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ARTICLE

Partitioning of assimilates and temporal distribution of productivity in grafted tomato plants[1]

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ABSTRACT: (Partitioning of assimilates and temporal distribution of productivity in grafted tomato plants). This study evaluated the morphology and partitioning of assimilates in grafted and non-grafted tomato plants in a greenhouse throughout the crop cycle. The plants were collected beginning on the 14th day after transplantation (DAT), at regular intervals of 14 DAT, until the end of the crop cycle. The dry mass of leaves, stems and fruits, number of leaves, leaf area, plant height, total number of fruits, number of unmarketable fruits, shoot/root ratio and harvest index were evaluated. Productivity was expressed in terms of mean fruit mass and non-commercial, commercial and total productivity in t ha^{-1} of fresh mass. Grafted plants had more leaves as well as greater allocation of dry matter to leaves and fruits, which resulted in a difference in the harvest index. However, the non-grafted plants proved superior in fruit production and in total and commercial productivity, compared to the grafted plants.
Key words: *Solanum lycopersicum* L., dry matter, production rate, metabolic drain.

RESUMO: (Partição de assimilados e distribuição temporal da produtividade de tomateiro submetido à enxertia). O trabalho objetivou avaliar as características morfológicas e a partição de assimilados entre plantas de tomateiro enxertado e pé-franco em ambiente protegido, ao longo do ciclo de cultivo. As plantas foram coletadas a partir do décimo quarto dia após o transplante (DAT), a intervalos regulares de 14 DAT até final do ciclo de cultivo. Foram determinados a matéria seca de folha, de caule e de fruto, o número de folhas, a área foliar, a altura das plantas, o número total de frutos, o número de frutos não comerciais, a razão parte aérea/raiz e o índice de colheita. A produtividade foi expressa pela massa média dos frutos, produtividade não comercial, comercial e total em t ha^{-1} de massa fresca. Plantas enxertadas apresentaram maior número de folhas, aliado à maior alocação de assimilados nas folhas e frutos, o que resultou um índice de colheita diferenciado. No entanto, o pé-franco demonstrou superioridade na produção de frutos e na produtividade comercial e total, quando comparado ao tratamento enxertado.
Palavras-chave: *Solanum lycopersicum* L., matéria seca, taxas de produção, dreno metabólico.

INTRODUCTION

Tomato is a vegetable native to subtropical regions of South America (Ploeg and Heuvelink 2005), which has high nutritional value (Dumas *et al.* 2003) and is widely used in Brazilian and international cuisines. In the last few years, farmers in Brazil have increased the productivity of this crop, which presently averages more than 63 t ha^{-1}, with more than 60,000 hectares now planted in tomatoes (IBGE 2009).

The increased use of greenhouses favors tomato cultivation in adverse weather conditions and periods (Moreira *et al.* 2009). The producer obtains a reduction in losses and increased productivity of various crops compared to field cultivation (Cardoso and Silva 2003). However, the intensification in land use under a protected environment has caused numerous problems for farmers, due to the increase of diseases in cultivated plants and salt accumulation in the soil (Goto *et al.* 2003).

Numerous alternatives that enable intensive cultivation in protected environments are being studied, aiming to overcome the typical problems of this type of management of production areas. These studies include the technique of grafting in vegetables to reduce or even eliminate problems caused by biotic and abiotic stresses (Goto *et al.* 2003). Grafting may affect plant growth as a whole, and therefore the partitioning of assimilates and productivity of crops should be particularly studied when these techniques are adopted.

In view of the lack of studies evaluating the productivity of grafted tomatoes, their economic importance, and the small number of studies on the influence of rootstock on biomass accumulation, referring to temperate climate conditions in a protected environment (Kleinhenz *et al.* 2006), this study analyzed the influence of environmental factors on morphological characteristics and partitioning of assimilates in grafted tomato plants, in a protected environment in subtropical climate conditions.

