SANDRI, M.A.; ANDRIOLO, J.L.; WITTER, M.; DAL ROSS, T. High density of defoliated tomato plants in protected cultivation and its effects on development of trusses and fruits. *Horticultura Brasileira*, Brasília, v. 20, n. 3, p. 485-489, setembro 2002.

High density of defoliated tomato plants in protected cultivation and its effects on development of trusses and fruits

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ABSTRACT

Tomato fruit setting on high density defoliated tomato plants with similar leaf area index was determined in three environmental conditions, inside polyethylene tunnels. Experiment 1 was carried out in autumn when average solar radiation received by the crop was 8.0 MJ m^{-2} day^{-1}. Average external temperature was 18.1ºC. Experiments 2 and 3 were conducted in spring, when average external temperature was 19.7ºC. In experiment 2, average solar radiation received by the crop was 12.4 MJ m^{-2} day^{-1}, whereas in experiment 3 it was reduced to 5.9 MJ m^{-2} day^{-1} by a 52% shading net. Plants were grown in bags, spaced 1.0 m between row and 0.3 m within row bags distance, using 5.5 L of a commercial substrate. Nutrients and water were supplied by means of a nutrient solution, delivered daily in order to replace volumes lost by transpiration. Treatments consisted of one (T1), two (T2) and three (T3) plants per bag, leading to plant densities of 3.3, 6.7 and 10 plants m^{-2}, respectively. In T1, three leaves per sympod were kept, with a ratio of 3:1 between number of leaves and inflorescences per sympod. In T2, two and one leaf was kept respectively on two consecutive sympods, alternatively on both plants. The ratio between number of leaves and inflorescences was 3:2. In T3, with three plants per bag, only one leaf per sympod was kept on each plant. The ratio between number of leaves and inflorescences was 3:3. In all experiments, the number of trusses per area in T2 and T3 was two and three times higher than in T1, respectively. The number of fruits per unit ground area was lower in T1 plants and similar in T2 and T3 plants in the first experiment, whereas in the second and third experiments similar values were observed among treatments. Results indicated that tomato plants adjust the number of fruits, and exceeding flowers are aborted. The use of a plant density of 6.7 plants m^{-2} combined with a 3:2 ratio between number of leaves and inflorescences per unit ground area seems to be the upper limit in maximizing the number of set fruits of this crop.

Keywords: Lycopersicum esculentum, *fruit number, fruit emission, fruit set, competition for assimilates.*

RESUMO

Alta densidade com desfolhamento de plantas de tomateiro em cultivo protegido e seus efeitos sobre o desenvolvimento de inflorescências e frutos

O número de frutos em plantas de tomateiro cultivadas em alta densidade e com índice de área foliar similar mantido através de desfolhamento foi determinado em três condições ambientais, no interior de túneis de polietileno. O experimento 1 foi conduzido no outono, com radiação solar média recebida pela cultura de 8,0 MJ m^{-2} dia^{-1} e temperatura média exterior de 18,1ºC. Os experimentos 2 e 3 foram conduzidos na primavera, com temperatura média exterior de 19,7ºC. No experimento 2, a radiação solar média recebida pela cultura foi de 12,4 MJ m^{-2} dia^{-1}, enquanto no experimento 3 foi reduzida para 5,9 MJ m^{-2} dia^{-1} por meio de uma tela com 52% de sombreamento. As plantas foram cultivadas em sacolas, com 1,0 m entre fileiras e 0,3 m entre sacolas, enchidas com 5,5 L de substrato comercial. Nutrientes e água foram fornecidos via solução nutritiva, de forma a repor os volumes perdidos pela transpiração. Os tratamentos consistiram de uma (T1), duas (T2) e três (T3) plantas por sacola, correspondendo a densidades de 3,3; 6,7 e 10 plantas m^{-2}, respectivamente. Em T1, três folhas por simpódio foram mantidas, com uma proporção de 3:1 entre o número de folhas e de inflorescências, em cada simpódio. Em T2, duas e uma folha foram mantidas respectivamente em dois simpódios consecutivos, alternativamente em ambas as plantas da sacola. A relação entre o número de folhas e de inflorescências foi de 3:2. Em T3, com três plantas por sacola, somente uma folha por simpódio foi mantida, com uma relação de 3:3. Em todos os experimentos, o número de inflorescências por unidade de área em T2 e T3 foi duas e três vezes maior que em T1, respectivamente. O número de frutos fixados por área de solo foi menor em T1 e similar em T2 e T3 no primeiro experimento, enquanto no segundo e terceiro experimentos valores similares foram observados entre os tratamentos. Os resultados indicaram que as plantas de tomateiro ajustam o número de frutos fixados e as flores excedentes são abortadas. Uma densidade de 6,7 plantas m^{-2} combinada com uma proporção de 3:2 entre o número de folhas e de inflorescências por unidade de área de solo é apontada como a mais indicada para maximizar a fixação de frutos da cultura.

