horticultura brasileira

Research

SILVA, CJ; PONTES, NC; GOLYNSKI, A; BRAGA, MB; QUEZADO-DUVAL, AM; SILVA, NEP. 2018.Performance of processing tomatoes under different supply levels of crop evapotranspiration. *Horticultura Brasileira* 36: 299-305 DOI - http://dx.doi.org/10.1590/S0102-053620180303

Performance of processing tomatoes under different supply levels of crop evapotranspiration

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ABSTRACT

Irrigation management is essential to promote appropriate plant growth and guarantee production and quality of the tomatoes for processing, increases the efficiency of nutrients use and contributes to ensure the sustainability of the production chain. This study was installed to evaluate productive performance of two processing tomato hybrids submitted to five water depths under drip irrigation system. Five levels of crop evapotranspiration (ETc) replacement (60%, 100%, 140%, 180% and 220%) and two tomato hybrids (BRS Sena and H 9992) were tested. The experimental design was a 5×2 factorial arranged in randomized complete block design with four replications. During the crop cycle, hybrids BRS Sena and H 9992 needed 692.20 and 418.43 mm of water, yielding 80 and 44.06 t ha^{-1}, respectively. For both hybrids, the higher water productivity was observed when lower levels of irrigation were applied. Higher productivities and pulp yields of 'BRS Sena' and 'H 9992' were noticed when replacing 150-166% and 99-101% ETc, respectively. We observed that improving the performance of processing hybrid tomatoes is possible by adjusting irrigation levels for each hybrid according to growing conditions.

Keywords: *Solanum lycopersicum*, irrigation water depth, drip irrigation.

RESUMO

Desempenho do tomateiro industrial submetido a diferentes reposições da evapotranspiração da cultura

O manejo da irrigação é essencial para promover o adequado desenvolvimento vegetativo, garantir a produção e a qualidade de frutos do tomateiro para processamento industrial, aumentar a eficiência de uso da água e de nutrientes e contribuir para promover a sustentabilidade dessa cadeia produtiva. O objetivo deste trabalho foi avaliar o desempenho produtivo de dois híbridos de tomateiro para processamento industrial submetidos a cinco lâminas de irrigação, em sistema de irrigação por gotejamento. Os tratamentos testados foram cinco níveis de reposição da evapotranspiração da cultura (ETc) (60%, 100%, 140%, 180% e 220%) e dois híbridos (BRS Sena e H 9992). O delineamento experimental foi em blocos ao acaso com quatro repetições, em esquema fatorial 5×2. Durante o ciclo da cultura, os híbridos BRS Sena e H 9992 necessitaram 692,20 e 418,43 mm de água com produtividades de 80 e 44,06 t ha^{-1}, respectivamente. Para ambos híbridos a maior produtividade da água foi observada quando foram aplicados níveis mais baixos de lâmina de irrigação. As maiores produtividades e rendimentos de polpa dos híbridos BRS Sena e H 9992 ocorreram com reposições na faixa de 150 a 166% e 99 a 101% da ETc, respectivamente. Observou-se que é possível melhorar o desempenho de híbridos de tomate para processamento industrial por meio do ajuste dos níveis de irrigação para cada híbrido conforme as condições de cultivo.

Palavras-chave: *Solanum lycopersicum*, lâminas de irrigação, irrigação por gotejamento.

Received on June 23, 2017; accepted on February 21, 2018

Processing tomato crop in Brazil is of great social and economic importance for the country. Goiás is the largest tomato grower, producing 1,427,144 t in 2009 (Silva Junior *et al*., 2015). The municipality of Morrinhos is the second largest producer in the State, being surpassed only by Cristalina, which produced 239,400 t in 2009 (DIEESE, 2010). In the municipality of Morrinhos, where three tomato processing companies are established, the crop is fundamental for generating income and jobs, directly or indirectly (Silva Junior *et al*., 2015).

