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Tomato growth analysis across three cropping systems

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ABSTRACT

The objective of this work was to analyze the growth of the *Upiã* tomato cultivar in the *Vertical*, *Crossed Fence* and *Viçosa* cultivation systems, in order to obtain explanations for the productive gains achieved in the *Viçosa* system. The experiment was conducted in Viçosa, Minas Gerais State, Brazil, from August 21st to December 5th, 2012, in the scheme of subdivided plots, being the plots represented by the cultivation systems: *Vertical*, using tape, 1.0x0.5 m spacing; *Crossed Fence*, staked with bamboo, 1.0x0.5 m spacing; and *Viçosa*, using tape, 2.0x0.2 m spacing. The subplots were composed by the sampling times of the plants: 15, 30, 45, 60 and 75 days after transplanting. The experimental design was in randomized blocks, with four replications. Each plot was composed by three lines of 10 plants, making a total of 30 plants per plot, being evaluated the four central plants of each plot. We evaluated the dry matter of leaves (MSF), stem (MSC), inflorescences (MSI), fruits (MSFr) and total (MST). Using the foliar area index, measured by digital scanners and the previously obtained dry masses, we determined the physiological growth indices: foliar area index (IAF), specific foliar area (AFE), relative growth rate (TCR), and net assimilation rate (TAL). The *Viçosa* system altered the growth pattern of the tomato, quantified by the growth analysis, in comparison to *Crossed* and *Vertical* Fences. The prolongation of the second growth phase for the dry matter of fruits could possibly explain the productive gains obtained in the *Viçosa* system. Additional studies are required in order to clarify the relationship between the duration of the second phase of fruit dry matter growth, the physiological indexes AFE, IAF and TAL with the size and fruit yield of the tomato.

Keywords: *Solanum lycopersicum*, ecophysiology, physiological indices.

RESUMO

Influência do sistema de cultivo no crescimento de plantas de tomate

O objetivo do trabalho foi avaliar o crescimento do tomateiro cultivar *Upiã* nos sistemas de cultivo *Vertical*, *Cerca Cruzada* e *Viçosa*, visando obter esclarecimento para os ganhos produtivos alcançados no sistema *Viçosa*. O experimento foi conduzido em Viçosa-MG, no período de 21 de agosto a 05 de dezembro de 2012, no esquema de parcelas subdivididas, sendo as parcelas representadas pelos sistemas de cultivo: *Vertical*, tutorado com fitilho em espaçamento 1,0 x 0,5 m; *Cerca Cruzada*, tutorado com bambu em espaçamento de 1,0 x 0,5 m; e *Viçosa*, tutorado com fitilho em espaçamento 2,0 x 0,2 m. As subparcelas foram compostas pelas épocas de amostragem das plantas: 15, 30, 45, 60 e 75 dias após o transplantio. O delineamento experimental foi em blocos casualizados, com quatro repetições. Cada parcela foi constituída por três linhas de 10 plantas, perfazendo um total de 30 plantas por parcela, sendo avaliadas as quatro plantas centrais de cada parcela. Avaliou-se matéria seca de folhas (MSF), caule (MSC), inflorescências (MSI), frutos (MSFr) e total (MST). Utilizando-se a área foliar, medida em escâner digital, e as massas secas previamente obtidas, foram determinados os seguintes índices fisiológicos de crescimento: índice de área foliar (IAF), área foliar específica (AFE), taxa de crescimento relativo (TCR) e taxa assimilatória líquida (TAL). O sistema *Viçosa* alterou o padrão de crescimento do tomateiro, quantificado pela análise de crescimento, em relação ao *Cerca Cruzada* e *Vertical*. O prolongamento da segunda fase de crescimento para a matéria seca de frutos, possivelmente, explicaria os ganhos produtivos obtidos no Sistema *Viçosa*. Estudos adicionais são necessários para esclarecer a relação entre a duração da 2ª fase de crescimento da matéria seca de frutos, os índices fisiológicos AFE, IAF e TAL com o tamanho e produção de frutos do tomateiro.

Palavras-chave: *Solanum lycopersicum*, ecofisiologia, índices fisiológicos.

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Annually, new tomato cultivars of *Solanum lycopersicum* for *natura* consumption are launched in the Brazilian market, aiming at resistance to diseases and increase of productivity. However, in order to achieve the productive potential of these cultivars, it is necessary to adjust the management and cultural practices of the cropping systems, which are appropriate to the

productive behavior of these new tomato cultivars.

