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Production, quality and water use efficiency of processing tomato as affected by the final irrigation timing

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ABSTRACT

A field study was conducted under "Cerrado" conditions of Brazil, during the dry season of 2000, to evaluate the effect of final irrigation timing on fruit yield, quality, and the use of water in processing tomatoes. Fourteen irrigation cut-off times were employed, 7 days apart, from blossom until harvest. Maximum marketable fruit yield took place when irrigations were cut-off 21 days before harvest (10% of red fruit). Total soluble solids content was linearly reduced at the rate of 0.34 ºBrix per each additional 10 days period of irrigation. Maximum pulp yield was obtained ending irrigation 34 days before harvest (20% of plants holding at least one red fruit). The highest tomato water use efficiency was observed when the last irrigation occurred between 37 and 45 days after blossom, respectively for fruit and pulp yield.

Keywords: *Lycopersicon esculentum*, sprinkle irrigation, water stress.

RESUMO

Produção, qualidade e uso de água do tomateiro para processamento em função da época de paralisação das irrigações

O estudo foi realizado nas condições de Cerrado do Brasil, durante o período seco de 2000, para avaliar o efeito da época de paralisação das irrigações na produção, qualidade de frutos e uso de água do tomateiro para processamento. Os tratamentos corresponderam a quatorze épocas de paralisação, espaçadas a cada 7 dias entre o florescimento e a colheita. A maior produtividade de frutos comercializáveis foi obtida quando as irrigações foram suspensas 21 dias antes da colheita (10% dos frutos maduros), enquanto que o maior rendimento de polpa foi alcançado quando as irrigações foram finalizadas 34 dias antes da colheita (20% de plantas com pelo menos um fruto maduro). O teor de sólidos solúveis totais foi reduzido linearmente à taxa de 0,34 ºBrix para cada 10 dias a mais com irrigação. A maior eficiência do uso de água pelo tomateiro foi obtida quando as irrigações foram paralisadas entre 37 e 45 dias após o florescimento, respectivamente para produção de frutos e de polpa.

Palavras-chave: *Lycopersicon esculentum*, aspersão, déficit hídrico.

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Processing tomato is economically the most important vegetable crop in the "Cerrado" region of Brazil. In 2002 the cultivated area in the states of Goiás and Minas Gerais reached 14,300 ha, representing 78% of the total tomato area in the country. The crop is almost totally irrigated by sprinkle systems and the center pivot prevails in the region.

In general, irrigation management with no criteria favor the occurrence of several problems that are frequently observed in the field such as diseases caused by fungi and bacteria, non-uniform fruit ripening, low yields, low soluble solids content, high rate of discolored and rotten fruit, and low crop water use efficiency (Marouelli & Silva, 2000). Fortunately, many of these problems may be minimized or even eliminated by anticipating the last irrigation (Marouelli & Silva, 1993; May, 1998).

According to Cahn *et al*. (2002), water deficit during fruit maturation stage is beneficial to some extent in order to increase tomato fruit soluble solids content. To improve fruit quality, the amount of water applied from the beginning of the maturation stage should be reduced and the last irrigation anticipated. Furthermore, such management strategy minimizes the occurrence of rotten fruit due to smaller disease incidence (Marouelli & Silva, 2000).

Studies in irrigation cut-off time in processing tomato have been carried out for several years (Martin *et al*., 1966), but this subject continues to be researched in different countries (Lowengart-Aycicegi *et al*., 1999; Lopez *et al*., 2001; Cahn *et al*., 2002) due to its dependence on soil water holding capacity, irrigation system, crop variety, evapotranspiration rate, hand pick or machine harvest and processor bonus for fruit quality (Marouelli & Silva, 2000; Lopez *et al*., 2001).

May & Gonzales (1999) evaluated ten processing tomato cultivars irrigated by furrows in California and observed that maximum tomato yield was obtained as irrigations were cut-off between 20 and 40 days before harvest, while the highest soluble solids content was met for the period between 45 and 60 days. For lower water retention capacity soils in Spain, Lopez *et al*. (2001) suggested cutting off irrigations 10 to 15 days before harvest. For drip irrigated tomatoes in Israel, Lowengart-Aycicegi *et al*. (1999) recommended cutting off irrigations as 50% of the fruit are fully red, whereas in California, for sprinkle irrigation, Sanders *et al*. (1989) suggested the limit of 30% of ripe fruit.