MATERIAL AND METHODS

The experiment was conducted in a vaulted-ceiling greenhouse, and the analyses were performed in the Laboratory of Plant Physiology, Universidade Federal de Pelotas, located at 31º52 'S, 52º21' W and 13 m a.s.l. The regional climate is temperate, with well-distributed rainfall and hot summers, Cfa type according to Köppen's classification.

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The seedlings were grown in a 'Pampeano' style vaulted greenhouse oriented north to south and covered with polyethylene film (150 µm thick). Seeds of the rootstock (Kaguemusha® hybrid tomato) were sowed on 12/30/2010 in 500-ml polyethylene cups, and seeds of the grafts (Gaucho® tomato) were sowed on 01/11/2011 in expanded polystyrene trays of 128 cells containing commercial substrate (H.Decker®). The grafting was performed on 01/30/2011, by the method of pile/terminal slot (cleft grafting) according to the recommendations of Goto *et al.* (2003, apud Yamakawa 1982).

The grafted seedlings were transplanted at the fifth leaf stage on 02/21/2011, into beds with Planosol soil, covered with black polyethylene film ("mulching"), with spacing of 0.40 x 0.50 m in a 'Pampeano' style vaulted greenhouse covered with 150-µm polyethylene film, oriented east to west. Fertilization and liming of soil were previously performed after soil analysis and based on the Manual of Fertilization and Liming for the states of Rio Grande do Sul and Santa Catarina (CQFS RS/SC 2004) as recommended for tomatoes, with an estimated production of 75 t ha^{-1}. Micronutrient requirements were supplied with Torped® foliar fertilizer at a rate of 1 mL L^{-1}, as indicated by the manufacturer.

The plants were irrigated as needed during the crop cycle. The plants were vertically staked, led to a single stem, and pruned weekly. The treatments consisted of grafted (E) and non-grafted (T) tomato plants. The data for mean temperature and solar radiation were obtained from the bulletin of the Estação Agroclimatológica de Pelotas (2011).

The plants were collected beginning on the 14th day after transplantation (DAT), at regular intervals of 14 d until the end of the crop cycle. At each harvest, the plants were separated into organs (root, stem, leaf and fruit), and the roots were washed in running water on a fine-mesh sieve. The organs were dried in a forced-ventilation oven at a temperature of 70 ± 2 °C, until constant mass. The numbers of leaves, leaf area, height, fruit number and number of unmarketable fruits of plants were evaluated, and adjusted through orthogonal polynomials (Richards 1969). Plant height (A) was determined using a tape measure, and expressed in meters from ground level to the upper end of the longest stem. The number of leaves (N_f), number of fruits and number of unmarketable fruits were obtained by direct counting, converted to number per area, and expressed per square meter. The leaf area (A_f) was determined using a leaf area meter (model LI-3100). Beginning 84 days after the transplantation (DAT), the tomatoes were harvested three times for evaluation of the mean fruit mass and the non-commercial, commercial and total productivity in t ha^{-1} fresh mass, for a total of 20 replicates per treatment. The morphological and productivity data were subjected to polynomial regression at 5% probability. The primary data for dry mass of leaves (W_f), stems (W_c) and fruits (W_{fr}) were adjusted using orthogonal polynomials (Richards 1969). The shoot/root ratio ($P_w = W_{sh}/W_r$) and harvest index ($H_i = W_{fr}/W_t$) data were submitted to variance analysis and were analyzed based on trend curves, as recommended by Radford (1967).

The experiment used a randomized block design, totaling nine harvests with five plants for each treatment. Data were subjected to analysis of variance and when significant at the 5% probability level, were expressed by orthogonal polynomials.

RESULTS AND DISCUSSION

The meteorological data for mean temperature and incidental solar radiation observed during the period and at the growing site are shown in Figure 1a and 1b. Temperature and solar radiation during the crop cycle have significant effects on partitioning of assimilates and the productivity of the cultivar (Papadopoulos and Hao 1997).