Processing tomato production in Cerrado region, Goiás, is performed mainly during the dry season, when highest thermal amplitudes are registered which favors the quality of the fruits, making irrigation essential for the crop productivity (Koetz *et al*., 2010; Marouelli *et al*., 2012). Although drip irrigation allows higher yields with lower water use, this system is rarely used in Brazil for processing tomato production (Marouelli *et al*., 2012).

(Koetz *et al*., 2008, 2010; Marouelli *et al*., 2012).

About efficiency of water use, tomato stands out from other horticultural crops as the most efficient. Higher water productivity could be noticed when the crop is grown under water deficit in studies carried out in Italy (Favati *et al*., 2009; Patanè *et al*., 2011), Lavras (Sá *et al*., 2005), Uberaba (Santana *et al*., 2010), and Piracicaba (Campagnol *et al*., 2014).

Processing tomato productivity is influenced by irrigation levels applied to the crop (Koetz *et al*., 2008; Moreira *et al*., 2012; Morales *et al*., 2015), and is considered severely impaired under water deficit. Generally, the effect of irrigation levels on fruit quality is the inverse of those on their yield and weight (Patanè & Cosentino, 2010; Patanè *et al*., 2011). Higher soluble solid contents and commercial fruit quality are obtained from plants grown under water stress (Patanè & Cosentino, 2010; Moreira *et al*., 2012; Patanè *et al*., 2011).

However, studies which consider water requirements and effects of water deficit on processing tomato productivity under the Cerrado weather conditions are scarce, mainly focusing on the improvement of productivity, soluble solid content, reduction of disease incidence and soil nutrient leaching (Koetz *et al*., 2008, 2010; Marouelli *et al*., 2012). These factors are considered the main challenge for processing tomato crop in Brazil, since appropriate irrigation management will lead to a relationship between productivity and fruit quality for processing, which ultimately save water and energy (Patanè *et al*., 2011; Silva *et al*., 2013).

The aim of this study was to evaluate productive performance of two processing tomato hybrids, submitted to five irrigation levels, applied through drip irrigation, under weather conditions in southern Goiás.

MATERIAL AND METHODS

The study was carried out from June to October 2013, in the experimental field at Instituto Federal Goiano, *Campus* Morrinhos, GO (18^{0}58'52"S, 48^{0}12'24"W, 852 m altitude). During the experiment, temperature ranged from 5.8 to 36.3^{0}C, average relative humidity from 24 to 82% and class A evaporation pan (ECA) from 0 to 11.50 mm day^{-1}. Total rainfall of 109.5 mm, where 73.5 mm occurred just before harvest started, when irrigations had already been suspended.

The soil, classified as Typic Hapludoz, was prepared conventionally, as follows: one under subsoiling (0.4 m-depth 50 days before the experiment was installed), and three steps of ground breaking up, two with disc harrows and one with levelling harrows. Preparation was carried out five days before experiment installation. The soil presented the following chemical characteristics, before experiment installation (0-20 cm-depth): pH_{H2O}= 6.1; P= 2.3 mg dm^{-3}; K= 40 mg dm^{-3}; Na= 9 mg dm^{-3}; Ca= 4.6 $cmol_c$ dm^{-3}; Mg= 1.8 $cmol_c$ dm^{-3}; Al= $cmol_c$ dm^{-3}; H+Al= 2.1 $cmol_c$ dm^{-3}; organic matter = 28.5 g dm^{-3}; and basis saturation = 75.56%.

Planting fertilization consisted of 50 kg ha^{-1} N, 400 kg ha^{-1} P_2O_5, 90 kg ha^{-1} K_2O and 2 kg ha^{-1} boron. Top-dressing fertilizations were performed at 30 and 60 days after seedling planting with 70 kg ha^{-1} N and 60 kg ha^{-1} K_2O, split into two applications and conventionally performed. Fertilization was performed into planting furrow at 15 cm depth on the day of experiment installation, using a non-tillage seeder especially regulated for this experiment. Seedlings were planted manually 26 days after sowing (on June 17, 2013), in little pits opened manually, using a hoe.