In Brazil, for sprinkle irrigated tomato growing under "Cerrado" conditions, Marouelli & Silva (1993) observed that maximum fruit yield was achieved as the last irrigation was performed with 50% of the fruit completely red. On the other hand, maximum soluble solids content was obtained as the last irrigation was done

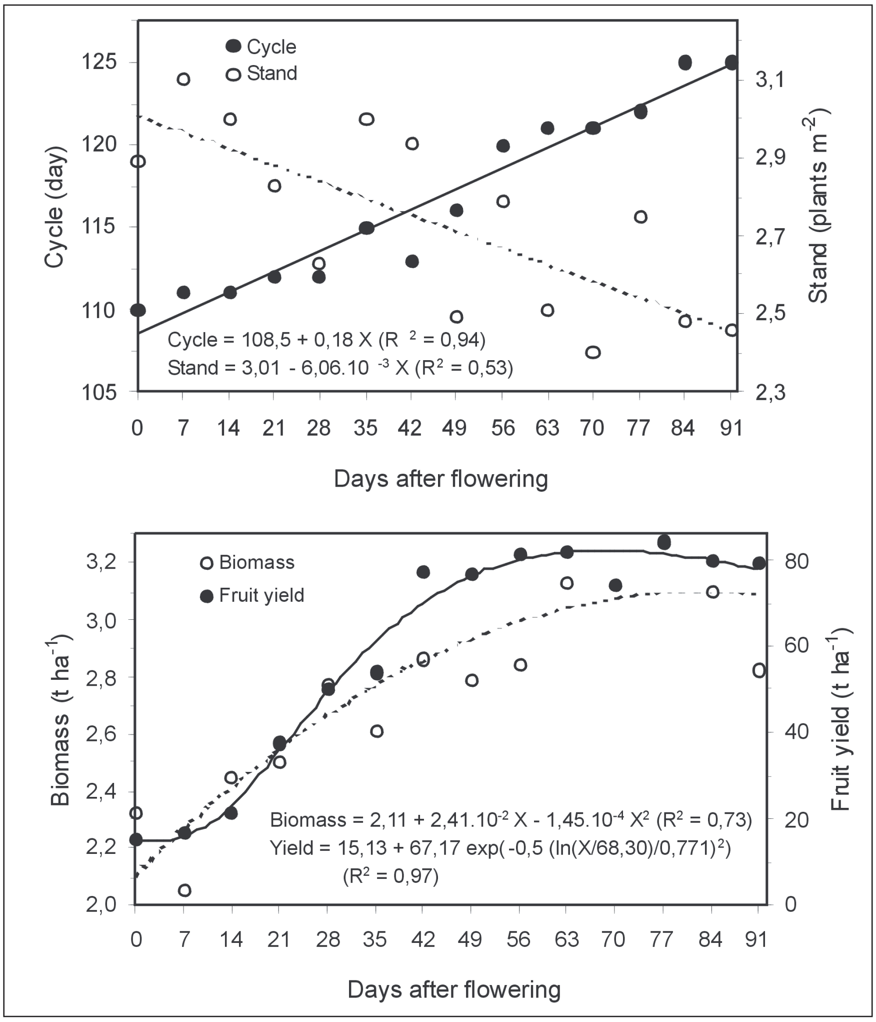

Figure 1. Tomato crop growing cycle, final stand, biomass production, and tomato fruit yield as affected by the final irrigation timing. Brasília, Embrapa Vegetables, 2000.

20 days earlier. In the reported study an open pollination tomato cultivar (IPA-5) was used under direct sowing and two-harvest systems.

In the last decade, however, processing tomato production system in Brazil has changed substantially, as open pollination cultivars have been almost completely replaced by hybrids (Giordano *et al*., 2000b). At the present time, all cropped areas employ the system of seedling transplant and harvest takes place in a sole operation. Hence, cultivars and management practices that allow higher fruit ripeness uniformity are extremely desirable.

The objective of this study was to establish, for the "Cerrado" region of Brazil, adequate final irrigation timing for processing tomato irrigated by sprinkle systems aiming to maximize fruit production and pulp yield, and to optimize crop water use.

