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Potential for macro and micronutrients extraction from tomato plants with different soil water stresses

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Abstract. Different tomato cultivars may present differentiated water needs, making it indispensable to study water demand. Thus, the objective of this work was to evaluate the influence of six water stresses in the soil on the extraction potential of macro and micronutrients in the aerial part of tomato in vegetative stage, cultivar 'Dominador' F1, under protected cultivation and drip. The experiment was installed in a greenhouse with a randomized block design with four replications. The treatments consisted of six soil water stresses as indicative of the time of irrigation. The preset stresses were 20, 45, 70, 95, 120 and 145 kPa at 20 cm depth. At 140 days after transplanting, the variables evaluated were: the macro and micronutrient content of shoots. The results showed that to obtain higher levels of macro (P and S) and micronutrients (B and Cu) of the total aerial part of the 'Dominador' tomato plant F1, it was obtained at a voltage of 20 kPa, and its value was reduced linearly with the increase of the water tension in the soil.

Key words: *Solanum lycopersicon* L., production, quality.

INTRODUCTION

Tomato (*Solanumly copersicon L.*) is one of the most cultivated vegetables in the world. Its fruits contain a large amount of water (93 to 95%), and the practice of irrigation is indispensable for its cultivation. It is one of the most demanding vegetables in the water, and the moisture content of the soil should show little variation. Both excess and water deficit are harmful to culture (Chitarra & Chitarra, 2005; Alvarenga et al., 2013).

Available water and soil fertility are among the main factors that affect crop productivity. Therefore, in the development of the tomato production system, irrigation management is extremely important. This practice increases the yield of the cultivated area, produces fruits with better quality and increases the efficiency of the absorption of macro and micronutrients by plants (Carrijo et al., 2004; Mantovani et al., 2009).

The main damages caused by inadequate irrigation management in tomatoes are morphological damages, such as: cracks, apical rot, fall of flowers and fruits, hollow fruits, less dry matter production, physiological changes due to the lack of absorption of nutrients that affect the nutritional quality of fruits. tomato, among other damages (Sun et al., 2013; Hott et al., 2014; Kuşçu et al., 2014).

The study of adequate irrigation management cannot be generalized for tomatoes, as each cultivar responds differently to the water content in the soil. According to Marouelli et al. (2012), the recommended water stress in the soil to restart irrigation varies from 30 to 70 kPa. This variation in water tension in the soil demonstrates the need for more specific studies for tomatoes, as there are different responses between cultivars.

Morales (2012), when assessing the resistance to water deficit in 20 tomato families, observed greater fruit production, productivity, apical rot and water content in the leaves in some tomato cultivars to the detriment of others. This fact corroborates the importance of studying the water needs for each cultivar.

Thus, the objective of this work was to evaluate the influence of six water stresses in the soil on the extraction potential of macro and micronutrients in the aerial part of tomato in vegetative stage, cultivar Dominador F1, under protected cultivation and drip.

MATERIAL AND METHODS

Characterization of the experimental area

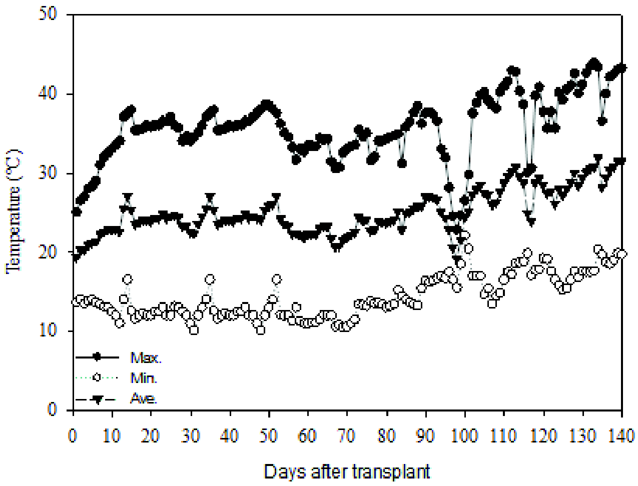

Figure 1, Maximum, minimum and average temperature (°C) of the air that occurred inside the greenhouse. UFLA, Lavras, MG, 2015.

The experiment was carried out in a greenhouse (protected environment) located in the experimental area of the Engineering Department of the Federal University of Lavras (UFLA), from March to October 2015. UFLA is located in the municipality of Lavras, south of Minas Gerais, which is at an average altitude of 910 meters, latitude 21°14' S and longitude 45°00' W. Fig. 1 and 2 shows the variation in temperature and relative humidity maximum, minimum and average air respectively inside the greenhouse, measured throughout the experiment (140 days). The average air temperature inside the greenhouse was 25.0 °C, the minimum mean reached was 14.4 °C and the average maximum was 35.6 °C, resulting in a thermal amplitude of 21.2 °C.