The method of staking is a key component of the tomato cultivation system, as it influences the interception of solar radiation by the plants, as well as the control of pests and diseases (Matos *et al.*, 2012).

The method of tomato staking most widely used in the country is

the so-called *Crossed Fence*, although it is not the system that results in the highest productivity (Matos *et al.*, 2012). In addition, this system reduces the efficiency of the application of pesticides since the products don't reach the entire plant, thus hindering the control of insect pests (Lopes *et al.*, 2015) and diseases (Singh *et al.*, 2012).

Another method of tomato staking

is called Vertical, with bamboo or clips, which appeared in an attempt to increase the distribution of solar radiation in the canopy of the plant, to promote better ventilation, thereby reducing leaf wetting time, in addition to improving the efficiency of the methods of pest and disease control (Wamser *et al.*, 2008).

Recently, the Viçosa system for tomato cultivation has been proposed (Almeida *et al.*, 2015). This system brought together the best results from scientific research into tomato crop management and treatment.

The productive and economic efficiency of the Viçosa system was compared to that of the Vertical and Cross-Fence systems (Almeida *et al.*, 2015), observing that the Viçosa system provided increases in productivity and production of larger fruit of up to 61 and 131%, respectively, however without affecting the taste of the fruits. In addition, the profitability was up to 223% higher than for the Crossed Fence system.

However, little or nothing is known about the physiological growth rates of tomatoes involved in the higher productivity scenario observed for the Viçosa system. In the present study, it was possible to evaluate the influence of the cultivation system on the assimilative capacity and the assimilation by the different organs of the plant (Heuvelink, 1999).

The greater productive gain achieved with the Viçosa system for tomato cultivation is still little understood today, from an ecophysiological point of view. Thus, the objective of the work was to analyze the growth of the tomato in the Vertical, Crossed Fence and Viçosa harvest systems, in order to obtain explanations for the productive gains achieved in the Viçosa system.

MATERIAL AND METHODS

The experiment was carried out in the Federal University of Viçosa (20°76 S, 42°86 W, 712 m altitude), in Viçosa, Minas Gerais State, Brazil, from August 21st to December 5th, 2012 in open-field conditions, in *Yellow*

Argissolo, with clay texture and flat topography (Almeida *et al.*, 2015) with the chemical characteristics of the layer of 0-20cm: pH (water)= 5.94, P= 95.7 mg/dm³; K= 115.0 mg/dm³; Ca²⁺= 3.17 cmolc/dm³; Mg²⁺= 0.57 cmolc/dm³; Al³⁺= 0.0 cmolc/dm³; H+Al= 4.2 cmolc/dm³; SB= 4.03 cmolc/dm³; t= 4.03 cmolc/dm³; T= 8.23 cmolc/dm³; V= 49.0%; m= 0.0%; Organic matter = 2.9 dag/kg; P-rem = 27.4 mg/L.

We used the commercial hybrid *Upiã* from the Santa Cruz group, with an indeterminate growth habit. The tomato seedlings were grown in styrofoam trays with 200 cells filled with Plantmax® substrate. Transplanting was performed when the seedlings were with three to four final leaves.

The distribution of fertilizers (via fertigation) and the cultural treatments carried out during the experiment followed the recommendations of Alvarenga (2004).

The Irripulus® computational program was used to manage irrigation, by which the water demand of the tomato was determined by means of the coefficients of adjustment (crop coefficient – kc, irrigation location – kl and soil – ks) over the reference evapotranspiration (ET_o), upon availability of daily information on: maximum, average and minimum temperatures (°C), wind speed (m/s), relative humidity (%), precipitation (mm) and radiation (W/m²), obtained from an automatic weather station installed in the experimental area. The total volume of precipitation and irrigation during the experiment was 323.7 and 162.9 mm, 323.7 and 159.2 mm, 323.7 and 142.2 mm, for the Viçosa, Vertical and Crossed Fence systems, respectively. The average maximum and minimum temperatures during the period were 27.1 and 14.6°C, respectively.

The experiment was conducted in a split plot scheme, and plots were represented by the cropping systems (Figure 1): Vertical, staked with narrow ribbon and 1.0x0.5 m spacing; Crossed Fence, staked with bamboo with 1.0x0.5 m spacing; and Viçosa, staked with narrow ribbon and spacing of 2.0x0.2m (Almeida *et al.*, 2015). The

subplots were composed by the times of samplings of the plants: 15, 30, 45, 60 and 75 days after transplanting (DAT). The experimental design was a randomized block with four replications. Each plot consisted of three rows of 10 plants, with a total of 30 plants per plot. We evaluated the four main plants in each plot.