MATERIAL AND METHODS

The experiment was carried out in the fields of Embrapa Vegetables in Brasília, Brazil (15º 56´ S and 48º 08´ W), during the dry season of 2000, in a clayey Oxisol (56% clay, 37% silt, 7% sand). The soil water retention (% vol.) in the 0 to 40 cm depth, from 5 to 1500 kPa, is described by the Van Genuchten equation:

$$\theta(h) = 23,1 + 14,1 / \left[1 + (0,057 \times h)^{1,756}\right]^{0,431}$$

where h is the soil water tension (kPa).

Treatments consisted of fourteen dates for performing the final crop irrigation distributed into 7-day intervals, from blossom (45% of plants) until harvest. The experimental design was random blocks with four replicates. The plot measured 2.2 x 4.2 m with a buffer strip of 1.1 m wide, and an extra 3.3 m strip around the experiment.

Seedling transplant (hybrid cultivar AP533) occurred in the last week of April, with the spacing of 0.3 m and 1.1 m between plants and rows, respectively. The fertilization consisted of 100; 200; 500; 80; 20; 5 and 2 kg ha^{-1} of N, K_2O, P_2O_5, Ca, Mg, Zn and B, respectively.

Irrigations were performed using microsprinklers spaced 2.2 x 2.1 m apart and mean application rate of 22 mm h^{-1}. The amount of applied water in each irrigation was calculated from Class A pan evaporation and crop coefficients recommended by Marouelli & Silva (2000). The Class A pan was placed in a 100 m diameter short green grass area located about 500 m from the experiment site. The net depth of water provided throughout the tomato growing season was estimated based on four collectors placed at the last irrigation cut-off treatment, in each replicate, considering an average application efficiency of 82%.

In the first 10-day period after seedling transplant irrigations were done each 2 days. From that point on, the crop was irrigated at every 7 days (Marouelli & Silva, 2000) in order to match the irrigation days with the date of performing the last irrigation for all the treatments. The first irrigation cut-off treatment occurred 31 days after seedling transplant.

By the time of performing the last irrigation, for each treatment, crop development status was evaluated by counting the number of flowering plants, total number of fruit and red fruit per plant. From the last irrigation until fruit harvest, the soil water content was evaluated weekly by gravimetric method. Soil samples from the 0 to 40 cm layer were taken using an auger tube, and soil water tension was estimated employing the water retention function of the experimental area.

The crop was harvested for each treatment as ripe fruit rate reached about 95%. The following variables were evaluated: crop growing cycle, final stand, biomass, fruit yield, mean fruit mass, marketable fruit per plant, pulp yield (28º Brix), percent of rotten fruit and rate of blossom-end rot, total soluble solids content, titratable acidity, fruit firmness and water use efficiency as related to the mass of marketable fruit or pulp production. Biomass was determined after drying the plant canopy material without any fruit at 60ºC. As marketable fruit was considered only red, not damaged fruit, independent of size. Soluble solids, acidity, and firmness were evaluated according Moretti *et al*. (1998) and Calbo & Nery (1995), in a sample of 15 marketable fruits. The water use efficiency was calculated as the relationship between marketable fruit or pulp yield and net amount of water applied per unit of area.

Variance analysis of the collected data was performed using the “F” test. Variables significantly affected by the treatments were fitted to polynomial and log-normal equations by means of linear regression, in order to adjust the data to response functions.

RESULTS AND DISCUSSIONS

During the experiment period a 29.7 mm amount of rainfall occurred from which 29.4 mm occurred in the last four days of the experiment. This fact most likely did not have any significant effect on the results.

All variables related to crop development, fruit production, fruit quality and crop water use efficiency were significantly affected ($p<0.01$) by the treatments.

Crop Development

The tomato crop development was characterized at the final irrigation timing treatment (0; 7; 14; 21; 28; 35; 42; 49; 56; 63; 70; 77; 84; 91 days after flowering, respectively) as follows: 45% of flowering plants, 33%; 52% of plants holding at least one fruit, 37%; 56%; 73% of plants holding at least one green fruit with 2.0 to 2.5 cm of diameter, 3%; 10%; 27%; 52% of plants holding at least one red fruit, and 11%; 38%; 71%; 95% of fully red fruit.