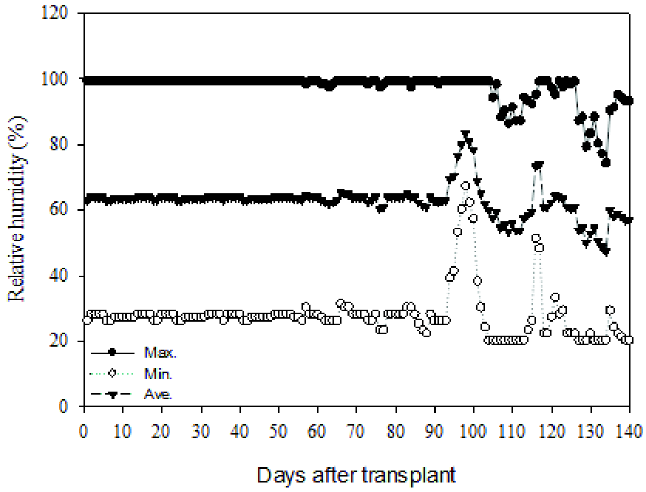

Figure 2. Relative humidity (%) average and minimum occurred inside the greenhouse. UFLA, Lavras, MG, 2015.

Irrigation equipment and management

The drip irrigation system was installed using in-line emitters, self-compensating and distanced by 0.30 m. The emitters presented an average flow rate of 1.74 L h^{-1} with pressure of 1.95 kgf cm^{-2}. Since each experimental plot was composed of two rows of plants, spaced at 1.0 m, in each line a drip tube was installed in order to provide water to the plants, that is, in each experimental plot two drip tubes were required.

A solenoid valve was used for each treatment. These valves were actuated by a controller previously programmed in each irrigation to function as long as necessary to replenish the blade indirectly estimated by the moisture sensors. In all irrigations, the humidity corresponding to the tension verified at the time of irrigation was increased to the field capacity.

The calculation of the operating time of the irrigation system in each treatment was made based on the installed humidity sensors. The moment of irrigation was established when four sensors, of six installed (three in block 1 and 2), presented the corresponding tension of the treatment, obtaining the mean reading. Irrigation management was performed based on soil moisture, using granular matrix sensors (watermark) and a matrix potential meter. All sensors used were previously tested. The net, crude depth and the operating time of the irrigation system, used to raise the current soil moisture to the field capacity, was determined by Eq. 1, 2 and 3, respectively.

$$LL = (\theta_{CC} - \theta_{atual})\, z \tag{1}$$

$$LB = \frac{LL}{Ea\, CUD} \tag{2}$$

$$T = \frac{LB\ A}{e\ qa} \tag{3}$$

In which: LL = Liquid irrigation depth (mm); θcc = Humidity in field capacity ($cm^3\ cm^{-3}$); θ actual = Current humidity ($cm^3\ cm^{-3}$); Z = Effective depth of the root system (mm); LB = Crude irrigation depth (mm); Ea = Water application efficiency by irrigation system (dimensional) (Ea used = 95%); CUD = Uniformity coefficient of distribution of the irrigation system (dimensional); T = Irrigation time to raise soil moisture to field capacity (h); A = area occupied by the plant (m^2); qa = average flow of emitters ($L\ h^{-1}$); e = number of emitters per plant (two).

For the determination of the CUD (Eq. 4), the uniformity of water application in one of the treatments randomly chosen was evaluated, using the mean of four repetitions (four blocks). For this, the flow rates of the 16 emitters contained in the plot were collected. The CUD value found was 98%.

$$CUD = 100 \frac{q_{25}}{q_m} \tag{4}$$

In which: $q25$ = average value of the 25% lower flows observed, $L\ h^{-1}$; qm = mean flow of drippers, $L\ h^{-1}$. The initial irrigation management before the differentiation of the treatments, up to 18 days after the seedling snare, was performed with watermark sensors, whose critical stress established for the beginning of irrigations was 13 kPa, thus trying to maintain soil moisture, close to the field capacity.

Voltages and water depths applied

Table 1 presents data on the management of irrigation (treatments) of tomato during the experiment. For this, the applied blade was calculated based on two depths, being 20 cm until the end of flowering and 40 cm after flowering (Alvarenga, 2013).

Table 1. Water stresses in the applied soil (kPa stress), blades applied before differentiating the treatments (1), during the cycle (2), total (3), mean by irrigation (4), mean interval between irrigations (5) and number of irrigations (6). UFLA, Lavras, MG, 2015

Tension (kPa)	Blade (mm)				5 (days)	6
	1	2	3	4		
20 (T1)	38.58	877.87	916.45	28.32	3.9	31
45 (T2)	38.58	481.24	519.82	43.75	10.7	11
70 (T3)	38.58	251.73	290.31	50.35	22.4	5
95 (T4)	38.58	159.39	197.97	53.13	33.3	3
120 (T5)	38.58	107.32	145.90	53.66	45	2
145 (T6)	38.58	108.57	147.15	54.28	49	2

In order to establish the crop, irrigations were made whenever the soil moisture sensor (‘watermark’) charged an average voltage of 13 kPa, resulting in a blade of 38.58 mm at 18 days after transplantation. On the 18th day after transplantation, the last irrigation of establishment was made and the differentiation of the treatments was initiated. The total water replaced by the crop throughout the cycle for each treatment was 916.45 mm (T1), 519.82 mm (T2), 290.31 mm (T3), 197.97 mm (T4), 145.90 mm (T5) and 147.15 mm (T6). Figs 3, 4, 5, 6, 7 and 8 show the average stresses recorded by the humidity sensors, installed at a depth of 20 cm, used for decision making and calculation of the applied irrigation depth.