Four tomato plants were collected per treatment for each sampling period, always in the morning. The plants were fractionated into stems, leaves, inflorescences and fruits, and placed in a greenhouse with forced air circulation, at a steady temperature of 75°C, until reaching constant mass.

We assessed the dry matter of leaves (MSF), stem (MSC), inflorescences (MSI), fruit (MSFr) and total (MST) by means of direct weighing of each part of the plant. Using the foliar area index, measured by digital scanners. From the previously obtained dry masses, we determined the following physiological growth indices: foliar area index: IAF= AF/S, where AF stands for foliar area (m²) and S is the available area of the leaf (m²); Specific foliar area: AFE= AF/MSF (cm²/g), where MSF stands for the dry leaf mass; Relative growth rate: TCR= [ln(MST2) – ln(MST1)]/(T2-T1) (g/g/day), where ln stands for the natural logarithms of MST2 and MST1 for the dry mass of two successive samplings; Net assimilation rate: TAL= [(MST2-MST1)/(T2-T1)] x {[ln(A2) – ln(A1)]/(A2 – A1)} (g/cm²/day).

The data were analyzed through analysis of variance and regression. For the qualitative factors the averages were compared using the Tukey test, adopting the level of 5% of probability. For the quantitative factors, the models were chosen according to the significance of the regression coefficients and the biological phenomenon.

For the case of non-linear regression the model used was:

$$Y = \frac{a}{1 + \exp(-b(X-c))} + e_i$$

where: a, b and c are adjustment parameters, and e_i is the error.

We also determined the minimum critical point (PC_{min}), which represents the moment in the accumulation curve

in which expressive gains in dry matter start to occur, and the maximum critical point (PC_{max}), which represents the moment when the accumulation of the components begins to stabilize, as previously described (Alves *et al.*, 2013):

$$PC_{min} = \frac{bc - 2}{b} PC_{max} = \frac{bc + 2}{b}$$

RESULTS AND DISCUSSION

There was no significant effect of the harvest systems on the dry matter data, and the interaction between season and cropping systems happened only for MSF. The MSF, MSC, MSI, MSFr and MST characters showed sigmoid behavior across all the tomato growing systems (Figure 2).

In general, PC_{min} for the MSC (35 and 33 DAT), MSI (45 and 45 DAT), MSFr (51 and 52 DAT) and MST (39 and 38 DAT) characters were similar for the Vertical and the Crossed Fence systems, respectively (Figure 2). On the other hand, PC_{min} for MSF was anticipated in six days in the Crossed Fence system in comparison to the Vertical and Viçosa systems, which occurred at 34 DAT for both systems. In the Viçosa system, PC_{min} was observed at 42, 48, 53 and 45 DAT for MSC, MSI, MSFr and MST, respectively.

During the period of assessment (75 DAT), it was not possible to determine PC_{max} in the Viçosa system for dry matter. On the other hand, in the Crossed Fence system it was possible to determine PC_{max} for MSF (57 DAT) and MSFr (70 DAT); in the Vertical system, PC_{max} occurred at 57, 70, 72, 67 and 68 DAT for MSF, MSC, MSI, MSFr and MST,

respectively (Figure 2).

Based on PC_{min} and PC_{max} , we were able to establish three growth phases for the evaluated characters of the tomatoes. The first phase of growth was slow with limited PC_{min} ; the second phase of intense growth showed limits between PC_{min} and PC_{max} , and finally, the third phase of maturation, initiated in PC_{max} .

The interaction between systems and times was not significant for the physiological growth characters of AFE, IAF, TAL and TCR. However, there was a significant difference between the cultivation systems specifically for the IAF at 75 DAT, when the Viçosa system was superior to the Crossed and Vertical Fence systems, the latter two having behaved very similarly to one another.

When analyzing the behavior of the growth curves, we have observed variations in growth as a response to the cultivation system for AFE, IAF, TAL and TCR (Figure 3). We have observed that while AFE showed exponential quadratic behavior, IAF was sigmoid, TAL was asymptotic in Crossed Fence and Viçosa, and cubic in Vertical systems, and TCR showed cubic behavior across all systems.