The processing tomato crop growing cycle increased linearly at the rate of 0.18 day, while the final stand decreased of 60.6 plants per hectare, for every

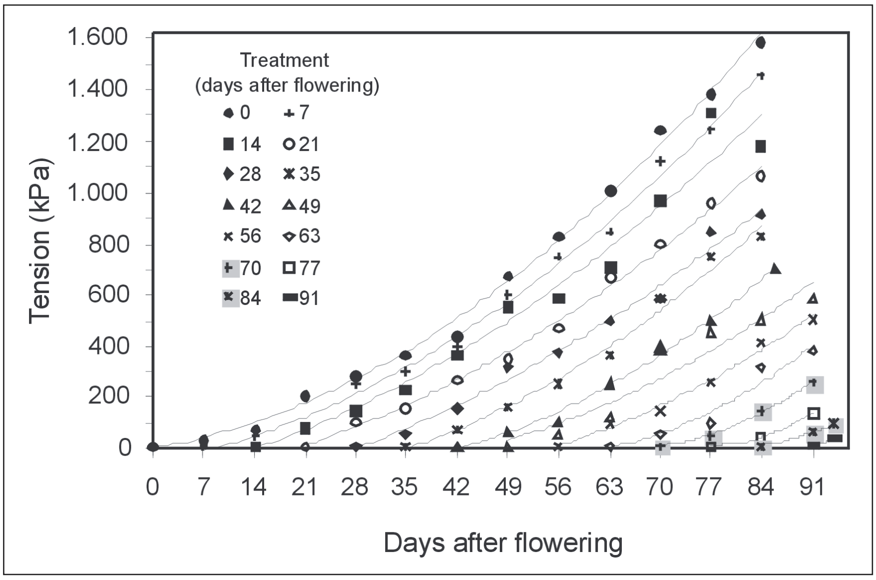

Figure 2. Soil water tension at 20 cm depth from irrigation cut-off to harvest for each treatment. Brasília, Embrapa Vegetables, 2000.

single day the last irrigation was delayed (Figure 1). The crop cycle increase was due to the smaller water deficit associated with treatments that had late final irrigation (Figure 2). For the case of the IPA-5 cultivar, under similar soil and climate conditions, Marouelli e Silva (1993) found a reduction in the crop cycle of 0.22 day for each day the last irrigation was anticipated.

The decrease in stand with the delay of the last irrigation may be attributed to the increase of soil borne and foliar diseases occurrence associated with treatments that were irrigated until late in the season (Silva *et al*., 2001). On the other hand, the relatively small stand reduction associated with the treatments that had the irrigation cut-off earlier confirms the relatively high tomato resistance to soil water deficit (Marouelli *et al*., 1991).

Biomass production, evaluated as the canopy dry matter without fruit, increased as a quadratic function until the 83rd day after the beginning of the treatments and decreased slightly after that (Figure 1), probably due to the stand reduction of the treatments which received irrigation until near to harvest.

Fruit Production

Fruit yield showed a log-normal relationship with the final irrigation timing (Figure 1). From the best equation fitted to the data, the highest marketable fruit yield (82.3 t ha^{-1}) was reached as the last irrigation was performed 68 days after the beginning of the treatments (21 days before harvest), i.e., when about 10% of the fruits were fully red. Considering a 95% confidence interval, best yield can be reached ending irrigations from 58 to 77 days after flowering (14 to 30 days before harvest), i.e., from 30% of plants holding at least one red fruit to 38% of fully red fruit.

For the case of an open pollination cultivar, employing the system of direct sowing and two harvests, Marouelli & Silva (1993) observed that maximum fruit yield was reached as irrigations were cut-off for 50% of ripe fruit. In the “Cerrado” region, however, the great majority of the growers cut-off irrigations only when 70-80% of the fruits are red, which means 7-10 days before harvest.

The number of marketable fruit per plant showed a quadratic relationship with the final irrigation timing (Figure 3), and maximum number was reached as irrigations were cut-off 66 days after flowering. Reduction of the number of fruit per plant associated with higher number of irrigations performed throughout the maturation stage was due to the increase of the rotten fruit rate (Figure 3). The mean marketable fruit mass, on the other hand, increased linearly to the rate of 0.40 g day^{-1} later

