the maximum soil salinity tolerated by tomato, with basis on the electrical conductivity of the saturation extract (ECe), is 2.5 dS m^{-1}, with reduction of 9.9% in the production for each unit increase of salinity above this limit. On the other hand, Ayers (1977) reports that the use of irrigation water with electrical conductivity of 1.7, 2.3, 3.4, and 5.0 dS m^{-1} reduces 0, 10, 25 and 50%

the tomato yield, respectively, assuming 0.15-0.20 leaching fractions.

The effects of the salinity on the tomato may be either harmful, reducing the yield and increasing the incidence of blossom-end rot, or beneficial (antioxidant), increasing fruits concentration of soluble solids (Mizrahi & Pasternak, 1985; Cuartero & Muñoz, 1999; De Pascale et al., 2001) and acidity (Vinten et al., 1986; De Pascale et al., 2001), resulting in larger profit at processing.

Several studies in the literature relate the effects of the salinity on tomato crop. However, because the tolerance of crop to salinity varies among species and genotypes (Tester & Davenport, 2003; Maggio et al., 2004), studies with new cultivars should be continued to evaluate their degree of tolerance to saline stress. Studying the effects of five levels of soil salinity (of saturation extract) in five cultivars of processing tomato, Souza (1990) observed decrease in the number of fruits and yield, starting from the level of 2.46 and 4.52 dS m^{-1}, respectively, with reduction of the average fruit weight, these effects being more pronounced at 9.60 dS m^{-1}. Scholberg & Locascio (1999) used waters of salinity up to 4 dS m^{-1} for drip irrigation of tomato and verified linear reduction in the number of fruits, total yield, and average fruit weight, while the number and production of marketable fruits were affected in a quadratic manner.

The objectives of the present study were determining yield and fruit quality of industrial tomato, cultivar 'IPA 6', irrigated with waters of different salinities and variable proportions of Na:Ca:Mg.

MATERIAL AND METHODS

The experiment was conducted in Campina Grande, PB (7°15'18" S, 35°52'28" W; altitude 550 m), during May 29 to October 10, 2000. According to classification of Köppen adapted to Brazil (Coelho & Soncin, 1982), the climate of the area is of the type Csa, i.e. a semi-humid climate, with hot and dry summer and rains in autumn and winter. The area's temperature and relative humidity measured in a conventional weather station are shown in Figure 1.

Treatments were of five salinity levels (electrical conductivity of the water - ECw = 1, 2, 3, 4, and 5 dS m^{-1}), and 2 equivalent proportions of Na:Ca:Mg (P1 = 1:1:0.5 and P2 = 7:1:0.5) in the irrigation water. The experiment was set in a 5 × 2 factorial scheme, completely randomized design (n = 3). The waters used for crop irrigation were prepared from tap water 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 and Mg. The amounts of salts or distilled water to be added were determined to obtain the desired ECw of the respective treatments 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 × 10 (Rhoades et al., 1992).

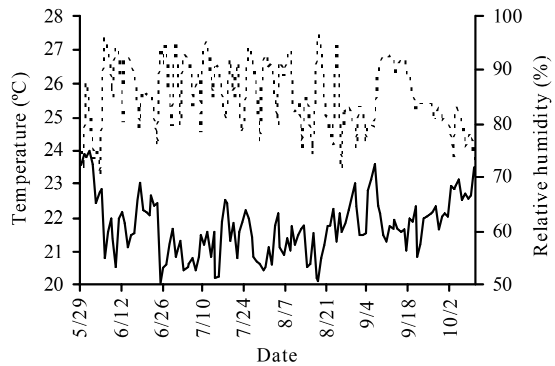

Figure 1 - Temperature (solid line) and relative humidity (dashed line) measured in a conventional weather station in Campina Grande during the experimental period.