The hybrid seedlings were produced with substrates and commercial seeds, on plastic trays with 450 cells, in a specialized nursery for tomato seedling production.

Weeds, pests and diseases were controlled following technical recommendations for the crop in the region. To control whitefly, pest with the highest incidence in this study, insecticides with the following ingredients were applied: thiamethoxan; pyriproxyfen and xylene; thiamethoxan, lambda-cyhalothrin; pymetrozine; acetamiprid; imidacloprid; and clothianidin. Applications were weekly, alternating products of different active principles and modes of action in each stage of crop development. Despite the use of insecticides, the authors could notice a natural occurrence of begomovirosis. Other diseases related to the crop were under appropriate control.

The experimental design was a randomized block design, with four replicates, in factorial scheme 5x2. The first factor consisted of five replacement levels of ETc (60, 100, 140, 180 and 220%), accumulated between two consecutive irrigations. The second factor consisted of two tomato hybrids for industrial processing, 'BRS Sena' (Embrapa) and 'H 9992' (Heinz Seeds®). The experimental plot, 144 m^2, consisted of three rows of plants, 6-m length, spacing of 1.2 m between rows and 0.27 m between plants, totalizing 66 plants per plot. The central row was considered useful area of the plot and the two lateral were considered border rows. The plots and blocks were spaced 2 and 3 m between them, respectively, thus no interference of irrigation water depth between the treatments was noticed.

A dripping irrigation system with self-compensating dripper was used, spaced 0.3 m, average flow of 1.5 L h^{-1} and lateral rows spaced 1.2 m. Using this spacing between the drippers rows, in the treatments in which the water depth was equal or superior to 100% ETc, a 1.2 m width wet track was formed between the drippers in the plots.

Using undisturbed samples of 0-10; 10-20; 20-30; and 30-40 cm, the authors determined soil water retention curves, and the values were adjusted through Van Genuchten model (1980) (Equation 1).

$$\theta = \theta_r + \frac{\theta_{sat} - \theta_r}{[1+(\alpha \cdot |\Psi m|)^n]^m} \quad \text{Eq. 1}$$

In which θ= soil moisture content (cm^3 cm^{-3}); θ_r= residual soil moisture content (cm^3 cm^{-3}); θ_{sat}= saturated soil moisture content (cm^3 cm^{-3}); $Ø_m$= soil water matric potential (kPa); α, n and m are dimensionless empirical parameters (m = 1-1/n);

Irrigation in the experimental area was performed one day before seedling planting. The area was irrigated up to the soil field moisture capacity (0.274 cm^3 cm^{-3}), based on soil water retention curve at 0-20 cm depth. After planting, treatments were irrigated, based exclusively on ETc. Irrigations were daily during the first four days. Then, plants were irrigated every other day until the eighth day, with replacement of 100% ETc in order to ensure seedling set in the field. From the eighth day on, after transplanting, plants started to be submitted to proposed treatments up to the 20th day before harvesting, when irrigation was completely suspended in all treatments, aiming to ensure greater uniformity of fruit ripeness.

Etc was calculated based on ECA, evaporation pan coefficient (Kp) and growing coefficient (Kc). Data of ECA and rainfall were obtained using class A evaporation pan and a pluviometer installed in the experimental area. Other weather data were obtained at the weather station of Instituto Nacional de Meteorologia (INMET), 6-km away from the experiment.

$$ETc = ECA \times Kp \times Kc \qquad \text{Eq. 2}$$

The authors adopted a medium Kp, 0.7, during the whole experiment, according to Sentelhas & Folegatti's recommendation (2003). For tomato Kc, FAO (Organização das Nações Unidas para a Alimentação e a Agricultura) recommendation was followed according to Allen *et al*. (1998): Stage I= vegetative (0.6); Stage II= from the end of phase I until 70 to 80% of vegetative development (beginning of flowering) (0.85); Stage III= from the end of phase II until beginning of maturity (1.15); Stage IV= from the end of phase III until end of harvest (0.9).