Palavras-chave: *Lycopersicum esculentum*, número de frutos, emissão de frutos, fixação de frutos, competição por assimilados.

(Recebido para publicação em 01 de outubro de 2001 e aceito em 25 de março de 2002)

Tomato is one of the most important horticultural crops grown around the world. In protected cultivation, the growing period could be extended for the whole year and fresh fruit yield can reach 50 kg.m^{-2} (Konning, 1994). In Southern Brazil, cultivation is made in two short growing periods, respectively in autumn and spring. Plants transferred to greenhouses at the beginning of March last in production until June. From June to August, solar radiation

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falls to values below 8.4 MJ m^{-2} day^{-1}, considered as the trofic limit for this crop (FAO, 1990). Thus, it is possible to grow seedlings and plants in the vegetative phase in winter. In spring, planting in greenhouses is made in August and the crop lasts until December, when air temperature could reach values higher than 30ºC.

To attain high fruit yield, high number of fruits per unit of ground area is needed. To avoid fruit abortion high rates of assimilate production are necessary. Number of fruits per plant depends on the number of trusses and also on the number of fruits per truss. Emission of new trusses is related to the emission of leaves, in a rate of one truss each three leaves (Atherton & Rudisch, 1986; Chamarro, 1995). The number of set fruits per truss depends on the assimilate supply (Bertin, 1993; 1995; Heuvelink, 1996). Absorption of radiation to sustain production of assimilates is related to the leaf area index (LAI) and saturation is reached at values of about 3.5 m^2 m^{-2} (Acock *et al.*, 1978). The fraction of dry matter allocated to fruits (FDMF) is regulated by complex interactions among sink strength of plant organs (Konning, 1994; Bertin, 1995; Heuvelink, 1996). In tomato crops, the FDMF could reach values higher than 0.60 over cropping periods of about 10 months (Cockshull, 1992; Heuvelink, 1996). In Santa Maria, observed values of FDMF varied between 0.40 in autumn and 0.50 in spring, and it was concluded that plants had an excessive vegetative growth (Andriolo *et al.*, 1998; Andriolo & Falcão, 2000).

To enhance the fraction of dry matter in fruits of tomato plants, pruning leaves is a practice that has been preconised (Garbi *et al.*, 1998; Martinez *et al.*, 1998). In an experiment carried out in spring in Santa Maria, Streck *et al.* (1998) compared fruit yield of plants grown in a plant density of 8 plants m^{-2} and detopped after the third truss against control plants grown in a plant density of 3 plants m^{-2} and bearing 7 trusses. Fruit yield was similar in both treatments. When one or two leaves per sympod (a stem segment with three leaves and one truss) were systematically picked out during the growth of plants, Andriolo & Falcão (2000) observed similar fruit yield among pruned and control plants with three leaves per sympod. They concluded that at least one leaf per sympod could be eliminated without any reduction in fruit yield. Thus, defoliation seems to be a practice that could be used to enhance the FDMF in crops having an excessive vegetative growth. Moreover, when plants are defoliated, LAI is reduced. Plant density should be increased to compensate leaf suppression, without changing the optimal LAI of the crop. An increased plant density implies higher number of trusses and fruits per ground area and could increase fruit yield of the crop. The aim of this work was to determine the effect of an increasing plant density of defoliated tomato plants on development of trusses and fruits.