Seedlings of industrial tomato, cultivar 'IPA 6', were transplanted in rhizotrons (one seedling per rhizotron) and conducted under plastic covering until fruit ripening. The rhizotrons were built with PVC pipes diameter 0.3 m; length 0.6 m and divided longitudinally to provide a semi-cylindrical piece with wood bottom and front face closed with an acrylic plate, volume = 21.21 L. A drainage tube linked to a collector was installed in the base of the rhizotrons. The rhizotrons were filled with soil and a 5 cm layer of gravel; 5 cm of washed sand were placed in the bottom and 48.2 g of calcium nitrate, 180 g of simple superphosphate and 54 g of potassium chloride were mixed to the soil before planting. A 5-cm free board was left at the top for addition of water. Total volume of irrigation water applied during the experiment ranged from 117 to 77 L $plant^{-1}$ for ECw of 1 and 5 dS m^{-1}, respectively. It was used a non-saline and non-sodic soil, whose physical and chemical characteristics are presented in the Table 1.

Irrigations were performed daily, always at late afternoon, without wetting the leaves and drained volume was collected the following morning. Each treatment had a different irrigation volume calculated in function of the evapotranspiration (difference between the applied and drained volume of water) of the previous day. The volume of water to be applied was estimated by dividing the evapotranspiration of the previous day either by 0.85, for the period between the transplanting and the beginning of the flowering, or by 0.80, from flowering to the harvest, to elevate the soil moisture to field capacity and provide desirable leaching fraction (0.15 or 0.20).

Table 1 - Characteristics of the soil material used[1].

Characteristic	Value
Bulk density (kg dm^{-3})	1.37
Sand (kg m^{-3})	635
Silt (kg m^{-3})	198
Clay (kg m^{-3})	167
Organic matter (g kg^{-1})	6.0
Saturation extract	
pH	4.54
ECe (dS m^{-1})	0.50
SAR ($mmol_c$ L^{-1})$^{0.5}$	1.84
Exchange complex ($mmol_c$ kg^{-1})	
H + Al	2.72
Ca	0.38
Mg	0.74
Na	0.20
K	0.06
CEC	4.10
V (%)	33.7
ESP	4.9
Water retention (g kg^{-1})	
10 kPa	87.2
1520 kPa	27.3

[1]Methodology recommended by EMBRAPA (1997).

During the crop development, 42.7 g of calcium nitrate and 20.9 g of potassium chloride were applied per plant, dissolved in the irrigation water and divided in 10 applications with graduated increments, as recommended by IPA (1998). After flowering, calcium was applied weekly through foliar application until the formation of last bunch, being sprayed with a solution containing 6 g L^{-1} of calcium chloride (78% pure), directing the spray towards the leaves close to the fruits.

The fruits were harvested starting 75 days after the transplanting (DAT) and concluded 134 DAT. Fruits were picked when totally ripe and classified in marketable or non-marketable fruits (fruits with mechanical, physiologic and/or phytosanitary damages). The marketable and total yield, the average fruit weight, the number of marketable and total fruits and the qualitative characteristics of the fruits (soluble solids, pH and titratable acidity) were evaluated. The qualitative characteristics were determined in a sample of 15 fruits per replication. Titratable acids were determined on filtrates of dried and homogenized samples titrated to pH 8.1 with 0.1 N NaOH, and expressed as grams of citric acid per 100 g of pulp; total soluble solids were measured on tomato juice samples with a refractometer and expressed as °Brix (Pregnolatto & Pregnolatto, 1985).

The concentrated pulp yield was also evaluated, once evaluation of production only is not sufficient to determine effects of salinity on industrial tomato, because increasing soluble solids results in increasing pulp yield. The concentrated pulp yield was estimated by the equation (Giordano et al., 2000):

$$CPY = \frac{MY \text{ x } ^{o}Brix}{28}$$

where CPY = concentrated pulp yield adjusted to 28 ºBrix (g pulp $plant^{-1}$), and MY = marketable yield (g $plant^{-1}$). The concentrated pulp yields of the treatments were expressed in relation to yield obtained in the treatment irrigated with water of ECw = 1 dS m^{-1}, and were adjusted to the piecewise regression (Maas & Hoffman, 1977) using the software SALT (Van Genuchten, 1983).