Total water depth required was calculated based on ETc and values of treatments (decimal), considering efficiency dripping system of 90% (Equation 3). Rainfall (during the experiment) was calculated as an effective rainfall of 50% of its total value. When rainfall (Px0.5) > LTN, treatments were not irrigated.

$$\mathrm{LTN} = \frac{ETc \cdot Trat}{0.90} \qquad \text{Eq.3}$$

In which LTN= total water depth required (mm); ETc= potential evapotranspiration of the crop; Trat= treatments (irrigation water depth) in decimal.

Operating times of the irrigation system (per position of the irrigation system) were controlled by closing valves on the top of the plot (Equation 4).

$$T = \frac{\mathrm{LTN \cdot Lf \cdot Eg}}{\mathrm{q}} \cdot 60 \qquad \text{Eq. 4}$$

In which T= irrigation time per position (minutes); Lf= wet track width (1.2 m); Eg= spacing between drippers (0.3 m); q= dripper flow (1.5 L h^{-1}).

Total irrigation water depths during crop growing cycle were 250.63, 417.72, 584.8, 751.90 and 918.98 mm, corresponding to treatments with replacement of 60, 100, 140, 180 and 220% ETc, respectively.

Harvesting was manual at 120 days after sowing. The evaluated traits were: productivity of green, ripe, rotten, and total fruits; number of blossom-end-rotten fruits, average mass and length of ten fruits; average diameter of fruits, both measured in ten fruits obtained randomly, using a digital caliper (Metrotools, São Paulo, SP, Brazil); total soluble solids content, from a sample of the juice of ten ripe fruits on the day when the irrigation was cut off and on the harvest day, measured with the aid of an analog refractometer (MASTER-T; Atago, Presidente Prudente, SP, Brazil); industrial yield of pulp, calculated based on the methodology proposed by Giordano *et al*. (2000); hydrogen potential (pH) of the irrigation suspension on the harvest date, measured with a pH meter (mPA 210; MS Tecnopon, Piracicaba, SP, Brazil), in a sample of juice of ten fruits; water productivity, considering only the applied water of the irrigation system.

Obtained data were submitted to variance analysis at 5% probability by F test. When significant, a regression analysis for the quantitative data was applied (irrigation levels) for each evaluated hybrid.

RESULTS AND DISCUSSION

The interaction between hybrids and irrigation levels was significant ($P \leq 0.05$) for the majority of analyzed variables, except for blossom-end-rotten fruits, average mass of ten fruits, average length of fruits, average diameter of fruits, and pH in irrigation interruption. These first four variables differed significantly only for hybrid factor, and the latter one was not influenced by any of the treatments.

Incidence of green fruits of 'BRS Sena' decreased linearly as the applied irrigation levels were reduced. Whereas for hybrid 'H 9992', lower green fruit productivity (2.82 t ha^{-1}) was estimated using a water depth of 157.5% ETc (657.91 mm) (Figure 1). Independent of the evaluated water depth, 'H 9992' showed lower incidence of green fruits in comparison to 'BRS Sena' (Figure 1). Results found for hybrid 'BRS Sena' corroborated the ones reported by Marouelli & Silva (2007), who verified lower green fruit incidence associated to lower water replacement in tomato crop. This is due to the fact that plants submitted to water deficit tend to anticipate growing cycle and consequently concentrate fruit maturity. The different behavior of these two hybrids, concerning green fruit incidence, may be related to genetic characteristics of the material itself and also to a high incidence and severity of begomovirosis of 'H 9992, which may have contributed to a differentiated behavior in relation to 'BRS Sena', considered a tolerant hybrid to the disease.

