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Planting density and number of stems for ecological crop determinate growth tomato

Denise de Souza Martins[1*], Maristela Watthier[2], José Ernani Schwengber[3], Diego Rosa da Silva[3], Ryan Noremberg Schubert[3] and Roberta Marins Nogueira Peil[4]

[1]Programa de Pós-graduação em Produção Agrícola Familiar - UFPel, P. O. Box 354, ZIP Code 96010-900 Pelotas, RS, Brazil.
[2]Departamento de Fitotecnia - UFV, Campus Universitário, ZIP Code 36570 900, Viçosa, MG, Brasil.
[3]Embrapa Clima Temperado, Estação Experimental Cascata, BR 392, Km 78, P. O. Box 403, ZIP Code 96010-971, Pelotas, RS, Brazil.
[4]Departamento de Fitotecnia, Faculdade de Agronomia Eliseu Maciel - UFPel, P. O. Box 354, ZIP Code 96010-900, Pelotas, RS, Brazil.

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Tomato growers adopting an ecologically based system have opted for determinate growth varieties due to their ease of staking and sprouting, and due to the fact that they have a shorter cycle, which reduces phytosanitary problems that usually occur towards the end of the growing season. This study aimed to evaluate yield components and fruit quality of 'Floradade' determinate growth tomato in an ecologically based production system with regard to plant density and number of stems per plant in two growing seasons, spring-summer (SS) and summer-fall (SF). Two experiments were conducted in Pelotas in the years 2010/2011 under open field conditions. Plants were trained with two or four stems and four plant densities were evaluated: 2.0; 2.5; 3.0 and 3.6 plants m^{-2} in SS, and 1.5; 2.0; 2.5 and 3.0 plants m^{-2} in SF. The fruit number, fruit average weight, fruit yield, ascorbic acid content, total soluble solids and fruit pH were evaluated. The average fruit yield obtained in SF was on average 80% lower than that in SS. The increase of plant density and number of stems per plant led to an increase in fruit number and fruit yield in the two crop seasons. There was an increase in total soluble solids and reduction in the ascorbic acid content of the fruit. Two stems per plant and plant density of 3.0 plants m^{-2} are recommended for the 'Floradade' tomato crop under an ecological production system and SS crop conditions.

Key words: *Solanum lycopersicum*, organic production, crop management, crop season.

INTRODUCTION

The growth of tomatoes can be a diversification strategy for family farms, as it allows high economic yield, especially when produced in ecologically-based systems. The use of open pollinated varieties in these systems allows farmers to select and produce their own seeds (Vizcayno et al., 2014).

In the State of Rio Grande do Sul, Brazil, two tomato crops are grown every year in the spring-summer (SS) and summer-fall (SF) seasons. In the SS season, there is growing availability of solar radiation and increasing air temperature averages; in the SF season, the opposite occurs (Pereira et al., 2002).

In addition to environmental factors and genetic characteristics of tomato varieties, other factors associated with plant management, such as planting density, may interfere with tomato growth and yield. Fruit yield is determined by a combination of number and average fruit mass components, whose association results in the total production per plant (Rocha et al., 2010). As these components are associated with planting density, they define the yield per area unit, which is a consequence of the balance between vegetative growth (source) and generative growth (drainage) for a given photoassimilate supply.

The appropriate balance between photoassimilate supply and demand can be obtained through a good source/drainage ratio, which is connected with the appropriate potential fruit load per area unit (Peil and Galvez, 2005). This adjustment should be made by varying planting density and number of stems per plant in accordance with available solar radiation and soil fertility.

The correct planting density choice provides greater efficiency in the interception and use of solar radiation on the canopy and, consequently, higher yield per area. However, higher planting density decreases average fruit mass (Candian et al., 2017), as it reduces solar radiation penetration in the canopy. Thus, lower planting densities would provide an increase in photoassimilate production in the plant, resulting in greater fruit number and size.

Planting density can also affect the ascorbic acid and soluble solid contents of the tomato (Borraz et al., 1991). The recommended ascorbic acid content is 23 mg/100 g of pulp (Crawford, 1996), but values between 10 and 30 mg/100 g of ascorbic acid in fresh fruit have been found (Davies and Hobson, 1981). For soluble solids, the average is 4.5° Brix. However, soluble solid content is inversely proportional to tomato production (Agbna et al., 2017).