The leaf number (Fig. 1c) as a function of DAT was adjusted by a cubic equation for both treatments $R^2 \geq 0.96$, and increased during the ontogeny of the plants. The number of leaves on grafted (94 leaves m^{-2}) and non-grafted (93 leaves m^{-2}) plants was similar. This small difference can be ascribed to the greater effect of temperature on the growth and development of the grafted plants. Temperature has significant effects on the development and/or appearance of new leaves in a wide range of cultivated plant species (Radin *et al.* 2004). Andriolo *et al.* (2003) obtained similar results when assessing the number of leaves during growth and development of tomato plants grown in substrate, as did Fayad *et al.* (2001), in relation to the age of tomato plants grown in a protected environment.

The leaf area (A_f) peaked at 98 DAT, with a subsequent decrease (Fig. 1d). The non-grafted plants showed an initial slight superiority compared to the grafted ones. This is due to the fact that grafted plants direct much of their assimilates to the full restoration of the grafting site (Goto *et al.* 2003). During the development, A_f was higher than in non-grafted plants. Aumonde *et al.* (2011) studied the effect of grafting on watermelon growth, and found a higher leaf area index in non-grafted plants, indicating the negative effect of the grafting technique on the initial A_f. Fontes *et al.* (2005) emphasized that high efficiency of the plant assimilatory system in photoassimilates production, results in a high allocation of dry matter to various organs, especially fruits, as was observed in the grafted tomato plants.

The number of fruits per plant is an important component of yield. In this study the total number of fruits (Fig. 1e) at the end of the cycle (112 DAT) was higher in non-grafted plants (88 fruits m^{-2}) compared to the grafted ones (83.5 fruits m^{-2}). Despite their superiority in total fruit number, non-grafted plants produced a larger number of unmarketable fruits compared to grafted plants (Fig. 1f). The high fruit production of non-grafted plants strongly influenced the allocation of W_{fr} and mean fruit mass, both of which decreased compared to grafted plants (Heuvelink 1997). Together with the increase in the interception of solar radiation during a period of time, this results in a large number of fruits per plant (Marcelis 1993).

Plant height (Fig. 2a). in both treatments, was obtained with a high coefficient of determination ($R^2 \geq 0.99$), with maximum values at 112 DAT for grafted plants (2.10 m) and non-grafted (1.98 m) respectively. This could be expected to stabilize at the end of the cycle, since Fayad *et al.* (2001) observed in tomato plants under greenhouse conditions that plant height increased rapidly.

The dry matter accumulation in leaves (W_f) increased until the end of the crop cycle (112 DAT), showing a cubic trend with high coefficients of determination ($R^2 = 0.98$). Grafted and non-grafted plants showed similar dry-matter allocation during the cycle (Fig. 2b). According to Aumonde *et al.* (2011), the high production of initial matter occurs due to the preferential allocation of assimilates to form the photosynthetic system; this initial production is higher in non-grafted plants, because they are not subjected to the grafting stress. The dry matter distribution can be described as the balance between water absorption, nutrients and