Both water deficit (60% Etc) and water stress irrigations (180 and 220% Etc) decreased the maturity of evaluated tomato hybrids. Irrigation water depths which provided higher productivity of ripe fruits (33.24 and 62.14 t ha^{-1}) were estimated in 107.94% (450.89 mm) and 162.14% (676.40 mm) Etc for hybrids 'H 9992' and 'BRS Sena', respectively (Figure 1). Thus, an increase in linear effect of water deficit was not observed on concentration of fruit maturity, according suggestion of Marouelli & Silva (2007), which may be related to the hybrid genetic difference in both studies.

Total soluble solid values decreased linearly as irrigation levels increased, except for 'H 9992' on the harvest day, which presented increasing linear behavior as the water depths increased (Figure 1). Hybrid 'BRS Sena', independent of the time and evaluated water depths, showed higher total soluble solids contents when compared to 'H 9992' (Figure 1). Several studies concluded that the increase of water deficit on tomato crop provides an increase of soluble solid contents, due to the concentration of fruit maturity (Patanè & Cosentino, 2010; Moreira *et*

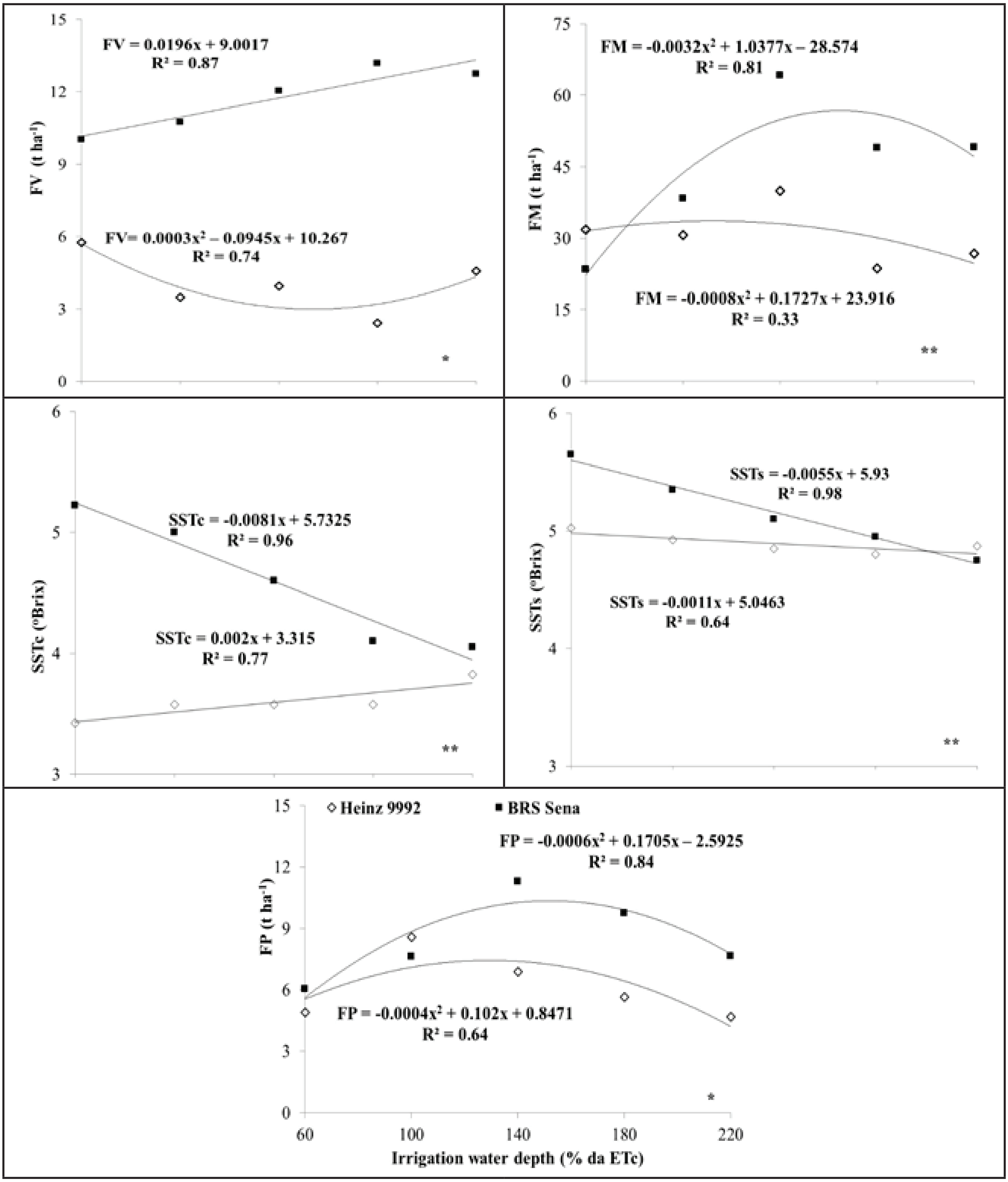

Figure 1. Green fruits (FV), ripe fruits (FM), total soluble solids on harvest (SST_C), total soluble solids after irrigation interruption (SSTs) and rotten fruits (FP) of two processing tomato hybrids related to irrigation water depth. **,*Significant at 1 and 5% probability, by F test, respectively. Morrinhos, IFGoiano, 2013.

al., 2012; Patanè *et al*., 2011), which corroborates the results found in this study.

Higher incidence of rotten fruits (7.34 and 9.52 t ha^{-1}) was estimated using irrigations equal to 127.5% ETc (532.59 mm) and 142.08% ETc (509.23 mm) for hybrid 'H 9992' and 'BRS Sena', respectively (Figure 1). Differently from the results found, Sá *et al*. (2005) observed in Lavras