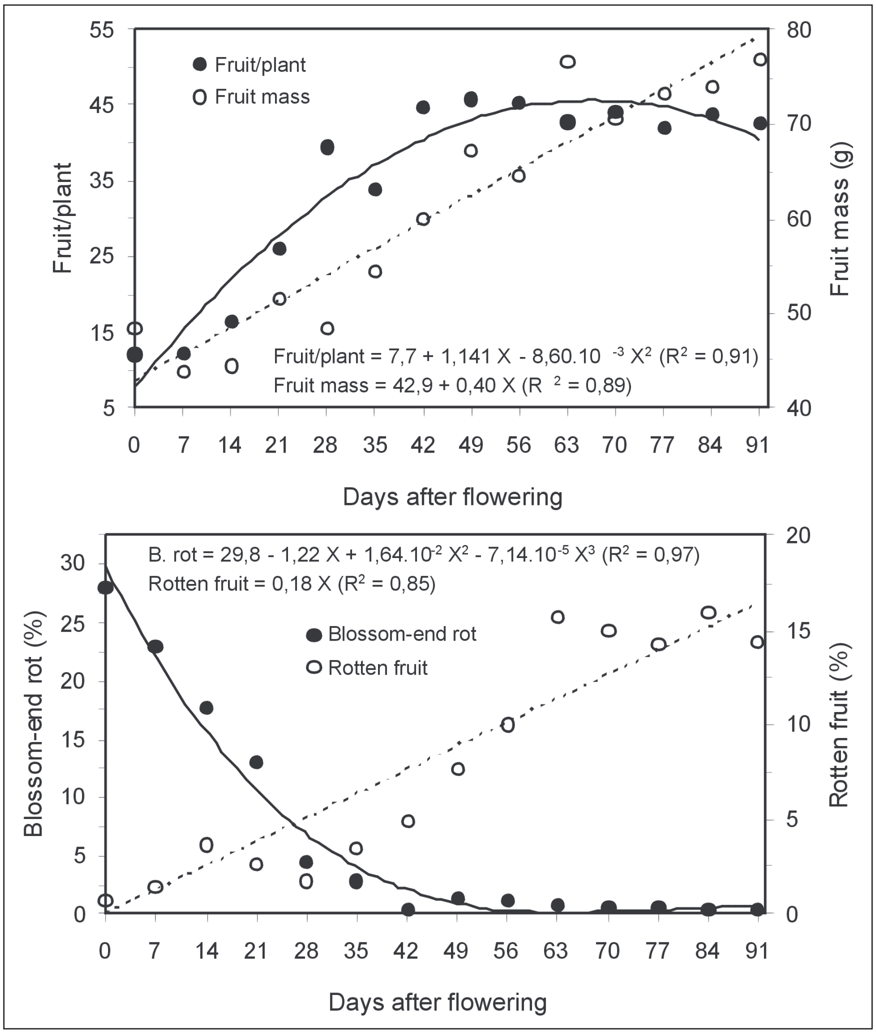

Figure 3. Number of tomato fruit per plant, mean fruit marketable mass, rate of blossom-end rot, and rotten fruit as affected by the final irrigation timing on tomato crop. Brasília, Brazil, Embrapa Vegetables, 2000.

the last irrigation was performed (Figure 3), due to the smaller soil water deficit for the plants (Marouelli *et al*., 1991).

Fruit Quality

The rate of blossom-end rot fruit showed a cubic relationship with the treatments (Figure 3). The higher percent of blossom-end rot in treatments the irrigations were cut-off until the 28^{th} day after the flowering was due to soil water deficit during the stage of fruit development (Figure 2), which limited the movement of calcium from the soil to the fruit (Pill & Lambeth, 1980). On the other hand, the incidence of blossom-end rot was negligible as the irrigations were cut-off from beginning of the fruit maturation stage, i.e., 42 days after flowering.

The occurrence of rotten fruit (not blossom-end rot) increased slightly to the rate of 0.19% per day as later the irrigations were cut-off (Figure 3). The highest soil covering, due to the higher biomass production, along with the higher number of sprinkle irrigations, provided favorable microclimatic conditions to increase the incidence of diseases, increasing the rate of rotten fruit (Marouelli *et al*., 1991; Silva *et al*., 2001).

Total soluble solids content was reduced to the rate of 0.34º Brix for each 10-day period after the last irrigation was performed (Figure 4). The variation of the soluble solids content among treatments ranged from 4.6 to 7.3º Brix, which confirms, according to Cahn *et al*. (2002), that cut-off irrigations in the correct timing, associated with adequate soil water management during fructification and maturation stages, is of primary importance for the obtainment of good raw material for the processing industry.