Regardless of the harvest system, AFE was reduced throughout the evaluations (Figure 3a), which was expected as AFE relates the leaf area with the leaf dry mass. Thus, self-shading increases as the plant grows, hampering leaf area expansion but without change to the patterns of leaf and total dry mass gain (Benincasa, 2003). In addition, AFE reduction was observed in plants growing under low light intensity as an adaptive mechanism to maximize available light capture and to meet photosynthetic demand (Fan *et*

al., 2013).

PC_{min} for IAF occurred near 30 DAT for the Crossed Fence and Viçosa systems, and later (at 36 DAT) for the Vertical systems. PC_{max} was close to 52 DAT for Crossed and Vertical Fence systems, and at 58 DAT for the Viçosa systems (Figure 3b). The PC_{max} values obtained for IAF are in agreement with those obtained by Fayad *et al.* (2001) in the same location as in this study, who observed maximum IAF at 58 days, reaching the end of the cycle at 0.17, which the authors attributed to the period of senescence and foliar abscission. The extension of the second phase for the IAF delayed the onset of senescence and foliar abscission of the tomatoes cultivated in the Viçosa system in comparison to the other cultivation systems, a fact that would explain, at 75 DAT, the highest IAF for the tomatoes cultivated in the Viçosa system.

The TAL presented similar behavior in the Crossed Fence and Viçosa systems at 75 DAT; in contrast, in the Vertical system TAL dropped sharply, representing half of the value observed in the Viçosa system (Figure 3c). It should be noted that the reductions in MST and IAF at 75 DAT may have potentiated reductions in TAL in the Vertical system, provided that they are parameters used to determine it. This was not observed for TAL in the Crossed Fence system, because it presented MST similar to the Viçosa system. In addition, PC_{max} for MST and MSF in the Vertical system were reached at 68 and 57 DAT respectively, a fact that reinforces the behavior of TAL in this system. The decline in TAL with increasing plant age seems to be common in short-cycle plants, since TAL represents the dry matter gain per area unit within the time unit, and provides inference to the photosynthetic efficiency (Farias & Saad, 2011).

The TCR showed maximum growth across all cultivation systems, close to 38 DAT when, from then on it decreased until the end of the evaluations (Figure 3d). Decreases in TCR values throughout the cycle are common for crops such as tomatoes and peppers.

The tomatoes cultivated in the Viçosa system presented a longer second

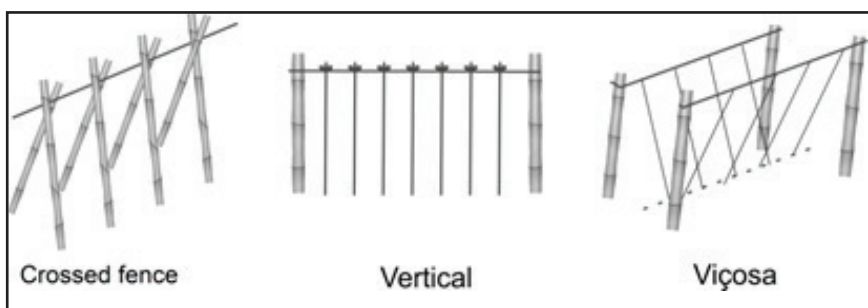


Figure 1. Illustration of the steering technique in harvest systems. Viçosa, UFV, 2012.