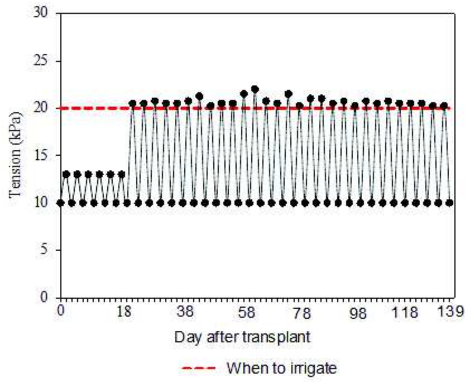

Figure 3. Variation of soil water stresses in treatment T1 (20 kPa) during conduction of the experiment. UFLA, Lavras, MG, 2015.

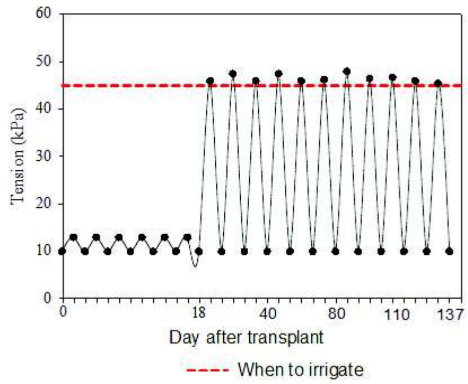

Figure 4. Variation of soil water stresses in the T2 treatment (45 kPa) during the conduction of the experiment. UFLA, Lavras, MG, 2015.

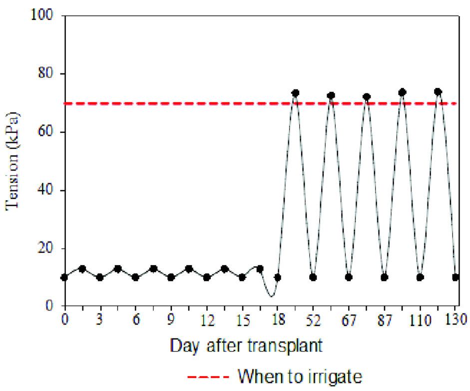

Figure 5. Variation of soil water stresses in the T3 treatment (70 kPa) during the conduction of the experiment. UFLA, Lavras, MG, 2015.

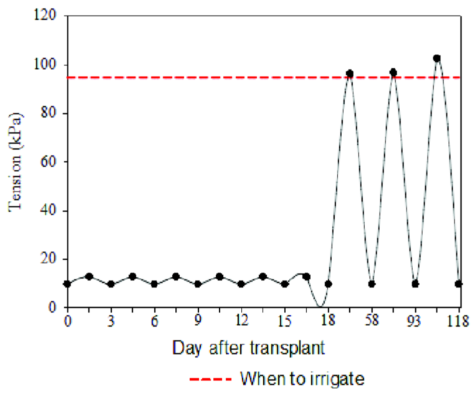

Figure 6. Variation of soil water stresses in T4 (95 kPa) during the conduction of the experiment. UFLA, Lavras, MG, 2015.

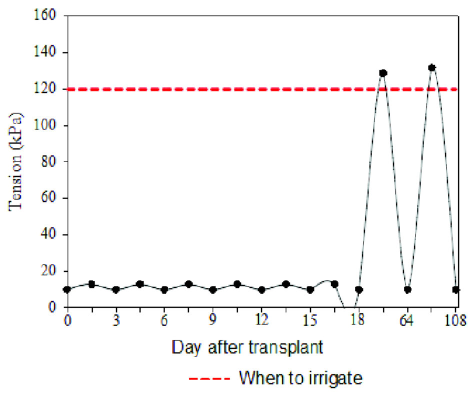

Figure 7. Variation of soil water stresses in the T5 treatment (120 kPa) during the conduction of the experiment. UFLA, Lavras, MG, 2015.

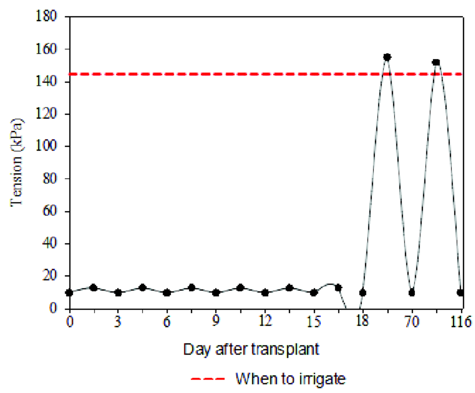

Figure 8. Variation of soil water stresses in the T6 treatment (145 kPa) during the conduction of the experiment. UFLA, Lavras, MG, 2015.