MATERIAL AND METHODS

Three experiments were carried out at the *Universidade Federal de Santa Maria, Rio Grande do Sul* State, Brazil, in autumn and spring 2000. In all experiments the indeterminately growing tomato beefsteak hybrid Monte Carlo was grown inside polyethylene tunnels (3 m height, 5 m wide, 15 m length, 83% transmissivity to global solar radiation). In the first experiment, conducted in autumn, sowing was made at February 23th, 2000, in polystyrene trays filled with a commercial substrate, and planting at March 30th. In spring, sowing was done at July 4th and planting at August 27th, in two polyethylene tunnels for experiments two and three, respectively. In experiment three, a plastic net was displayed over the canopy of the crop, in order to reach a 52% reduction in the inside solar radiation. In all experiments, plants were grown in up-right bags containing 5.5 L of a commercial substrate, in 1.0 m between rows and 0.3 m within the row and trained according to the high-wire system, with one stem per plant. Water and nutrients were delivered daily to plants by means of a nutrient solution, in order to replace water volumes lost by transpiration, with a coefficient of drainage of about 25%. The composition of the nutrient solution was the same used to grow tomatoes in substrate culture (CTIFL, 1995), with the following quantities of fertilizers, in mmol.L^{-1}: KNO_3, 4.0; K_2SO_4, 0.9; $Ca(NO_3)_2$, 3.75; KH_2PO_4, 1.5; $MgSO_4$, 1.0; iron chelate 19 ′ 10^{-3}. Microelements were added by a commercial mixture. Static ventilation of tunnels was done in sunny days, by opening lateral sides, to reduce air humidity and stimulate natural pollination.

Treatments consisted of three plant densities combined with defoliation in order to keep similar number of leaves per unit ground area. In treatments 1; 2 and 3 (T1; T2 and T3) one, two and three plants per bag were used, corresponding to plant densities of 3.3; 6.7 and 10 plants m^{-2}, respectively. Defoliation started after the emission of the second truss. In T1, three leaves per sympod were kept, as control (Figure 1). The ratio between number of leaves and inflorescences per sympod in each bag was 3:1. In T2, with two plants per bag, one leaf was kept in the first sympod of one of the plants and two leaves in the sympod of the same order in the other plant. In the second sympod, two and one leaves were kept, inversely from the preceding one, and so on until the end of the experiment. Pruned leaves were always the second of the sympod when one leaf was picked out and the first and the third of the sympod when two leaves were picked out. The ratio between number of leaves and inflorescences was 3:2. In T3, with three plants per bag, only one leaf per sympod was kept on each plant. The ratio between number of leaves and inflorescences was 3:3. A randomized block experimental design was used, with three replications and 16 bags per plot.

Four plants were harvested at 19; 33; 44; 49; 56; 62 and 69 days after the anthesis (DAA) in experiment 1 and at 19; 26; 33; 40; 47; 54; 61; 75 and 89 DAA in experiments 2 and 3, in plots of each treatment. After harvest, number of leaves (> than 1 cm), visible trusses and setted fruits (> than 1 cm diameter) were counted. Data from temperature and sunshine were recorded by the