Tomato growers adopting an ecologically based system have opted for determinate growth varieties due to their ease of staking and sprouting, and due to the fact that they have a shorter cycle, which reduces phytosanitary problems that usually occur towards the end of the growing season. However, there are few studies available aiming at the analysis of plant density management and the number of determinate growth tomato stems in ecologically based production systems.

This study aimed to evaluate yield components and the fruit quality of Floradade determinate growth tomato with regard to planting density and number of stems per plant in an ecologically based production system.

MATERIALS AND METHODS

Two experiments were conducted at *Embrapa Clima Temperado / Estação Experimental Cascata* (latitude 31º37'S, longitude 52º31'W and altitude 181 m), located in the municipality of Pelotas, Rio Grande do Sul State, Brazil. Field cultivation was carried out using the determinate growth habit Floradade® (Feltrin) variety which bears persimmon-shaped fruit, with fruits of very attractive physical and organoleptic characteristics, possessing determined growth habits and it is indicated for organic crops in Rio Grande do Sul for resistance to fungus and insect attack.

Seedlings were grown in expanded polystyrene trays (128 cells) filled with Germina Plant® commercial substrate. Sowing was done on September 17, 2010 for the spring-summer (SS) cycle and transplanting to the field at 32 DAS (days after sowing). Sowing for the summer-fall (SF) crop was carried out on December 17, 2010 and seedling transplant to the field was performed 27 DAS. The culture cycle was 111 days for the SS crop, and 81 days for the SF counting from transplant.

The incident global solar radiation and air temperature were obtained by an automatic agro-climatic station located in a meteorological shelter close to the experiment location.

The local soil was the Acrisol type (Embrapa, 2006), having been ecologically managed for ten years, showing the following chemical and physical characteristics: pH water = 5.5; Ca = 2.6 $cmol_c\ dm^{-3}$; Mg = 0.9 $cmol_c\ dm^{-3}$; exchangeable H + Al = 3.5 $cmol_c\ dm^{-3}$; Base saturation = 52%; SMP index = 6.2; Organic matter = 1.9%; Clay = 25%; P (Mehlich) = 11.9 mg dm^{-3}; $CTC_{pH\ 7.0}$ = 7.3 $cmol_c\ dm^{-3}$ and K = 119 mg dm^{-3} in the SS cycle experimental area; and water pH = 5.5; Ca = 2.3 $cmol_c\ d^{-3;}$ Mg = 1 $cmol_c\ dm^{-3}$; exchangeable H + Al = 3.5 $cmol_c\ dm^{-3}$; Base saturation = 51%; SMP index = 6.2; Organic matter = 1.9%; Clay = 24%; P (Mehlich) = 20.2 mg dm^{-3}; $CTC_{pH\ 7.0}$ = 7.1 $cmol^c\ dm^{-3}$ and K = 121 mg dm^{-3} in the SF cycle experimental area.

Soil correction based on chemical analysis was performed in its entirety prior to transplant using 28 g limestone, 5 kg earthworm humus, 5 kg avian bed, 14 g natural phosphate, 10 g bone meal and 3 g boron micronutrient (Borax) per linear meter. Drip irrigation was used.

The plants were staked vertically with bamboo from 30 days after transplant (DAT) onwards by using the so-called "Mexican" system (Wamser et al., 2007), in which all shoots below the first inflorescence are removed. Pest and disease control were carried out by means of curative and preventive methods with the application of Bordeaux mixture and lime sulfur spray, *Bacillus thuringiensis* based products, the use of yellow and blue adhesive baits, light trap, attraction pheromones for the tomato moth (*Tuta absoluta*) and the release of butterfly egg parasitoids (*Trichogramma pretiosum*). Manual weeding was performed for spontaneous plant control.

The plants were conducted with two or four stems. After the first inflorescence, the development of a lateral stem or three lateral stems was allowed, thus maintaining two stems or four stems per plant. All other stems and shoots were removed.

Four planting densities were also evaluated: 2.0. 2.5. 3.0 and 3.6 plants m^{-2} in the SS experiment, corresponding to 0.50. 0.40. 0.33 and 0.28 m plant spacings; and 1.5. 2.0. 2.5 and 3.0 plants m^{-2} in the SF experiment, corresponding to 0.65. 0.50. 0.40 and 0.33 m plant spacing in the planting row. Spacing between rows as 1 m.