Design and experimental assembly

A randomized complete block design (RCB) was used, with six (6) treatments and four (4) repetitions. The treatments consisted of six soil water stresses, as an indication of restarting irrigations (20, 45, 70, 95, 120 and 145 kPa). Four (4) granular matrix sensors (Granular Matrix Sensor, GMS, watermark® model 200SS) were installed, 3 (three) ‘watermark’ at 20cm of soil depth, which served as indirect indicators in each plot to know on when and how much to irrigate (decision sensors), and 1 (one) to 40 cm deep to only monitor soil moisture, at this depth, using the spacing between 60 cm sensors.

Each experimental plot was 1.40 m wide and 2.90 m long (4.06 m^2). The experimental plots were composed of two rows of plants spaced 1.0 m between them and 0.60 m between plants. Useful plots were considered those composed by the central plants (four plants), because, in the total of 8 plants that composed each experimental plot, 4 plants were discarded, two plants at each end, aiming to reduce the border effect. The spacing between the plots was 0.80 m.

Macro and micronutrient content of shoots

To obtain the levels of macro (N, P, K, Ca, Mg and S) and micronutrients (B, Cu, Mn, Zn and Fe) of the aerial part of the tomato, the plant was also divided into three thirds (lower, middle and upper). The content of the elements of the total shoot was obtained by the sum of the three thirds of the plant. Samples were taken from leaves and stem for drying in an oven at 65 ~ 70 °C until constant weight. The samples were crushed in a Wiley knife mill, conditioned in paper bags and taken to the Foliar Analysis Laboratory of the UFLA Chemistry Department, and the contents of the elements were determined by the methodology of Sarruge & Haag (1974) adapted by the laboratory.

Statistical analysis

The statistical analysis of the data included the analysis of variance with the f test and regression analyses at 5% and 1% probability.

RESULTS AND DISCUSSION

Macro and micronutrient content of shoots

Tables 2, 3 and 4 present the abstracts of variance and regression analyses for the macronutrient contents of the lower, middle and upper third, respectively, of the Dominating Tomato F1 submitted to different water stresses in the soil. Table 5 shows this analysis for the total aerial part of the plant. According to the analysis, it was noted that there was no significant effect among treatments for macronutrient levels N, K, Ca and Mg in the three thirds of the plant and in the whole plant (mean of 5.59; 2.96; 9.12 and 1.73% - equivalent to 55.9; 29.6 and 17.3 g kg^{-1} - for N, K, Ca and Mg, respectively). There was significant effect only for element P in the three thirds of the plant. And for element S the effect of the treatments was significant only in the lower third of the plant.

The results obtained in this study indicate that tomatoes require the same amounts of water to extract nutrients for the lower third and total plant. The best vegetative development of the tomato occurred at a tension of 20 kPa. however, the tomato has a lower water demand in the vegetative stage. The lower water consumption may be associated with the low evapotranspiration surface of the tomato during the vegetative period (Duarte et al., 2010).

Table 2. Summary of variance and regression analysis for macronutrient content of the lower third of Dominator Tomato F1, submitted to different water stresses in the soil

Source of Variation	D. F	M. S.					
		N	P	K	Ca	Mg	S
Tension	5	0.29^{ns}	0.01^{**}	0.03^{ns}	0.25^{ns}	0.00^{ns}	0.08^{**}
Block	2	0.29^{ns}	0.00^{ns}	1.11^{**}	0.28^{ns}	0.01^{**}	0.08^{*}
Residue	10	0.10	0.00	0.03	0.11	0.00	0.01
Mean (%)	-	1.78	0.13	1.09	3.10	0.58	0.62
C. V. (%)	-	17.83	17.19	15.76	10.66	4.51	18.54
Linear	1	-	0.05^{**}	-	-	-	0.31^{**}
Quadratic	1	-	0.01^{**}	-	-	-	0.05^{ns}
Cubic	1	-	0.00^{ns}	-	-	-	0.01^{ns}
Deviation	2	-	0.00^{ns}	-	-	-	0.00^{ns}
Residue	10	-	0.00	-	-	-	0.01

*and**significant at 5 and 1% probability by the F test, respectively; ^{ns}not significant. UFLA, Lavras, MG, 2015.

Table 3. Summary of variance and regression analysis for macronutrient content of the middle third of Dominator Tomato F1, submitted to different water stresses in the soil

Source of Variation	D. F	M. S.					
		N	P	K	Ca	Mg	S
Tension	5	0.22^{ns}	0.00^{**}	0.07^{ns}	0.14^{ns}	0.00^{ns}	0.03^{ns}
Block	2	0.29^{ns}	0.00^{ns}	0.41^{**}	0.13^{ns}	0.01^{**}	0.02^{ns}
Residue	10	0.08	0.00	0.05	0.16	0.00	0.01
Mean (%)	-	1.91	0.13	0.95	3.21	0.59	0.61
C. V. (%)	-	15.12	16.69	24.27	12.35	6.29	20.46
Linear	1	-	0.02^{**}	-	-	-	-
Quadratic	1	-	0.00^{**}	-	-	-	-
Cubic	1	-	0.00^{ns}	-	-	-	-
Deviation	2	-	0.00^{ns}	-	-	-	-
Residue	10	-	0.00	-	-	-	-

*and**significant at 5 and 1% probability by the F test, respectively; ^{ns}not significant. UFLA, Lavras, MG, 2015.