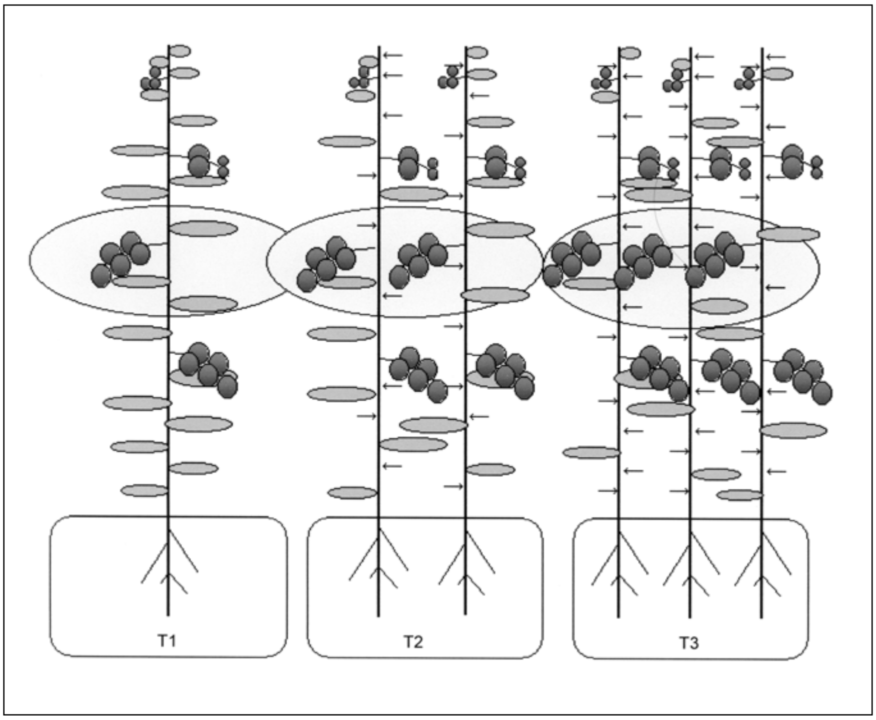

Figure 1. Schematic representation of treatments: one plant per bag with ever three leaves per sympod and a ratio 3:1 between leaves and inflorescences (T1); two plants per bag with one and two leaves per sympod and a ratio of 3:2 (T2); three plants per bag with only one leaf per sympod on each plant and a ratio of 3:3 (T3). Santa Maria, UFSM, 2000. (Arrows show pruned leaves). Santa Maria, UFSM, 2000.

Climatological Station, situated 100 m far from the experimental area. Daily average temperatures were calculated from maximum and minimum values and solar radiation estimated by the Ångstron's model, with coefficients adjusted for Santa Maria by Estefanel *et al*. (1990).

RESULTS AND DISCUSSION

Daily average solar radiation inside the greenhouse during the experiments was 8.04 and 12.40 MJ m^{-2} day^{-1} in the first and second experiments, respectively. In the first experiment, values were 9.51 MJ m^{-2} day^{-1} until 44 days after planting and 6.61 MJ m^{-2} day^{-1} from this day until the end of the experiment. The cumulative solar radiation received by crops in the first and second experiments was 731.91 and 1362.57 MJ m^{-2}, respectively. In the third experiment this value was 233.69 MJ m^{-2} from planting date to 21th September, when the shading net was displayed. Afterwards, daily average solar radiation was 5.02 MJ m^{-2} dia^{-1} and accumulated 427.71 MJ m^{-2} until the end of the experiment. Daily outside average air temperatures were 18.1ºC in the first experiment and 19.7ºC in the second and third experiments. Daily average thermal amplitude of the air was 9.8ºC in the first experiment and 10.9ºC in the second and third experiments. During the experimental period, daily air temperatures decreased from 21ºC to 15ºC in the first and increased from 15ºC to 26ºC in the second and third experiments.

Number of leaves per unit ground area was similar in all treatments during growth of crops, as a consequence of periodic defoliation (Figure 2a, c, e). In the first experiment values increased until last evaluation. In the second and third experiments, this variable increased until 61 DAA and decreased afterwards. No significant differences were observed among treatments, but fewer leaves in T1 plants was recorded at the two last harvests in the third experiment (Figure 2e).

The number of fruits per unit ground area was lower in T1 plants and similar in T2 and T3 plants in the first experiment (Figure 2b). Values at last harvest were 52; 80 and 90 fruits m^{-2} in T1; T2 and T3, respectively, only T1 differing significantly from T2 and T3 (Table 1). In the second experiment, similar values were observed among treatments until 54 DAA (Figure 2d). At last harvest values were 96; 126 and 125 fruits m^{-2}, in T1; T2 and T3, respectively, and T1 differed significantly from T2 and T3 (Table 1). In the third experiment, similar values were recorded in all harvests, reaching at the last evaluation 80; 101 and 105 fruits m^{-2} in T1; T2 and T3, respectively, and differences among treatments were not significant (Figure 2f and Table 1).