that different water tensions in soil did not influence the productivity of a tomato cultivar called 'Raisa N'. Marouelli & Silva (2007) verified increasing linear effect on the incidence of rotten fruits as soil water replacement was increased, on Cerrado soil conditions of Brasilia. The authors could conclude that other factors, with greater or lesser presence of rotting microorganisms in different locations, may be related to the influence or not of irrigation levels for this variable.

Both deficit irrigation (60% ETc), and excess irrigation treatments (180 and 220% ETc) hindered the productivity of the hybrids 'H 9992' and 'BRS Sena' (Figure 2). Higher fruit productivity, 44.06 and 80.33 t ha^{-1}, was estimated with water depths of 100.17% (418.43 mm) and 165.71% (692.20 mm) ETc, for hybrids 'H 9992' and 'BRS Sena', respectively (Figure 2). Independent of the evaluated water depth, hybrid 'BRS Sena' showed higher fruit productivity when compared to 'H 9992', except for replacement of 60% ETC, in which 'H 9992' was more productive (Figure 2).

Lower productivity and water consumption observed for hybrid 'H 9992' in relation to 'BRS Sena' can be explained by higher tolerance of this latter hybrid to begomovirosis. The severe manifestation of the symptoms of vein yellowing, internerval chlorosis, roughness and leaf distortion, typical for hybrids infected by begomovirus on 'H 9992', caused reduction in plant development and may be a result of a lower water absorption observed for this hybrid and consequently lower productivities according to what was mentioned by 'Inoue-Nagata (2005) and Quezado-Duval *et al*. (2014). Another fact which probably may have contributed to these differences is the characteristic of the hybrids themselves, since 'BRS Sena' shows, apparently, to have a greater vegetative development compared to 'H 9992', in good health conditions.