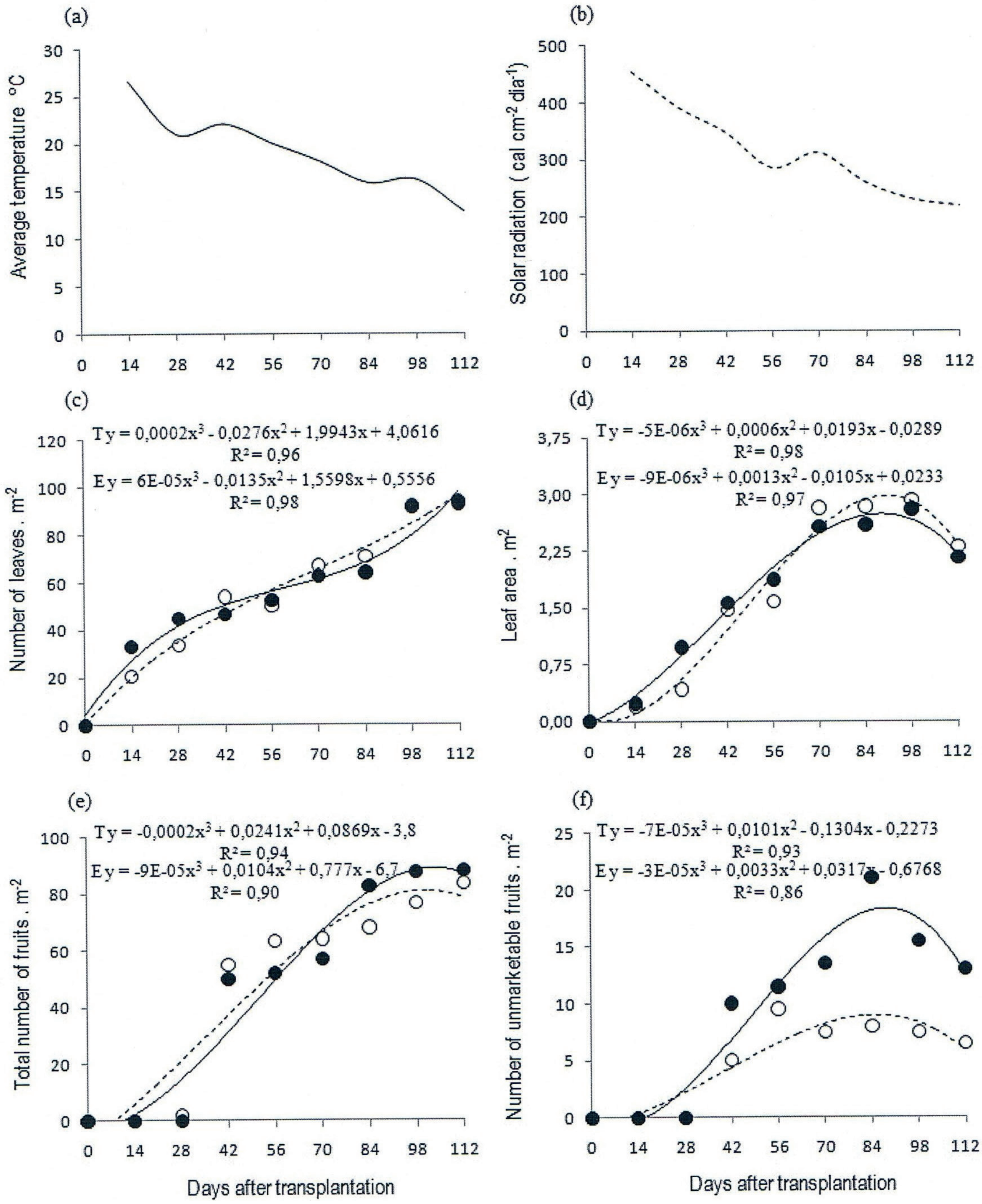

Figure 1. Mean temperature (a), solar radiation (b) leaf number (c), leaf area (d), total number of fruits (e) and number of non-commercial fruits (f) of tomato plants throughout the crop cycle. Non-grafted (● and ———) and grafted (○ and - - - - - -).

photoassimilate production, physiological processes that are less affected in non-grafted plants (Marcelis 1993). Observations on pepper and tomato plants, for accumulation of leaf dry matter, showed a continuous increase in production of leaf dry matter until the end of the cycle (Fayad *et al.* 2001; Silva *et al.* 2010). Guimarães *et al.* (2009) found a decrease in dry matter of tomato leaves in recent field evaluations.

The production of fruit dry matter (W_{fr}) fit the cubic trend in both treatments, with $R^2 \geq 0.98$. The W_{fr} increased beginning at 28 DAT and continued to increase up to 112 DAT, reaching higher values in grafted plants (509.9 g m^{-2}) compared to non-grafted plants, with a final value of 395.3 g m^{-2} (Fig. 2c). The increase in leaf area is not synonymous with increased production of assimilates; it is possible that grafted plants were more efficient in capturing incident solar radiation and converting it into carbohydrate compounds, causing the high W_{fr}. It must be noted that W_{fr} is also influenced by the number of fruits per plant and environmental factors during the development of a tomato crop (Heuvelink 1997). Ho (1996) concluded that the tomato plant yield is related to the availability of assimilates, due to the effect of temperature together with solar radiation.