The values obtained for each variable were submitted to analysis of variance and test F. When significant, the effects of the salinity levels were evaluated by polynomial regression and the effects of the different proportions of sodium by the Tukey test (Gomes, 2000).

RESULTS AND DISCUSSION

Except for fruits' pH, number of marketable fruits, number of total fruits and concentrated pulp yield, the other variables were found to be affected linearly by the salinity of the irrigation water (Table 2). Tomato yield was reduced with increasing salinity of the irrigation water, the reduction being 11.8 and 10.1% for total yield of P1 and P2, respectively, and 11.0% for marketable yield, for each unit increased in the salinity of the irrigation water above 1 dS m^{-1} (Figure 2A and 2B). Such reductions are slightly lower than those (15.6%) reported by Ayers & Westcot (1999) and they were just related to the effects of salinity of the water, once no plant died from saline stress. In addition, Ayers & Westcot (1999) registered that yield decrease only occurs for ECw above 1.7 dS m^{-1}; in the present study, the results did not allow establishing the salinity threshold and crop yield decreased linearly beginning at 1 dS m^{-1}.

Higher marketable yield was 3,191 g $plant^{-1}$ for treatment irrigated with water of 1 dS m^{-1}, while the lower yield was 1,538 g $plant^{-1}$ for ECw of 5 dS m^{-1}. Many factors, such as cultivar, climatic conditions and evapotranspiration, and types of salts present in the soil solution can influence the tolerance of a crop to salinity (Tester & Davenport, 2003). Grattan & Grieve (1999) and White & Broadley (2003) present evidences

Table 2 - Summary of analysis of variance (test F) and mean values of marketable (MY) and total (TY) yield, average fruit weigh (AFW), number of marketable (NMF) and total (NTF) fruits, soluble solids, pH, titratable acidity and concentrated pulp yield (CPY) of the fruits of processing tomato, under different salinity levels and proportions of sodium in the irrigation water[1].

Cause of variation	MY	TY	NMF	NTF	AFW	Soluble solids	pH	Titratable Acidity	CPY
					F				
Levels of Salinity (S)	11.19**	38.67**	1.46	1.22	9.10**	16.84**	1.85	3.99*	2.66
Linear	42.76**	146.05**	-	-	35.42**	64.96**	-	14.74**	-
Quadratic	0.80	1.84	-	-	0.83	0.47	-	0.26	-
Proportions of Sodium (P)	9.78**	23.28**	6.72*	3.32	0.95	2.20	1.72	0.79	5.82*
SxP	0.71	3.70*	0.48	1.44	0.21	1.16	1.59	1.51	1.61
CV (%)	30.3	24.6	19.9	14.6	20.8	18.8	3.3	19.9	9.3
Proportion Na:Ca:Mg					Mean				
	g plant^{-1}		fruits plant^{-1}		g fruit^{-1}	ºBrix		g 100 g^{-1}	g plant^{-1}
P1 (1:1:0,5)	2730 a	3120 a	58.6 a	69.1 a	45 a	5.5 a	4.4 a	0.30 a	520 a
P2 (7:1:0,5)	2207 b	2658 b	48.7 b	63.1 a	43 a	5.8 a	4.3 a	0.30 a	442 b

[1]Different letters in the same column indicate different means by the test of Tukey ($P < 0.05$).
*,** Significant at 0.01 and 0.05 of probability by test F, respectively.