Table 4. Summary of variance and regression analysis for macronutrient content of the upper third of Dominator Tomato F1, submitted to different water stresses in the soil

Source of Variation	D. F	M. S.					
		N	P	K	Ca	Mg	S
Tension	5	0.22^{ns}	0.00^{**}	0.18^{ns}	0.17^{ns}	0.00^{ns}	0.03^{ns}
Block	2	0.16^{ns}	0.00^{ns}	0.37^{**}	0.01^{ns}	0.01^{**}	0.04^{ns}
Residue	10	0.10	0.00	0.07	0.11	0.00	0.01
Mean (%)	-	1.90	0.12	0.92	2.81	0.56	0.54
C. V. (%)	-	17.34	17.81	27.28	11.84	4.50	21.23
Linear	1	-	0.03^{**}	-	-	-	-
Quadratic	1	-	0.00^{ns}	-	-	-	-
Cubic	1	-	0.00^{ns}	-	-	-	-
Deviation	2	-	0.00^{ns}	-	-	-	-
Residue	10	-	0.00	-	-	-	-

*and**significant at 5 and 1% probability by the F test, respectively; ^{ns}not significant. UFLA, Lavras, MG, 2015.

Table 5. Summary of variance and regression analysis for the macronutrient content of the total aerial part of the Dominator Tomato F1, submitted to different soil water stresses

Source of Variation	D. F.	M. S.					
		N	P	K	Ca	Mg	S
Tension	5	0.53^{ns}	0.07^{**}	0.33^{ns}	1.23^{ns}	0.01^{ns}	0.42^{*}
Block	2	2.16^{**}	0.00^{ns}	5.28^{**}	0.99^{ns}	0.11^{**}	0.44^{**}
Residue	10	0.22	0.00	0.30	0.79	0.00	0.06
Mean (%)	-	5.59	0.38	2.96	9.12	1.73	1.77
C. V. (%)	-	8.38	14.99	18.24	9.75	3.91	13.90
Linear	1	-	0.30^{**}	-	-	-	1.74^{*}
Quadratic	1	-	0.05^{**}	-	-	-	0.23^{ns}
Cubic	1	-	0.00^{ns}	-	-	-	0.03^{ns}
Deviation	2	-	0.00^{ns}	-	-	-	0.04^{ns}
Residue	10	-	0.00	-	-	-	0.06

*and**significant at 5 and 1% probability by the F test, respectively. ^{ns}not significant. UFLA, Lavras, MG, 2015.

Delazari (2014) also found no significant effect of the applied irrigation depths on the levels of N, Ca and Mg. The values found by this author were between 36.1 to 61.9 g kg^{-1}for N, between 56.7 to 66.4 g kg^{-1} for Ca and between 5.8 to 8.4 g kg^{-1}for Mg. According to Jones Junior (1999), the values considered ideal for tomato is 28 to 60 g kg^{-1} for N (2.8 to 6.0%), from 9 to 72 g kg^{-1} for Ca (9.0 to 7.2%) and from 4 to 13 g kg^{-1} for Mg (0.4 to 1.3%).

The high production of biomass with the highest availability of water can be attributed to one of the processes played by the plant - loss of water through transpiration, to assimilate carbon dioxide (Steduto et al., 2007). Physiologically, CO2 uptake by the stomatal cell occurs during sweating. However, stomatal closure directly implies phloem sap flow, allowing macro and micronutrient extraction to stagnate, one of the main mechanisms of vegetation to prevent water loss and directly reducing the assimilated photo (Taiz & Zeiger, 2009), which may have contributed to the lower extraction of macro and micronutrients submitted to greater water stress in the soil. (Hott et al., 2018) in studies with tomato crops subjected to a tension of 70 kPa observed less development of the root system with 56.31% compared to 15 kPa (Hott et al., 2014). In addition, (Silva et al., 2014) found an increase of 43% for the dry mass of the roots and 70% for the dry mass of the aerial part, when comparing the highest and lowest water depth.

Therefore, it is noted that the values found in the present study are within the ideal limits, with the exception of Mg, which is slightly above the upper limit of the ideal. When evaluating the macronutrient content in the total shoot, it was noted that the effect was significant only for P and S, not differing among the other treatments. The regression analysis for the phosphorus content in the three thirds of the plant and the total shoot is shown in Fig. 9.

It is noted that the phosphorus content presented decreasing linear behavior with the increase of water tensions in the soil. The highest values, in 20 kPa, were 0.27% in the lower third, 0.20% in the middle third, 0.19% in the upper third and 0.66% in the whole plant (sum of three thirds). When evaluating the total phosphorus content of the plant, it is observed that the minimum content found (0.28%) and the maximum (0.66%) within the limits (0.25 to 0.75%) adequate levels of this element obtained in leaf analysis for tomato crop, according to Embrapa (2006).