Number of trusses per unit ground area differed among treatments. At ending dates, values were 26; 45 and 60 in the first, 23; 47 and 67 in the second and 23; 47 and 70 in the third experiment, for T1; T2 and T3, respectively.

Number of fruits in tomato plants has been considered as depending on the simultaneous effect of ovule fertilization and fruit abortion. Fertilization includes pollen production, viability and transfer, being rather influenced by extreme air temperatures, out of the range between 10 and 35°C (Maisonneuve & Philouze, 1982; Atherton & Harris, 1986; Chamarro, 1995). After fertilization, the number of fruits that develop on a truss depends mainly on assimilate supply. An important question in experiment 1 is whether or not the number of fruits was limited by unfavorable temperatures and lack of assimilates. The number of fruits per truss on control plants (T1) of experiment 1 was about half of that on similar plants of experiment 2 and it might be concluded that production of assimilates was affected negatively by the environment in experiment 1 (Table 1). On the other hand, average number of fruits per unit ground area was influenced significantly by plant densities in experiments 1 and 2, by an average factor of 1.6 and 1.3, respectively (Table 1). Bertin (1993) showed that within an inflorescence, flowering of distal flowers coincided with fruit set of the proximal ones. As a consequence, fruit set of distal flowers was disfavored, reducing the number of fruits on the plant. In our experiments, it might be expected that an increased

Table 1. Number of fruits per unit ground area and number of fruits per truss in experiment 1, 2 and 3. Santa Maria, UFSM, 2000.

Treatment	Number of fruits m^{-2}			Number of fruits per truss		
	Exp. 1	Exp. 2	Exp.3	Exp. 1	Exp. 2	Exp.3
T1	52 b	96 b	80a	2.00a	4.17a	3.48a
T2	80a	126a	101a	1.78ab	2.68 b	2.15 b
T3	90a	125a	105a	1.50 b	1.86 c	1.50 c

*/ Means with the same letter within the column did not differ significantly at 5% probability by Duncan's test.
/ Experiment 1 = autumn; experiment 2 = spring; experiment 3 = spring with 52% artificial shading.
T1, T2 and T3 = plant densities of 3.3; 6.7 and 10 plants m^{-2} with ratios between number of leaves and trusses of 3:1; 3:2 and 3:3, respectively.

number of trusses in T2 and T3 could lead plants to have a higher proportion of proximal fruits, increasing the number of set fruits per unit area. This was the case only in T2 from experiments 1 and 2, suggesting at highest plant density competition for assimilates reduced fruit set.

The competition for assimilates is more visible in experiments 2 and 3, when number of fruits per unit ground area reached a saturation in treatments T2 and T3 (Table 1). In experiments using a round tomato hybrid, without defoliation and in a plant density of 2.5 plants m^{-2} carried out in Netherlands, Heuvelink (1996) showed the number of fruits per m^2 saturating near values of 100 fruits m^{-2}. Actual maximum value of 126 fruits m^{-2} observed in experiment 2 was above of that reported by Heuvelink (1996) and might be attributed to a reduced competition among fruits within trusses, under non limiting climatic conditions for assimilate production. The lack of response in T3 suggests that at excessively high plant densities the reduction in competition of assimilates within trusses was counterbalanced by an increased competition between vegetative organs and fruits. In fact, when number of stems per unit ground area was increased by plant density, more assimilates were needed to sustain the growth of them, which precedes that of inflorescences and fruits during plant growth and development. As a consequence, availability of assimilates to fruits was reduced.