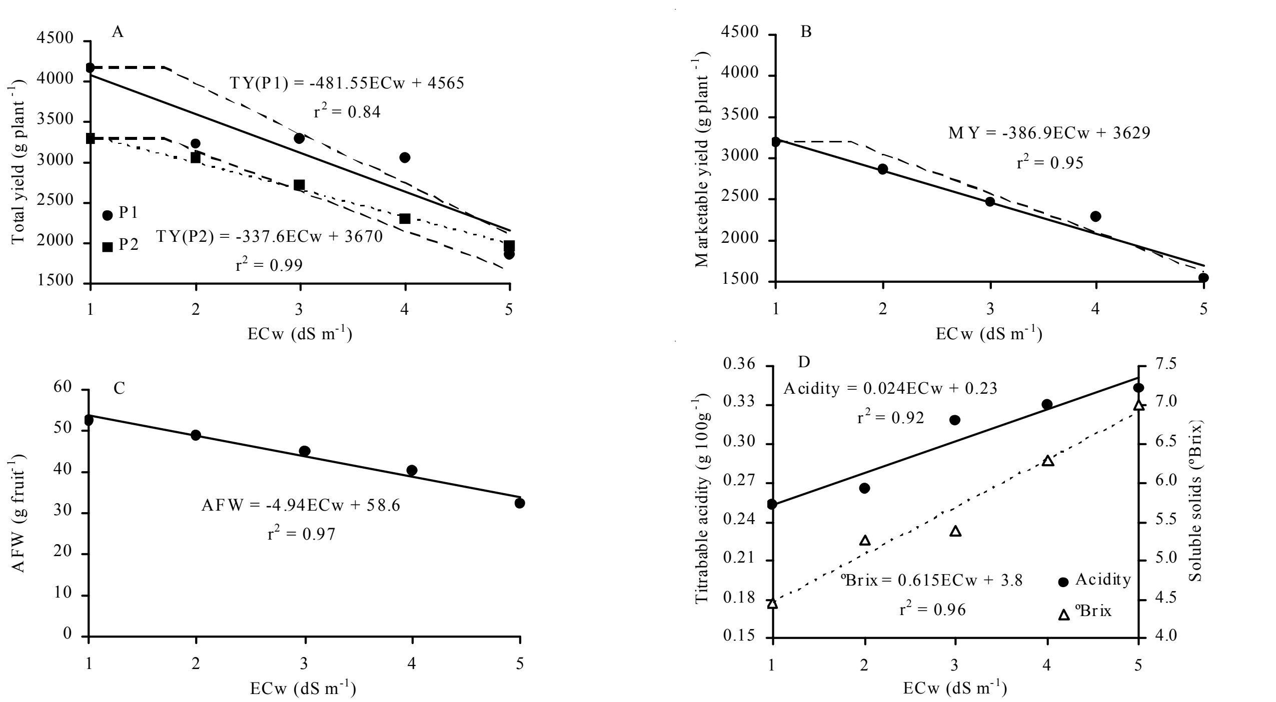

Figure 2 - Regression equations for the effects of the salinity levels in the total (A) and marketable (B) yield, average fruit weight (AFW) (C), and soluble solids and titratable acidity (D) of the fruits of industrial tomato. Long-dashed lines of A and B are the values of TY and MY calculated by the threshold-slope model of Maas & Hoffman (1977) from the values of ECw, assuming threshold ECw = 1.7 dS m^{-1} (Ayers & Westcot, 1999).

that some nutrients, when present in soil solution in high amounts, could promote increase in the crops' tolerance to salinity; among others, K and Ca deserve special attention once these ions are responsible to keep K/Na and Ca/Na ratios in the leaves closer to the values found in plants cultivated in non-saline conditions. In the present study, plants were grown under conditions of high doses of fertilizers containing K and Ca, therefore, the higher tolerance to salinity could be attributed to plants nutritional conditions.

Average fruit weight (AFW) decreased from 53 g to 32 g for ECw = 1 and 5 dS m^{-1}, respectively; reduction was 9.2% for unit increase of ECw above 1 dS m^{-1} (Figure 2C). Under moderate salinity conditions, reduction of tomato yield results mainly, from reduction in average fruit weight, while in high salinity conditions, yield reduction results from smaller number of fruits produced (Cuartero & Muñoz, 1999). The significant reduction of average fruit weight and the non-significant effects on number of marketable and total fruits with increasing salinity (Table 2) corroborate the previous statement, and yield reduction in the present study can be attributed mainly to the reduction of fruits' size.