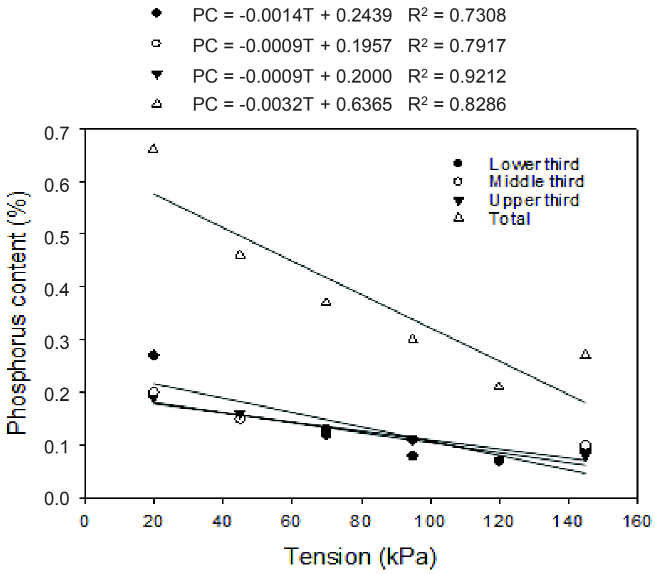

Figure 9. Phosphorus content (TP) in the lower, middle, upper and total third of the Dominating Tomato Plant F1 at different soil water stresses (20, 45, 70, 95, 120 and 145 kPa).

This difference was expected because, in water deficit conditions, there is greater root expansion due to the lack of moisture on the soil surface (Taiz & Zeiger, 2009; Nangare et al., 2016). On the other hand, the low availability of water causes a reduction in the leaf area to prevent sweating (Moreira et al., 2012), which may have contributed to the occurrence of greater variations in the extraction of nutrients from the aerial part at high tensions.

Delazari (2014), evaluating irrigation depths and nutrient doses, found a significant effect for irrigation depths on phosphorus content in the leaf of the commercial hybrid tomato carina TY, finding variations between 3.44 to 5.71 g kg^{-1} of this nutrient, very close to those found in this study (2.8 to 6.6 g kg^{-1}). Fig. 10 presents the regression analysis for the behavior of the sulfur content as a function of water tensions in the soil.

The sulfur content in the lower third and in the whole plant (total) showed a decreasing linear response with the increase of water tensions in the soil. The highest values were obtained in the voltage of 20 kPa (0.85 and 2.34% for the lower and total third of the plant, respectively) and the lowest were observed in the voltage of 145 kPa (0.52 and 1.53%, for the lower and total third of the plant, respectively). According to the equations generated, for both parties evaluated, more than 80% of the variation in sulfur content in the plant according to soil water stresses can be explained by the linear regressions presented.

Evaluating approximate values of stresses along the tomato cycle, Moreira et al., 2012 found that the highest productivity was obtained with the voltage of 28.5 kPa. However, the use of controlled water deficit during the vegetative stage provided the best performance of the tomato (Nangare et al., 2016), while the use of stresses below 35 kPa during the same period can affect the productivity of the plant (Marouelli & Silva, 2007). Therefore, it can be inferred that the best macronutrient extraction potential from tomatoes subjected to 20 kPa.

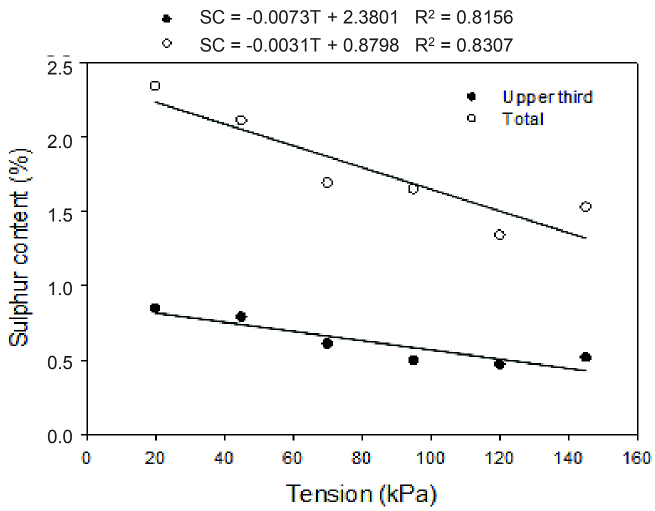

Figure 10. Sulfur content (TS) in the lower, middle, upper and total third of the Dominating Tomato Plant F1 at different soil water stresses (20, 45, 70, 95, 120 and 145 kPa).

Delazari (2014), when evaluating the influence of irrigation depths on the sulfur content on the tomato leaf, found a statistical difference between the treatments, and that the equation estimated by the regression analysis showed that the sulfur content in the leaf fell linearly with the increase of the applied water depth, presenting a content between 5.4 and 12.4 g kg^{-1} (0.54 to 1.24%). For the lower third, the present study found values between 5.2 and 8.5 g kg^{-1} (0.52 to 0.85%) and for the total shoot the values were higher (between 15.3 and 23.4 g kg^{-1}) (1.53 to 2.34%). However, these values are within the considered adequate according to Jones Junior (1999), whose range should be between 3.0 and 42.0 g kg^{-1}(0.3 to 4.2%). Tables 6, 7 and 8 present the abstracts of variance and regression analyses for the micronutrient contents of the lower, middle and upper third, respectively, of the Dominating Tomato F1 submitted to different water stresses in the soil. Table 9 shows this analysis for the total aerial part of the plant.