The dry-matter production of stems (W_c) in grafted and non-grafted plants was obtained with a high coefficient of determination (R^2 = 0.97) and an increasing cubic trend until the end of the cycle (Fig. 2d). At 112 DAT

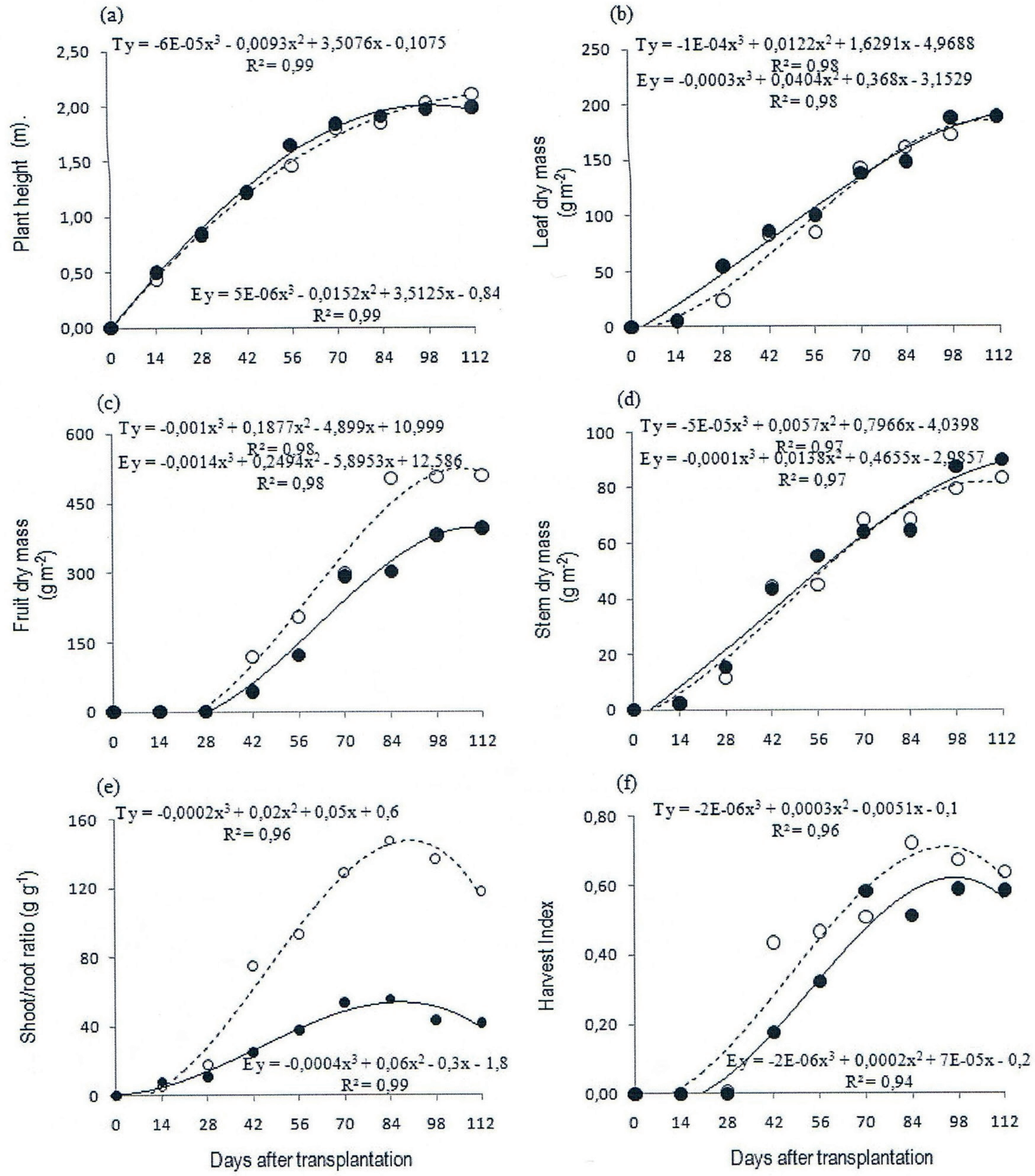

Figure 2. Plant height (a), dry matter of leaf (b), fruit (c), stem (d), shoot/root ratio (e) and harvest index (f) of tomato plants over the crop cycle of the plants. Non-grafted (● and ———) and grafted (○ and - - - - - -).