The values commonly obtained for soluble solids and acidity of tomato fruits range from 4 to 6 ºBrix and 0.3 to 0.4 g 100 g^{-1} for acidity (Alcántar et al., 1999; De Pascale et al., 2001; Cramer et al., 2001). In the present study there was linear increase of soluble solids and acidity of the fruits with increasing salinity, equivalent to 13.9 and 9.4%, respectively, for unit increase of ECw above 1 dS m^{-1} (Figure 2D). The minimum value of soluble solids found in the present study, (around 4.5 ºBrix), is considered low for industrial tomatoes. According to Giordano et al. (2000) the cultivar 'IPA 6' should present about 5.0 to 5.5 ºBrix. The leaching fraction of 0.15 and 0.20 adopted in the present study could explain the low concentration of soluble solids in the treatment of low level of water salinity (ECw = 1 dS m^{-1}), as high irrigation depths are usually associated to low soluble solids concentrations in industrial tomato fruits (Hanson & May, 2004). The increase of soluble solids with the increasing water salinity might have been caused by the reduction of the import of water by the fruit in saline conditions (Sakamoto et al., 1999), and an active accumulation of solutes, mainly ions and organic molecules typically produced in salt-stressed plants (Munns, 2002), with consequent concentration of the soluble solids in the pulp.

The pH of the fruit pulp was in the range considered appropriate for industrial tomato, varying from 4.3 to 4.4, and was not influenced by the studied factors. According to Giordano et al. (2000), pH below 4.5 is a desirable trait, because it halts proliferation of microorganisms in the final product of the industrial processing. Kaplan et al. (1999) also did not observe significant differences in the pH of the fruit pulp under increasing levels of ECw.

Low titratable acidity was observed for the low salinity treatment, but it increased linearly with increasing water salinity (Figure 2D). This increase is advantageous, once fruits with titratable acidity below 0.35 g 100 g^{-1} of fresh weight require extra time and high temperature for processing (Giordano et al., 2000), resulting in higher cost of the final product. However, the maximum value observed was 0.34 g 100 g^{-1}, which is below the minimum value for processing.

In a comparative study, George et al. (2004) evaluated the titratable acidity in fruits of 12 tomatoes genotypes and reported that the acidity varied from 0.256 to 0.704 g 100 g^{-1}. Therefore, the low values of acidity registered could be related to the intrinsic characteristics of the cultivar 'IPA 6', with improvement of fruits quality with increasing ECw. Increased acidity of salt-stressed vegetable crops has been reported for tomato (Feigin et al., 1987; Martinez & Cerdá, 1989), cucumber (Martinez & Cerdá, 1989), eggplant (Savvas & Lenz, 1996), and melon (Feigin et al., 1987), and it has been associated to an increase in the level of organic acids.

The different proportions of sodium affected marketable and total yield, number of marketable fruits, and concentrated pulp yield, the interaction salinity vs sodium proportions being significant only for total yield (Table 2). The proportion P1 was found to be superior to P2 for all variables, i.e., the highest proportion of Na in relation to Ca and Mg in the water contributed to yield reduction. Considering that the total number of fruits was not influenced by the proportion of sodium, it can be inferred that the main effect of increasing Na concentration in the water was increasing the number of non-marketable fruits (10.5 fruits $plant^{-1}$ for P1 against of 14.5 fruits $plant^{-1}$ for P2, on average). Yield reduction was mostly associated with smaller fruit size rather than fruit number. This may have been caused by a reduced enlargement rate during the exponential phase of fruit growth, which has been reported to be particularly sensitive to ionic and osmotic damages of the ions accumulated in the plants throughout the growth season (Bolarin et al., 2001). In addition, the existence of antagonism between Na and Ca in the absorption process by the plant (Tester & Davenport, 2003) could reduce Ca uptake, because the high concentration of Na in the soil solution is associated with the occurrence of blossom-end rot and, consequently, reducing the marketable yield of the tomato (Cuartero & Muñoz, 1999; Grattan & Grieve, 1999).