Results similar to the ones found for

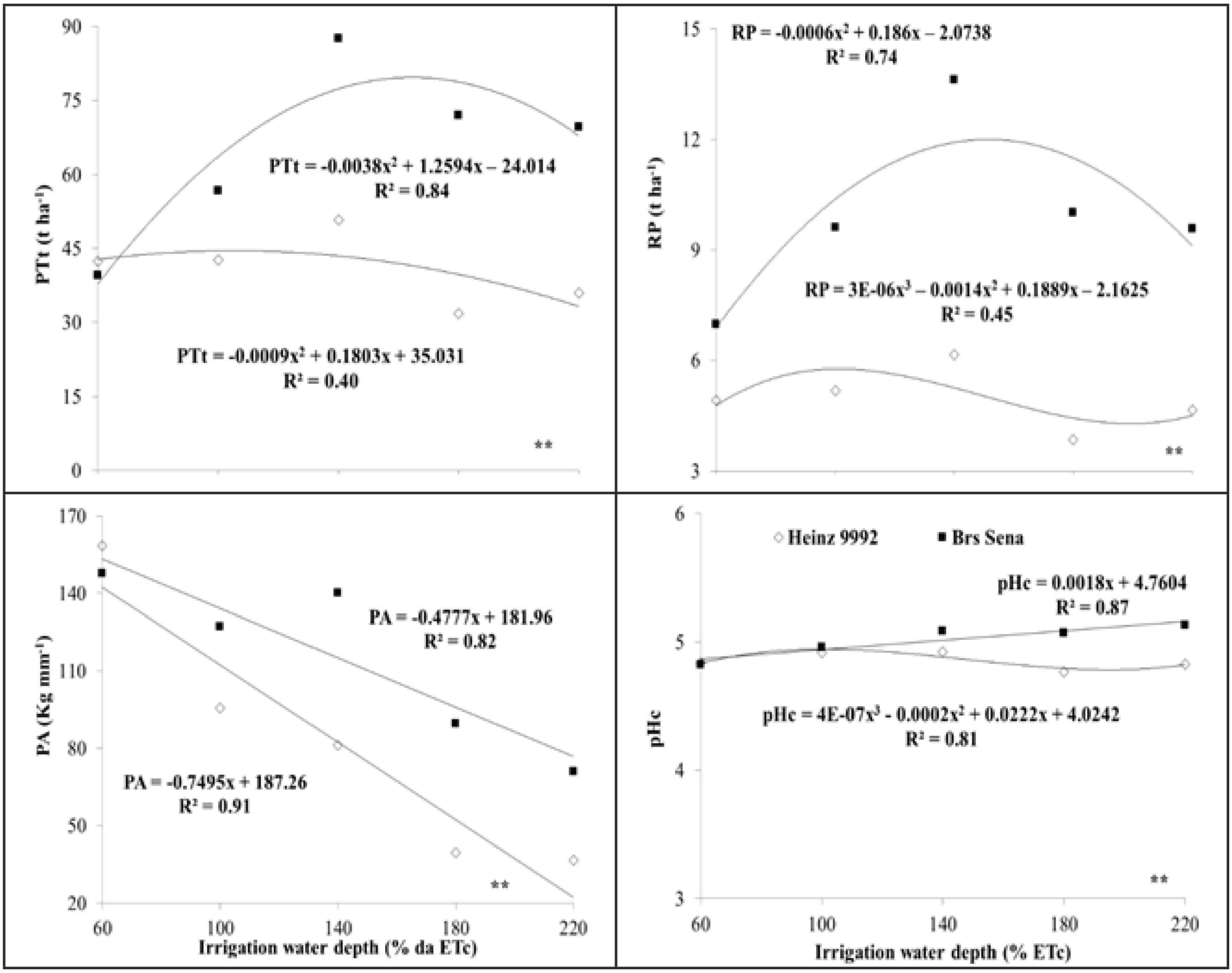

Figure 2. Total productivity (PTt), pulp yield (RP), water productivity (PA) and pH after harvest (pHc) of two processing tomato hybrids related to irrigation water depth. **,*Significant at 1 and 5% probability, by F test, respectively. Morrinhos, IF Goiano, 2013.