Thus, the experiments had a factorial design (2×4), with treatments resulting from the combination of levels of two factors: number of stems per plant and planting density. The experiment had a randomized block design, with three replications. Each block consisted of three cultivation rows, and only the central row was considered useful for evaluation. Each experimental plot included

*Corresponding author. E-mail: denisedesouzamartins@gmail.com.

51 plants.

Five plants per experimental plot were selected for data collection. The harvest started on 68 DAT for the SS crop and 62 DAT for the SF crop, and was performed once a week until the end of the cycle, when ripening and fully ripened fruit were collected (Ceagesp, 2003). Next, counting, fresh mass (FM) determination and fruit categorization were carried out (Ceagesp, 2003). Fruit with mild or severe defects were considered non-marketable. The analyzed variables were number of fruit, average mass and total production (commercial and non-commercial) by area.

A sample of eight fully ripened tomatoes was randomly collected from each treatment in the middle of the productive period for chemical analysis in the Food Technology Laboratory of Embrapa Clima Temperado, and three technical analyzes of ascorbic acid (official 967 method), soluble solid total (refractometry) and pH (digital parameter) were performed.

The results were submitted to analysis of variance and tests of hypotheses by means of factorial analysis, aiming to obtain main effects of factors involved and their interaction. Levels of the number of stems factor were interpreted by comparison of means by the Fisher's Least Significant Difference (LSD) test at a 5% error probability and the plant density factor by means of regression analysis.

RESULTS

The solar radiation, relative humidity and temperature obtained during the experiment are shown in Figure 1. There was no interaction between the number of stems and planting density for most response variables in both crop cycles (p>0.05). Results referring to the isolated effects of factors are shown in Tables 1 and 2 and Figure 2. Results concerning response variables in which there was interaction between factors are shown in Figure 3.

For both crop cycles, the number of commercial fruit produced by area as well as commercial productivity increased proportionally to planting density as a consequence of the higher number of plants per area unit (Figures 2a and 2b). It was also observed that fruit yield was very similar in higher densities in the SS cycle (3.0 and 3.6 plants per m^{-2}), 101.2 and 101.0 t ha^{-1}, respectively. In the SF cycle, the increase from 2.5 to 3.0 plants m^{-2} led to a 22% increase in productivity, from 18.6 to 22.8 t ha^{-1} (Figure 2b). Yields obtained in the SF crop cycle were on average 80% lower than those obtained in SS cultivation - below 25 t ha^{-1}, being considered low. Nevertheless, during the latter period the farmer is able to market the product at much higher prices, which compensates low productivity financially-wise.

The number of stems per plant affected the number of fruit and crop productivity in the SS cycle; this effect, however, was not observed in the SF cultivation. The plants with four stems showed higher fruit number and higher commercial fruit yield than those with two stems in the SS cycle (Table 1).

In the SS crop, there were more non-commercial fruits per area in four-stemmed plants (Table 1). There was interaction between factors for the ascorbic acid (AA) content variable in the SS fruit crop (Figure 3a). In two-stemmed plants, the increase in planting density proportionally decreased the AA fruit content. In four-stemmed plants, the AA content responded to the increase in crop density in a quadratic way, with higher initial values for the 2.0 plant m^{-2} density. Upon comparing the number of stems within the same planting densities in the SS cycle, it was noticed that the increase in the number of stems per plant caused a decrease in the fruit AA content (Figure 3a). In the SF cycle, planting density and number of stems per plant did not affect the fruit AA content, with an average of 19.8 mg/100 ml of fruit pulp.

Increased planting density in the SS crop affected the soluble solids (SS) content in the fruit quadratically, with maximum values of 4.75 and 4.70, respectively, at 3.0 and 3.6 m^{-2} plant densities (Figure 3b). The SS content was also higher when there was a lower number of stems per plant (Table 2), and when there was higher plant density and productivity (Figure 2b) in the SS cycle.

There was an inverse relation between the AA and SS content in fruit in the SS crop (Figures 3a and b). Fruit acidity (pH) was not influenced by experimental factors, showing an average of 4.3 in both crop cycles. The pH values found in this study were similar to those found in an organic production system (Carvalho et al., 2017; Candian et al., 2017), and within a range that is thought to be desirable for *in natura* tomato consumption, with values higher than 3.7. As a rule, overly acidic tomatoes are rejected by consumers (Borguini and Silva, 2007).