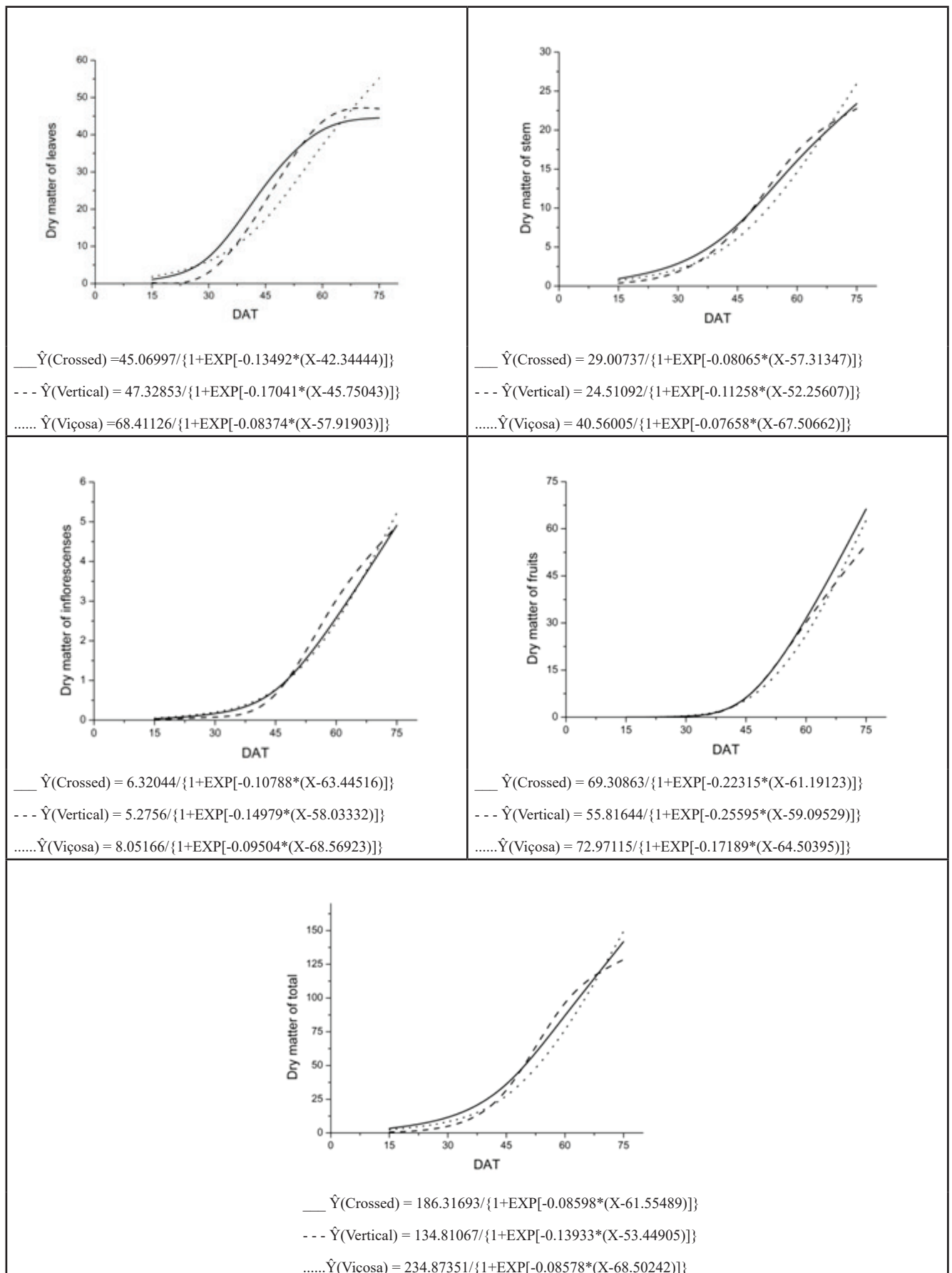


Figure 2. Estimates for dry matter (g/plant) for the cultivation systems in relation to the days after transplanting (DAT). Viçosa, UFV. 2012.