Based on the best fitted equation the highest titratable acidity occurred as irrigations were cut-off 27 days after the beginning of flowering (Figure 4). The reduction of the titratable acidity as the last irrigation was delayed is in accordance with Colla *et al*. (1999), who reported that high water supply to the crop during the fructification and maturation stages significantly reduces fruit titratable acidity. Thus, the anticipation of the last irrigation favors the production of fruits with higher acidity, which reduces the time and the processing temperature needed for avoiding microorganism proliferation in processed products (Giordano *et al*., 2000b). Lower acidity, on the other hand, as irrigations were cut-off from flowering stage, could have resulted from the rapid fruit maturation (Sanders *et al*., 1989), induced by the high water deficit imposed to the crop (Figure 2).

Fruit firmness increased according to a second-degree curve, as a function of the timing of the last irrigation treatments (Figure 4). The regression equation show a small variation of fruit firmness as the irrigations were suspended from the beginning of fruit maturation stage. However, an average reduction of 15%, in relation to the other treatments, occurred for the first three cut-off treatments. Deterioration of fruit consistence under soil water deficit was also reported by Varga (1987).

Pulp Yield

Pulp yield at 28º Brix was maximized as irrigations were cut-off 53 days after the beginning of the treatments (Figure 4) with about 20% of the plants presenting at least one ripe fruit (34 days before harvest), i.e., 15 days before the date that maximized fruit yield. For a 95% confidence interval, maximum pulp yield can be obtained as irrigations were cut-off from 48 to 57 days after flowering (31 to 38 days before harvest), i.e., from 10 to 30% of plants holding at least one red fruit.

Both tomato growers and processors are interested in maximizing the economical revenues of their products.

However, while the main objective of the growers is to obtain a high fruit yield, the processors seek for high pulp production. Besides that, high soluble solids content lowers transportation costs and energy consumption during the pulp processing (Cahn *et al*., 2002).

In Brazil, until a few years ago, growers were paid as a result of fruit production, not for the soluble solids production. More recently, some processors have adopted the system of bonus based on quality. An example, reported by Giordano *et al*. (2000a), is 5% bonus for a fruit load with soluble solids content ranging between 4.8 and 5.2º Brix, and 10% bonus for the case of soluble solids higher than 5.2º Brix. In spite of that, very few growers are willing to anticipate significantly the timing of the last irrigation.

Crop Water Use

The total number of irrigations, including the one before the seedling transplant, ranged from 9 to 22 and the net amount of applied water from 103 to 383 mm, depending upon the final irrigation timing. The average Class A pan evaporation rate from April to August was 5.4, 6.1, 5.9, 5.7, and 8.1 mm day^{-1}, respectively.

Crop water use efficiency was evaluated in relation to fruit (Wue-fruit) and pulp (Wue-pulp) production. Using the adjusted response functions (Figure 5), the highest Wue-fruit was attained for the case of cut-off irrigations 45 days after the beginning of flowering (about 5% of plants holding at least one fully red fruit), while the highest Wue-pulp corresponded to the 37th day (about 75% of plants holding at least one median size fruit).

Cut-off irrigations aiming to maximize crop water use efficiency reduces significantly tomato yield. Thus, irrigations should be cut-off aiming to maximize either fruit or pulp yield. Regarding the final irrigation timing largely adopted by the growers (70-80% of red fruit), there was an increase in the Wue-pulp of about 30% as the irrigations were cut-off for maximizing fruit yield (10% of red fruit) and of 55% as irrigations were cut-off for maximizing pulp yield (20% of plants