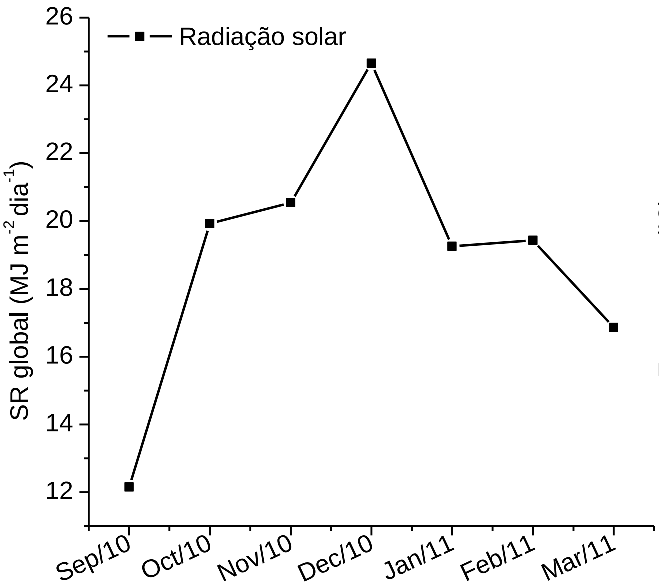
In the SS crop, for plants with two stems, the increase in planting density did not affect the average fruit mass, which remained at 222.94 g $fruit^{-1}$ (Figure 3c). There was a linear fruit average mass reduction as planting density increased with reference to four-stemmed plants in SS crop (Figure 3c).

In the SF crop, neither factor affected the average fruit mass, showing an average of 139.7 g $fruit^{-1}$. In this experiment, the low radiation availability prevented the occurrence of differences between treatments. The average fruit mass in the SF cycle was much lower than that for the salad-type fruit, which is at least 250 g, that is, 90 g below the lowest value.

DISCUSSION

The higher fruit yield in higher planting density treatments occurred due to the greater interception of photosynthetically active light and, consequently, greater canopy photosynthesis, leading to a higher production of photoassimilates that were made available for the growth of the fruit (Jiang et al., 2017).

The productivity obtained in the SS crop - between 82 and 101 t ha^{-1} - can be considered excellent, since it is similar to that obtained by indeterminate hybrids in conventional crop (Mueller et al., 2013; Heine et al., 2015). Also, it exceeds the national average productivity of the fruit, which is 60 t ha^{-1} (IBGE, 2012). Yields obtained in SF cultivation were on average 80% lower



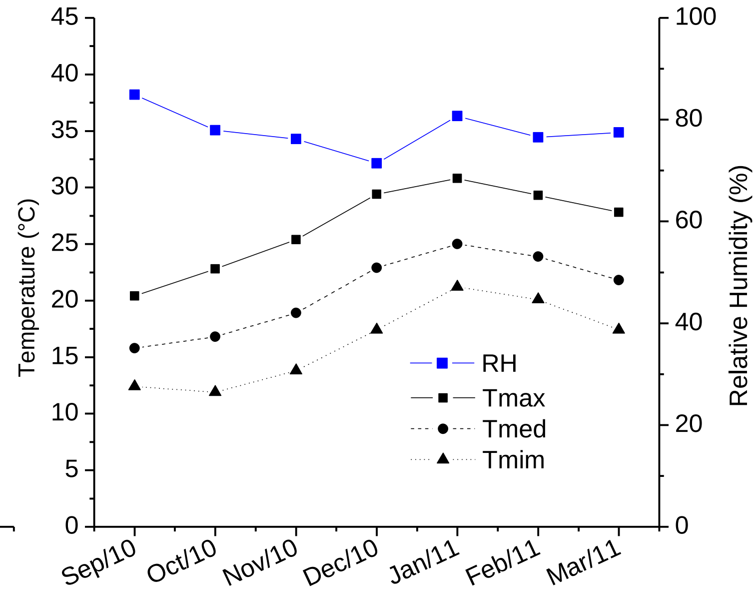


Figure 1. Solar radiation (SR), relative humidity (%) and maximum, medium and minimum air temperature throughout crop cycles.

Table 1. Number of fruits (NF) and commercial (COM) and non-commercial (NCOM) yield of tomato 'Floradade' in two crop seasons as a function of number of stems per plant in ecological production system.