Table 6. Summary of variance and regression analysis for micronutrient content of the lower third of the Dominator Tomato F1, submitted to different soil water stresses

Source of Variation	D. F.	M. S.				
		B	Cu	Mn	Zn	Fe
Tension	5	51.06^{ns}	52.48^{**}	$9,237.60^{ns}$	209.74^{*}	$9,433.69^{ns}$
Block	2	97.40^{ns}	0.09^{ns}	111.33^{ns}	316.43^{*}	$98,456.19^{*}$
Residue	10	29.93	5.29	3,332.41	50.86	5,390.66
Mean (mg kg^{-1})	-	18.03	9.09	190.48	45.23	688.93
C. V. (%)	-	30.35	25.31	30.31	15.77	10.66
Linear	1	-	218.68^{**}	-	149.69^{ns}	-
Quadratic	1	-	43.33^{*}	-	201.79^{ns}	-
Cubic	1	-	0.06^{ns}	-	113.62^{ns}	-
Deviation	2	-	0.16^{ns}	-	291.79^{*}	-
Residue	10	-	5.29	-	50.86	-

*and**significant at 5 and 1% probability by the F test, respectively; ^{ns}not significant. UFLA, Lavras, MG, 2015.

Table 7. Summary of variance and regression analysis for micronutrient content of the middle third of Dominator Tomato F1, submitted to different water stresses in the soil

Source of Variation	D. F.	M. S.				
		B	Cu	Mn	Zn	Fe
Tension	5	106.94*	49.35**	2,614.03^{ns}	95.55^{ns}	19,260.07^{ns}
Block	2	1.85^{ns}	0.49^{ns}	3,967.84^{ns}	124.20^{ns}	43,161.99*
Residue	10	20.45	3.34	3,163.36	152.08	10,485.19
Mean (mg kg^{-1})	-	21.03	9.89	212.77	39.24	697.99
C. V. (%)	-	21.50	18.48	26.43	31.43	14.67
Linear	1	362.74**	181.72**	-	-	-
Quadratic	1	93.99^{ns}	60.47**	-	-	-
Cubic	1	7.23^{ns}	2.35^{ns}	-	-	-
Deviation	2	35.36^{ns}	1.11^{ns}	-	-	-
Residue	10	20.45^{ns}	3.34	-	-	-

*and**significant at 5 and 1% probability by the F test, respectively; ^{ns}not significant. UFLA, Lavras, MG, 2015.

Table 8. Summary of variance and regression analysis for the micronutrient content of the upper third of the Dominating Tomato F1, submitted to different water stresses in the soil

Source of Variation	D. F.	M. S.				
		B	Cu	Mn	Zn	Fe
Tension	5	73.62^{ns}	31.18**	3,825.98^{ns}	67.16^{ns}	20,720.46^{ns}
Block	2	21.85^{ns}	0.10^{ns}	5,701.31^{ns}	1.78^{ns}	26,810.88^{ns}
Residue	10	35.20	2.41	2,334.39	80.80	14,073.27
Mean (mg kg^{-1})	-	20.95	9.85	193.24	32.93	598.55
C. V. (%)	-	28.32	15.75	25.00	27.30	19.82
Linear	1	-	126.90**	-	-	-
Quadratic	1	-	16.02*	-	-	-
Cubic	1	-	8.25^{ns}	-	-	-
Deviation	2	-	2.34^{ns}	-	-	-
Residue	10	-	2.41	-	-	-

*and**significant at 5 and 1% probability by the F test, respectively; ^{ns}not significant. UFLA, Lavras, MG, 2015.

Table 9. Summary of variance and regression analysis for micronutrient content of the total aerial part of the Dominating Tomato F1, submitted to different water stresses in the soil

Source of Variation	D. F.	M. S.				
		B	Cu	Mn	Zn	Fe
Tension	5	454.08*	385.89**	27,211.59^{ns}	882.17^{ns}	31,481.52^{ns}
Block	2	177.30^{ns}	0.76^{ns}	59,517.71^{ns}	831.97^{ns}	442,269.36^{ns}
Residue	10	95.41	26.90	8,439.47	587.51	28,001.44
Mean (mg kg^{-1})	-	60.01	28.83	596.49	117.40	1985.47
C. V. (%)	-	16.28	17.99	15.40	20.65	8.43
Linear	1	2,110.90**	1,562.92**	-	-	-
Quadratic	1	50.04^{ns}	337.19**	-	-	-
Cubic	1	61.54^{ns}	21.64^{ns}	-	-	-
Deviation	2	23.95^{ns}	3.85^{ns}	-	-	-
Residue	10	95.41^{ns}	26.90	-	-	-

*and**significant at 5 and 1% probability by the F test, respectively; ^{ns}not significant. UFLA, Lavras, MG, 2015.