'BRS Sena' were observed in Cerrado of Jataí, GO, where the replacement of 732.2 mm during the cycle of 'H 9498' provided higher crop productivity (111.98 t ha^{-1}) (Koetz *et al*., 2008). Despite being a field research, hybrid 'BRS Sena' presented results similar to the ones found by Santana *et al*. (2010) in a greenhouse in Uberaba, MG, when the replacement of 581.4 mm used during the cycle of tomato 'Andrea', provided maximum productivity of 72.63 t ha^{-1}. Productivity of processing tomatoes is severely impaired under water deficit, resulting in lower plant vegetative development, higher fruit set failure, lower number and size of fruits (Moreira *et al*., 2012; Morales *et al*., 2015; Patanè & Cosentino, 2010; Patanè *et al*., 2011), which corroborate the results found in this study.

'H 9992' showed an average pulp yield of 4.95 t ha^{-1} whereas 'BRS Sena' obtained a higher pulp yield (12.34 t ha^{-1}), estimated with a replacement of 155% (647.47 mm) Etc (Figure 2). Pulp yield is directly related to total soluble solid content and with productivity, which explain yield variation among cultivars. Overall, the observed results corroborate the ones found in literature. Pulp yield was inversely proportional to water deficit in tomato plants (Marouelli & Silva, 2007; Patanè & Cosentino, 2010; Patanè *et al*., 2011).

Higher water productivity was observed using a replacement of 60% ETc for both evaluated hybrids (Figure 2). The results found are consistent with several studies, which prove that tomato crop is more efficient under water deficit (Sá *et al*., 2005; Favati *et al*., 2009; Santana *et al*., 2010; Patanè *et al*., 2011; Campagnol *et al*., 2014).

Generally, pH values were above 4.8, which is not desirable, since values lower than 4.5 reduce microorganism proliferation in the final product (Giordano *et al*., 2000). Hybrid 'H 9992' showed medium pH during harvest (4.86), whereas 'BRS Sena' showed increasing linear response as the replacement of water depth increased (Figure 2). The results found corroborate Marouelli & Silva (2007) and Moreira *et al*. (2012), who observed an increase in fruit acidity due to water restriction in processing tomato crop. Values of pH found in this study may have suffered influence of rainfalls at the end of the experiment, which could account to, at least partially, any effect of treatments, mainly that of water deficit (60% ETc).

For the Cerrado region conditions, south of Goiás, using drip irrigation, 'BRS Sena' needed a water depth 65% higher in comparison to 'H 9992' in order to reach higher productivity. Independent of the tested irrigation level, 'BRS Sena' was more productive than 'H 9992'. This fact can be an indication that the used crop coefficients are probably not the most suitable for 'BRS Sena', since higher productivities were noticed with replacements above 100% ETc. Higher productivities and pulp yields of 'BRS Sena' and 'H 9992' were verified in a range of 150-166% and 99-101% (replacement of Etc), respectively. These results show that studies on water requirement are necessary for several weather conditions in Brazil, since the material developed abroad ('H 9992') obtained optimal correlation in terms of productivity gain, when replacing 100% ETc, showing that for this hybrid management using Kc data recommended by FAO would be the correct one, whereas the same is not true for 'BRS Sena'.

Thus, planning an irrigation management in order to obtain better performance of processing tomato hybrids is possible. Irrigation levels should be determined for each hybrid, according to the growth conditions, taking into consideration genetic predisposition to phytopathogen infections, so it is quite likely that a hybrid susceptible to different diseases may behave differently according to its health level in cultivation.

ACKNOWLEDGEMENTS

We thank Instituto Federal de Educação, Ciência e Tecnologia Goiano (IFGoiano) and Embrapa Hortaliças for financial support, and company Mudas Brambilla for providing the seedlings for the study.

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