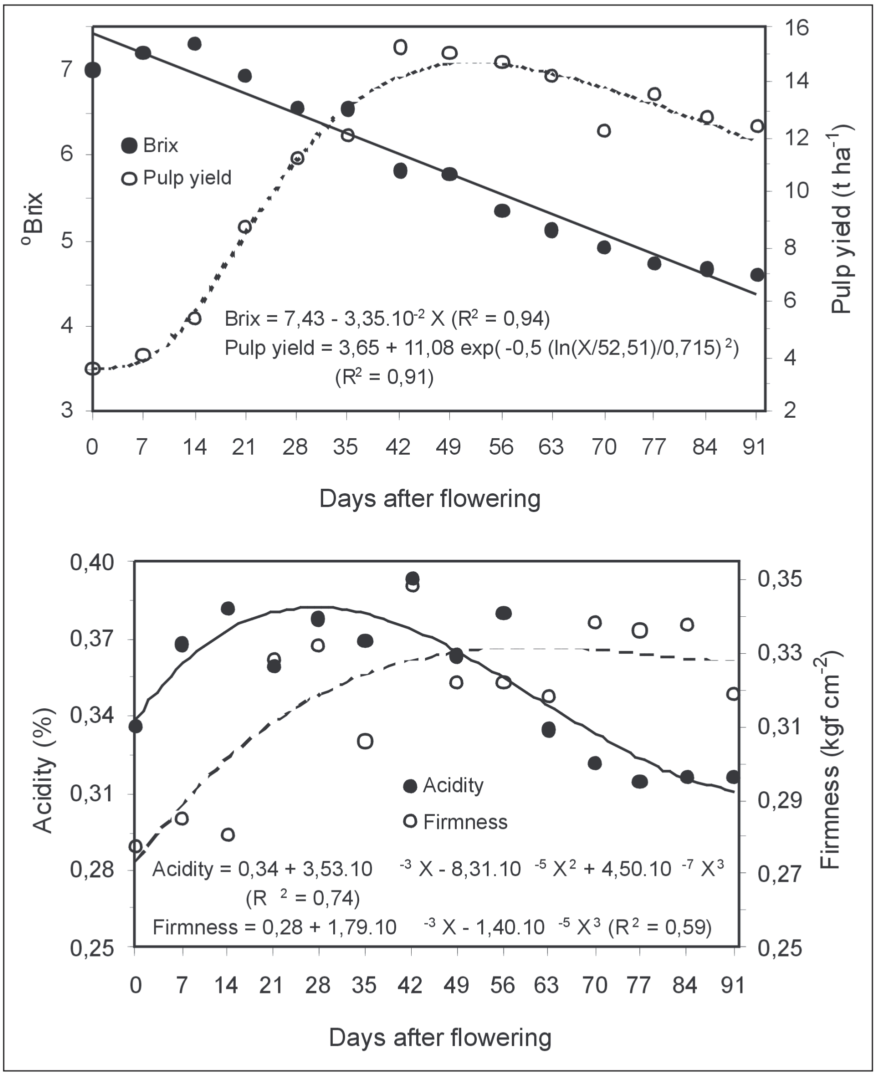

Figure 4. Total soluble solids content, pulp yield, titratable acidity, and fruit firmness as affected by the final irrigation timing on tomato crop. Brasília, Embrapa Vegetables, 2000.

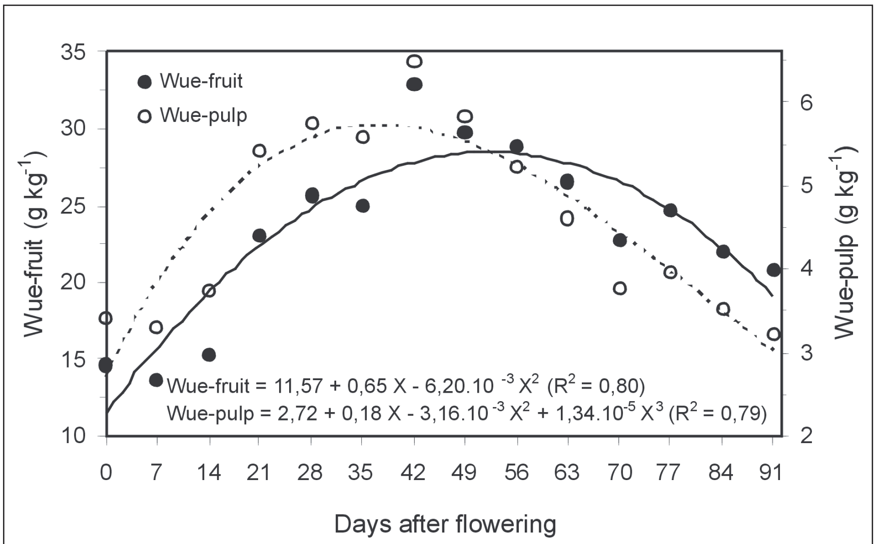

Figure 5. Tomato crop water use efficiency related to fruit (Wue-fruit) and pulp yield (Wue-pulp) as affected by the final irrigation timing. Brasília, Embrapa Vegetables, 2000.

holding at least one red fruit).

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