The analysis was noteworthy that there was a significant effect between treatments for the micronutrient contents Cu and Zn in the lower third, for B and Cu in the middle third, for Cu in the upper third and for B and Cu in the total aerial part of the plant (sum of three thirds). When evaluating the micronutrient content in the total shoot, it was found that the effect was significant for B and Cu, not differing for the other nutrients (Mn, Zn and Fe) (mean of 596.49; 117.40 and 1,985.47 mg kg^{-1} respectively).

However, Delazari (2014) when evaluating and effect of irrigation depths on the micronutrient content in tomato leaves (leaf immediately below the bunch, at the time of harvesting the first ripe fruit), found significant effect only for the manganese nutrient (Mn), with reduction of this nutrient with increased irrigation depths. According to the author, the range obtained was between 360.5 and 718.9 mg kg^{-1}, higher value just above the range considered appropriate by Jones Junior (1999), whose value should be between 250.0 and 500.0 mg kg^{-1}. In the present work the manganese content was also slightly above (596.49 mg kg^{-1}) than recommended by Jones Junior (1999). This fact can be justified by the fact that the samples were taken from the leaves and stem of the tomato plant and by the sum of the three thirds of the plant (total plant).

The average value of Zn content (117.40 mg kg^{-1}) found in this study is slightly above the range considered appropriate by Jones Junior (1999), which is 20.0 to 100.0 mg kg^{-1}. Delazari (2014) found no significant response to Zn content in tomato leaves submitted to different soil water stresses, observing levels between 35.3 and 45.4 mg kg^{-1}. The mean Fe content found in this study (1,985.47 mg kg^{-1}) is well above the range considered ideal by Jones Junior (1999), and should be between 40.0 and 300.0 mg kg^{-1}. Delazari (2014) also found no significant response to this nutrient as a function of irrigation depths, observing levels between 254.8 and 389.0 mg kg^{-1}. The regression analysis for the copper content in the three thirds of the plant and the total shoot is shown in Fig. 9.

The copper content showed decreasing linear behavior with the increase of water stresses in the soil in all parts of the plant evaluated. The highest values, in 20 kPa, were 16.2 mg kg^{-1}in the lower third, 16.7 mg kg^{-1} in the middle third, 14.3 mg kg^{-1} in the upper third and 47.03 mg kg^{-1} in the whole plant (sum of three thirds). Delazari (2014) did not observe a significant effect of irrigation depths on the copper content in tomato leaves. According to the author, the range observed in the leaf was between 660.2 to 868.1 mg kg^{-1}. According to Malavolta et al. (1997) and Jones Junior (1999), the copper contents in plants varied between 2 and 75 mg kg^{-1} of dry matter, considering levels between 5 and 20 mg kg^{-1} as suitable for normal growth.

It is worth mentioning that phloem sap is the main conductor of mineral salts, contributing to translocation and distribution (Grange & Andrews, 1994). However, the transport of the elaborated sap, among other physiological processes, such as turgidity, stretching, cell division and expansion, is limited by water deficit (Taiz & Zeiger, 2009), hindering the potential for nutrient extraction. The use of the 20 kPa voltage throughout the culture cycle has demonstrated the potential to increase micro nutrient increments. However, the water demand of the tomato varies according to its phenological stage (Nangare et al., 2016). Therefore, in order to improve water use management, it is suggested to carry out irrigation management according to the tomato development stages. The results found in these studies indicate that plants obtain greater potential for the extraction of macro and micronutrients r with a tension of 20 kPa during the vegetative phase.

The copper contents in the present study, in the whole plant, were between 47.03 mg kg^{-1} (20 kPa) and 21.67 mg kg^{-1} being outside the limits considered ideal. Fig. 10 shows the variation in boron content as a function of soil water stress for the middle third and throughout the plant (sum of three thirds). The total boron content of the plant (sum of three thirds) presented decreasing linear behavior with increased soil water tension. The highest value was observed at the voltage of 20 kPa (80.57 mg kg^{-1}) and the lowest in 145 kPa (45.40 mg kg^{-1}). According to the equation generated, for each unit of tension added, there is a reduction in boron content of 0.2537 mg kg^{-1}. Similar behavior was observed in the middle third of the plant, but with lower concentrations, ranging from 31.87 to 17 mg kg^{-1} at stresses of 20 and 145 kPa, respectively.

Delazari (2014), when evaluating the effect of irrigation depths on boron content in tomato leaves, did not find a significant effect between treatments. The concentration range obtained was 49.4 to 84.0 mg kg^{-1}, values close to those found in this study. According to Jones Junior (1999), the adequate values for Boron concentration should be between 25.0 to 100.0 mg kg^{-1}.

CONCLUSIONS

The highest values of the variables evaluated were found at the voltage of 20 kPa, suggesting the study in lower values of water tension in the soil. The highest levels of macro (P and S) and micronutrients (B and Cu) of the total aerial part of the Dominator tomato F1, was obtained at the voltage of 20 kPa, with its value reduced with the increase of water tension in the soil.

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