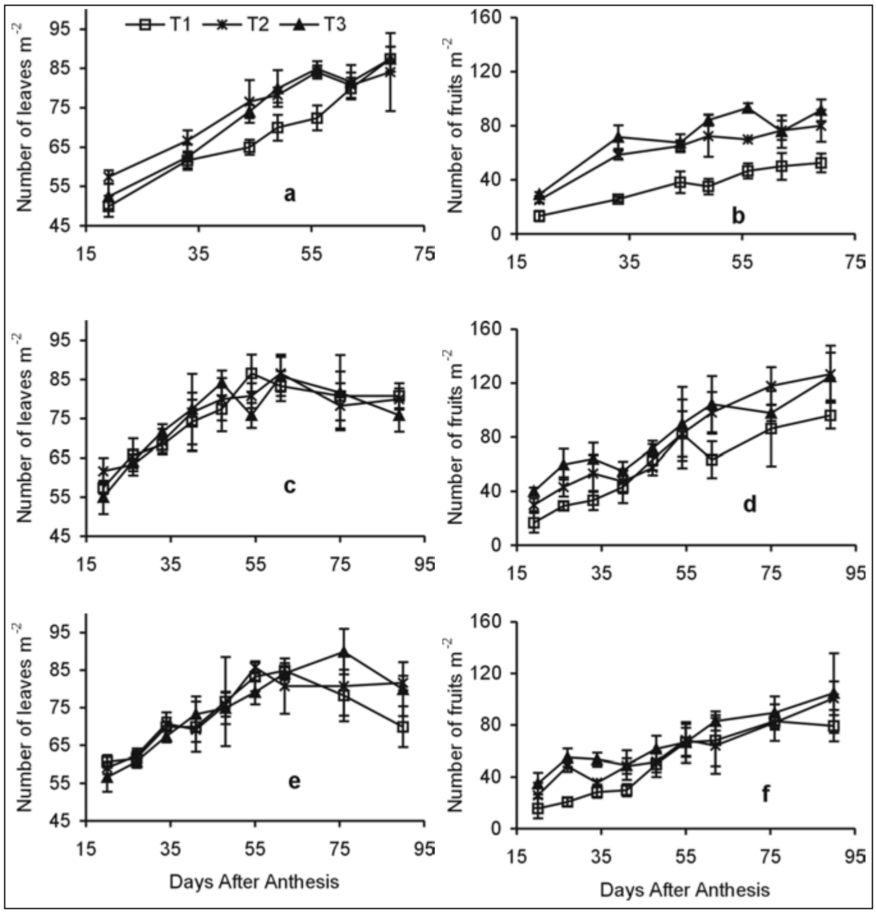

Figure 2. Number of leaves and fruits in experiment 1 (a,b), 2 (c,d) and 3 (e,f) during experimental periods. Santa Maria, UFSM, 2000. (Experiment 1 = autumn; experiment 2 = spring; experiment 3 = spring with 52% artificial shading. T1, T2 and T3 = plant densities of 3.3; 6.7 and 10 plants m^{-2} with ratios between number of leaves and trusses of 3:1; 3:2 and 3:3, respectively). Santa Maria, UFSM, 2000.

In experiment 3, reduction of 53% in solar radiation affected the number of fruits m^{-2} in only 8.2%, in average, independently of plant density (Table 1). Radiation levels received by plants during this experiment were low: 5.02 MJ m^{-2} day^{-1}, over the period of truss and fruit development. This level was higher than that used by Cockshull *et al*. (1992) in England, varying from about 0.5 and 4.8 MJ m^{-2} day^{-1} in experiments with shaded and unshaded plants. These authors showed that number of fruits per truss was strongly correlated with radiation when values were below 1.5 MJ m^{-2} day^{-1}. For values above this limit, correlation was weak. In our experiments, shading reduced the number of fruits per ground area and also in a per truss basis in a similar way. It might be concluded that the number of set fruits per m^2 was dependent on both availability and competition for assimilates among plant organs.

Results presented in this paper indicated that tomato plants adjust their number of set fruits, and exceeding flowers are aborted. For practical purposes, the use of a plant density of 6.7 plants m^{-2} combined with a 3:2 ratio between number of leaves and inflorescences per unit ground area seems as the upper limit in maximizing the number of set fruits of this crop.

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