Salinity levels did not affect the concentrated pulp yield, although it was 17.6% higher in P1 in relation to P2 (Table 2). The mean pulp yields were 505, 533, 472, 511 and 383 g $plant^{-1}$ for ECw of 1, 2, 3, 4 and 5 dS m^{-1}, respectively. The concentrated pulp yield varied little between ECw of 1 and 4 dS m^{-1}, and reduced in larger scale only in ECw of 5 dS m^{-1}, it is thus fair to infer that the irrigation of industrial tomato with water up to 4 dS m^{-1} is acceptable for pulp production. In spite of the reduction in the marketable yield, this salinity did not promote losses in concentrated pulp yield, as it was found to be reduced only by the proportions of sodium in irrigation water due to its negative effect on marketable yield.

The adjustment of the piecewise regression function revealed that the relative pulp yield decreased starting from ECw of 2.65 dS m^{-1}, with reduction of 8.8% for each unit increase on salinity above this level. The extrapolation of the regression line indicates that ECw = 14 dS m^{-1} would result in relative pulp yield equal to zero (Figure 3). According to the relationships between ECw, electrical conductivity of the saturation extract (ECe) and electric conductivity of the drainage water (ECd), proposed by Ayers & Westcot (1999), the estimated values of ECe and ECd for zero concentrated pulp yield would be 21 and 42 dS m^{-1}, respectively. These values may be used in the calculations of the leaching fraction or leaching requirements seeking to control soil salinity in irrigated agriculture. Therefore, although the mean values of concentrated pulp yield have been similar up to ECw = 4 dS m^{-1}, the calculated salinity threshold was 2.65 dS m^{-1}, and the irrigation of the industrial tomato with waters that present salinity above this value is not recommended if the market of fruits *in natura* is aimed.

Considering that a sandy loam soil was used in this study, and the relationship between ECw and ECe for this type of soil is 1.5 (Maas & Hoffman, 1977), the salinity threshold of the soil (ECe) should be $2.65 \times 1.5 = 3.97$ dS m^{-1}, thus the tolerance of cultivar 'IPA 6' is higher than that reported by Maas & Hoffman (1977) for tomato (2.5 dS m^{-1}). If only marketable yield is taken into consideration, the result would be different, once linear reduction in yield occurred from ECw of 1 dS m^{-1}.

Therefore, marketable yield data of the industrial tomato alone is not enough to evaluate the effects of the salinity on the crop. Carvalho et al. (2003) evaluated 30 families of industrial tomato and registered

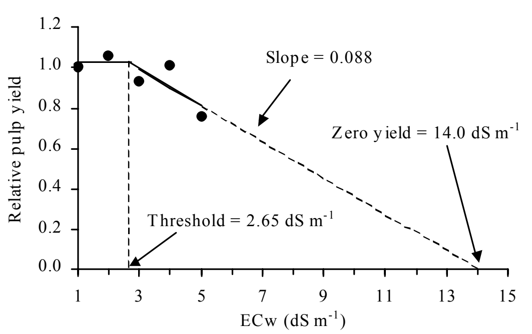

Figure 3 - Relative pulp yield and response function to the salinity of the irrigation water (ECw) of the processing tomato.

negative correlation between marketable yield and soluble solids, similar to observed in the present study. Therefore, once the pulp yield is related to these variables, concentrated pulp yield should always be evaluated in salinity studies, because only the evaluation of marketable yield could lead growers to reject waters that could still be used without damage.

Using saline water for irrigation of processing tomato, particularly if water contains high proportion of sodium, may result in several problems, like reduction of water infiltration rate and hydraulic conductivity of the soil; increase of the concentration of some toxic elements to the plants, like Na^+ and Cl^-; clay dispersion, with consequent increase of the soil penetration resistance (Santos, 2004; Al-Nabulsi, 2001; Barreto Filho et al., 2003). Therefore, long term effects on chemical and physical characteristics of the soil and on environment must be monitored and appropriate techniques adopted to avoid soil degradation when using marginal quality water for irrigation.

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