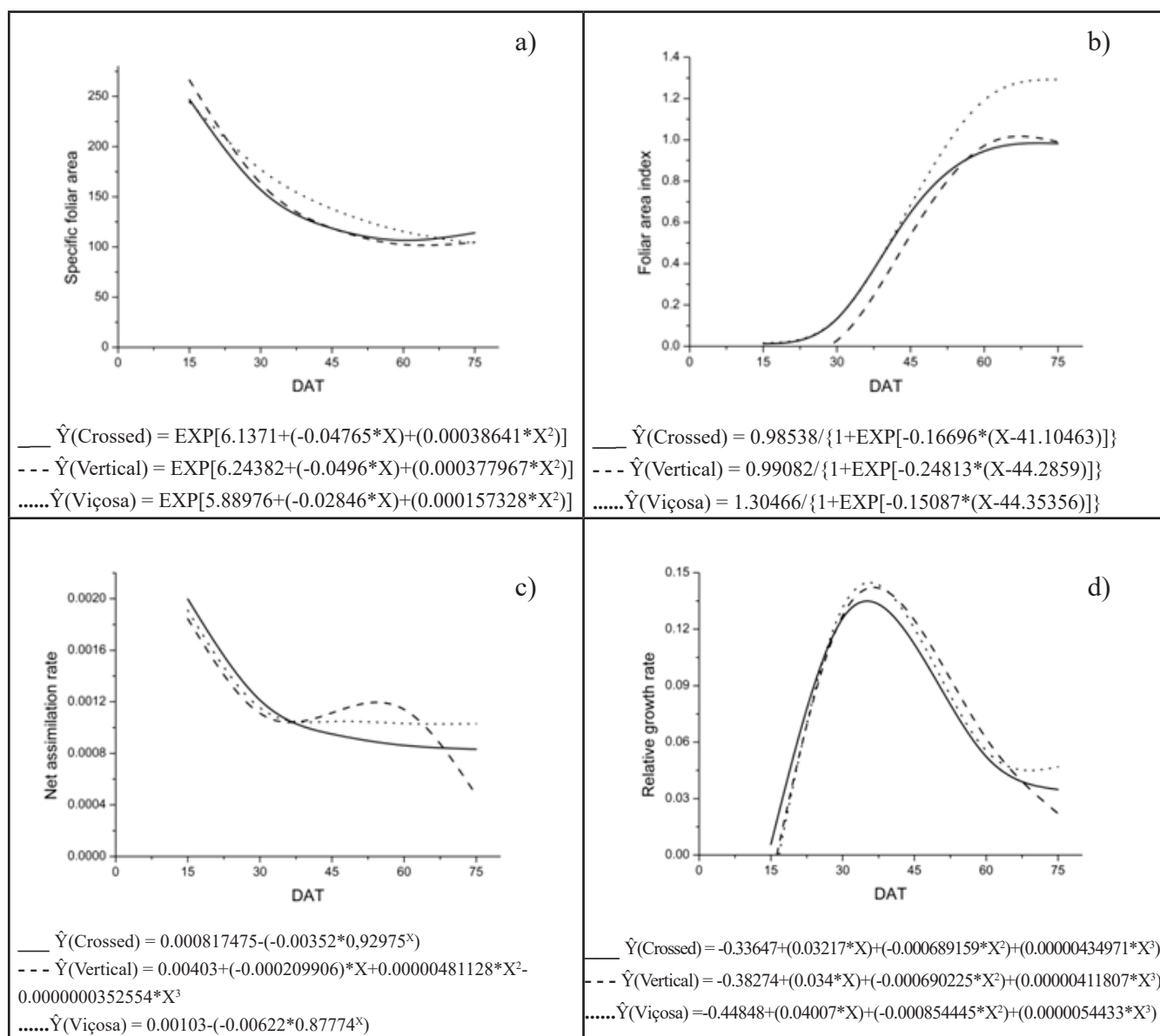


Figure 3. Estimates of the physiological indices for the cultivation systems in relation to the days after transplanting (DAT): a) Specific leaf area (cm²/g); b) Foliar area index (m²/m²), c) Net assimilation rate (g/cm²/day), d) Relative growth rate (g/g/day). Viçosa, UFV. 2012.

stage and consequently, by inference the maturation of the evaluated characters ($PC_{\max}$) occurred later in comparison to the other systems. Thus, the fruiting period was prolonged in this particular system, which would explain the gains of up to 61 and 131% respectively, in terms of productivity and production of large tomato fruits when grown in the Viçosa system, as observed in another study (Almeida *et al.*, 2015).

Although no significant differences have been observed, additional studies are required to elucidate evidence of the possible relationship between the greater extent of the second stage of

MSFr growth of tomatoes cultivated in the Viçosa area and greater AFE, IAF and TAL during this phase in this system. In addition, one must study the environmental factors that favor this evidence. The Crossed Fence system promotes the convergence of cauline apices, which can accelerate self-shading and consequently, reduce AFE, LAI, TAL, as well as the duration of the second phase of MSFr growth and fruit size in this system in comparison to the Viçosa system. Inference could explain the higher production of average tomato fruits in the Crossed Fence system in comparison to the Viçosa system as

observed by Almeida *et al.* (2015).

In light of the above, and according to the results obtained, it is possible to conclude that the Viçosa system altered the growth pattern of the tomatoes, quantified by the growth analysis, in comparison to the Crossed and Vertical Fence systems. The second growth phase for the dry matter of the fruit would possibly explain the productive gains obtained by Almeida *et al.* (2015). Further studies are required to clarify the relationship between the duration of the second phase of fruit dry matter growth, as well as the relationship between the physiological indexes AFE, LAI and

TAL and the size and fruit yield of the tomatoes.

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