the non-grafted plants showed slightly higher dry-matter accumulation in the stems (89.7 g m^{-2}), compared to the grafted plants, with a final value of 83.3 g m^{-2}.

The influence of the shoot on the plant root system can be measured through the ratio of shoot/root (P_w). In this study, the P_w was higher in the grafted tomato plants through almost the entire the crop cycle, increasing up to 84 DAT in both treatments (Fig. 2e). The high P_w in grafted plants is due to the lower allocation of dry matter in the root system, compared to non-grafted plants. Thus, changes in the allocation of dry matter in shoots and roots lead to changes in the P_w (Vieira *et al.* 2008).

The harvest index (H_i) reached its highest peak at 98 DAT for both grafted and non-grafted plants, with values of 0.67 and 0.59 respectively (Fig. 2f). H_i is an important tool to evaluate the efficiency of the conversion of dry matter into economically important material, and it is directly influenced by environment and genotype (Peixoto and Peixoto 2009). The increase in the Hi is attributed to higher fruit dry matter accumulation in grafted plants, in relation to the total plant dry matter (Fig. 7c). Similar trends were found for soybeans (Santos *et al.* 2004).

The mean fruit mass was similar in grafted and non-grafted plants (Fig. 3a). Thus, grafting does not affect the mean mass of tomato fruits of grafted plants compared to non-grafted plants (Cardoso *et al.* 2006). Temperature has a significant effect on the metabolism and fruit growth when the water supply is not limited (Ho 1996). Thus, the size of the tomato fruit is determined by farming practices and environmental conditions, and in this case the efficiency of the root system may lead to increases in the mean mass.

The total fruit yield was higher in non-grafted plants, except for the first harvest (Fig. 3d). The early superiority in productivity of non-grafted plants may be related to the absence of the grafting stress effect. Such plants, because they do not need to regenerate tissue, can allocate carbohydrates exclusively to growth (Goto *et al.* 2003).

Comparing the proportions of commercial and non-commercial fruit produced, the grafted plants produced a smaller proportion of unmarketable fruits than the non-grafted plants (Fig. 3b). However, the higher total fruit productivity in non-grafted plants resulted in a higher commercial production in the three harvests (Fig. 3c). Fontes *et al.* (2005), studying dry matter distribution and production of peppers in a greenhouse, observed that the

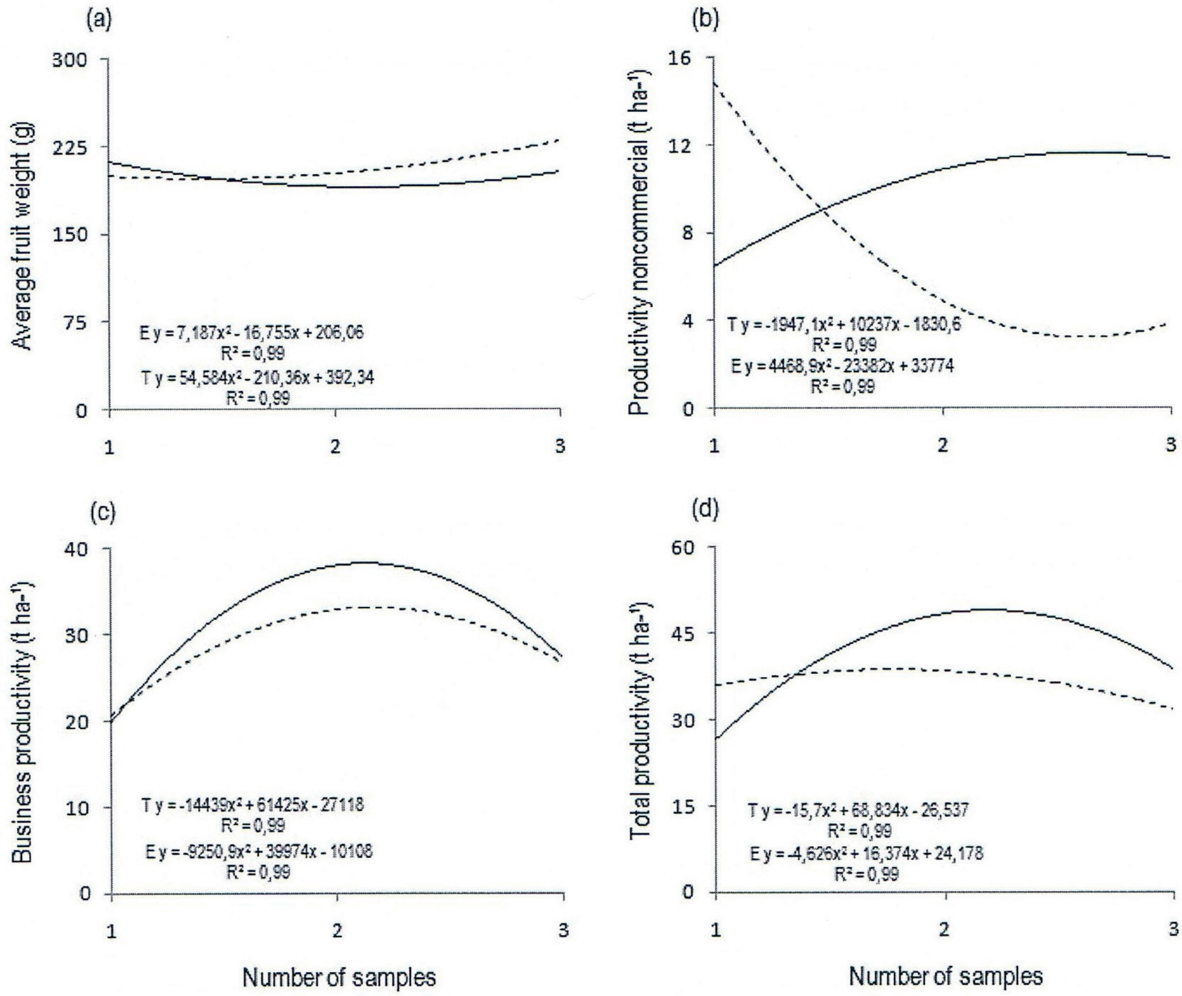

Figure 3. Mean fruit mass (a), non-commercial productivity (b), commercial productivity (c), and total productivity (d) of tomato plants throughout the crop cycle. Non-grafted (———) and grafted (- - - - - -).

mean mass and fruit yield were influenced by leaf area and temperature, and the first harvest comprised 29.4% of the total production. Papadopoulos and Hao (1997) emphasized that in addition to temperature, CO_2 concentration and leaf efficiency in intercepting radiation are essential to increase the productivity in a protected environment.

These results, however, do not indicate that the grafting technique is ineffective in vegetables, since its main purpose is to increase resistance to biotic and abiotic stresses via superior rootstocks. This advantage will only be effectively perceived if some kind of stress that could be overcome by grafting actually occurs, allowing the rootstock to express its superior resistance to stress conditions. The results from the first harvest showed a significant precocity of grafted compared to non-grafted plants (Fig. 5d), but by the end of the cycle, this supposed advantage disappeared.

CONCLUSIONS

Tomato plants of the Gaúcho cultivar grafted on Kaguemusha hybrid rootstock, had higher precocity, fruit dry matter, mean fruit mass, shoot/root ratio, and harvest index than non-grafted plants.

The non-grafted plants were more productive than the grafted plants, but produced a higher proportion of nonstandard marketing fruits.

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