Stems/plant	Spring-summer2010/2011				Summer-fall2011			
	NF m^{-2}		Yield (t ha^{-1})		NF m^{-2}		Yield (t ha^{-1})	
	COM	NCOM	COM	NCOM	COM	NCOM	COM	NCOM
02	39.8^{b}*	2.8^{b}	88.7^{b}	4.1^{ns}	12.4^{ns}	3.1^{ns}	18.7^{ns}	2.5^{ns}
04	46.2^{a}	5.2a	99.1^{a}	6.4	11.1	3.8	17.1	3.7
CV (%)	11.0	24.8	11.6	24.3	32.8	24.0	26.0	23.2

*Means followed by the same letter per column do not differ by Fisher's LSD test (p<0.05), ns, not significant.

Table 2. Soluble solids (as 0Brix) of tomato 'Floradade' fruits in two crop seasons as a function of number of shoots per plant in ecological production system.

Stems/plant	Spring-summer (2010/2011)	Summer-fall (2011)
02	4.63^{a}	4.0^{ns}
04	4.43^{b}	4.1
CV (%)	2.77	6.8

*Means followed by the same letter per column do not differ by Fisher's LSD test (p<0.05), ns, not significant.

than those obtained in SS - below 25 t ha^{-1} - being considered low. However, during this period the farmer is able to market the product at higher prices, which compensates low productivity financially-wise.

The highest fruit production in the SS cycle was due to a greater solar radiation accumulation, since the global solar radiation flux in this period totaled 2333 MJ m^{-2}, whereas in SF it was only 1368 MJ m^{-2}. In addition, in the SS period, there is a growing evolution of available solar radiation, which increases considerably along this crop cycle under Rio Grande do Sul State climatic conditions. Taking into consideration healthy plants having an adequate supply of water and nutrients, liquid photosynthesis and phytomass production are proportional to the amount of radiation absorbed by the canopy, (Monteith, 1972) increasing production (Hachmann et al., 2014). On the other hand, in the SF period, solar radiation decreases along the culture cycle; also, the high temperatures at the beginning of the cycle have a negative impact on the number of flowers per

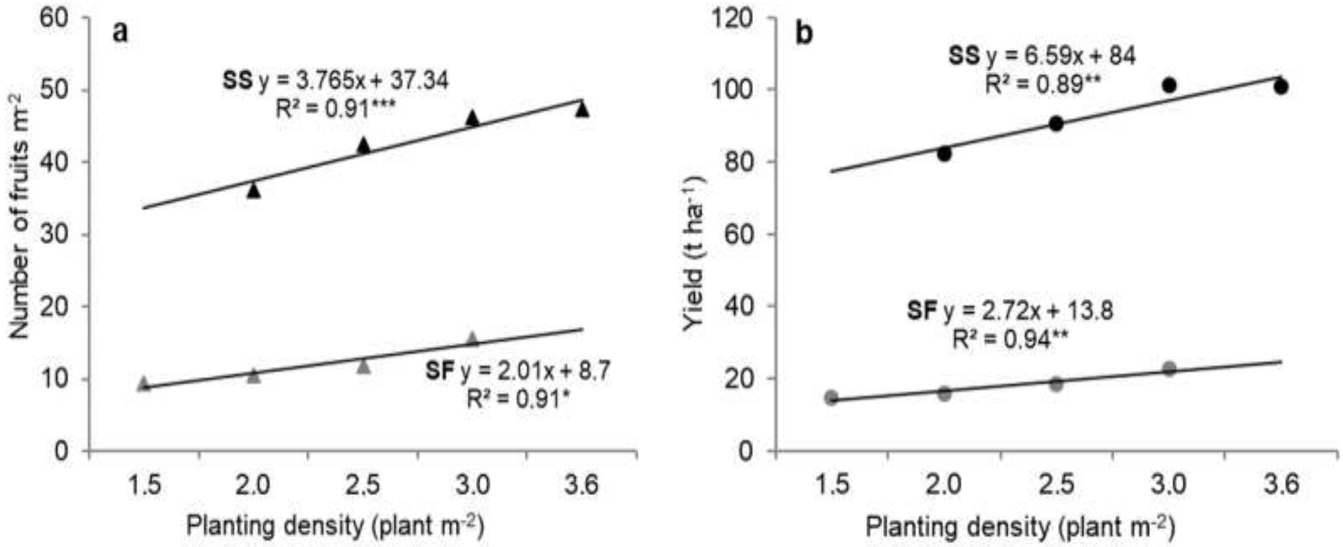


Figure 2. Number of fruits (a) and commercial yield (b) of tomato Floradade in Spring-summer (SS) and Summer-fall (SF) crop seasons and ecological production system.

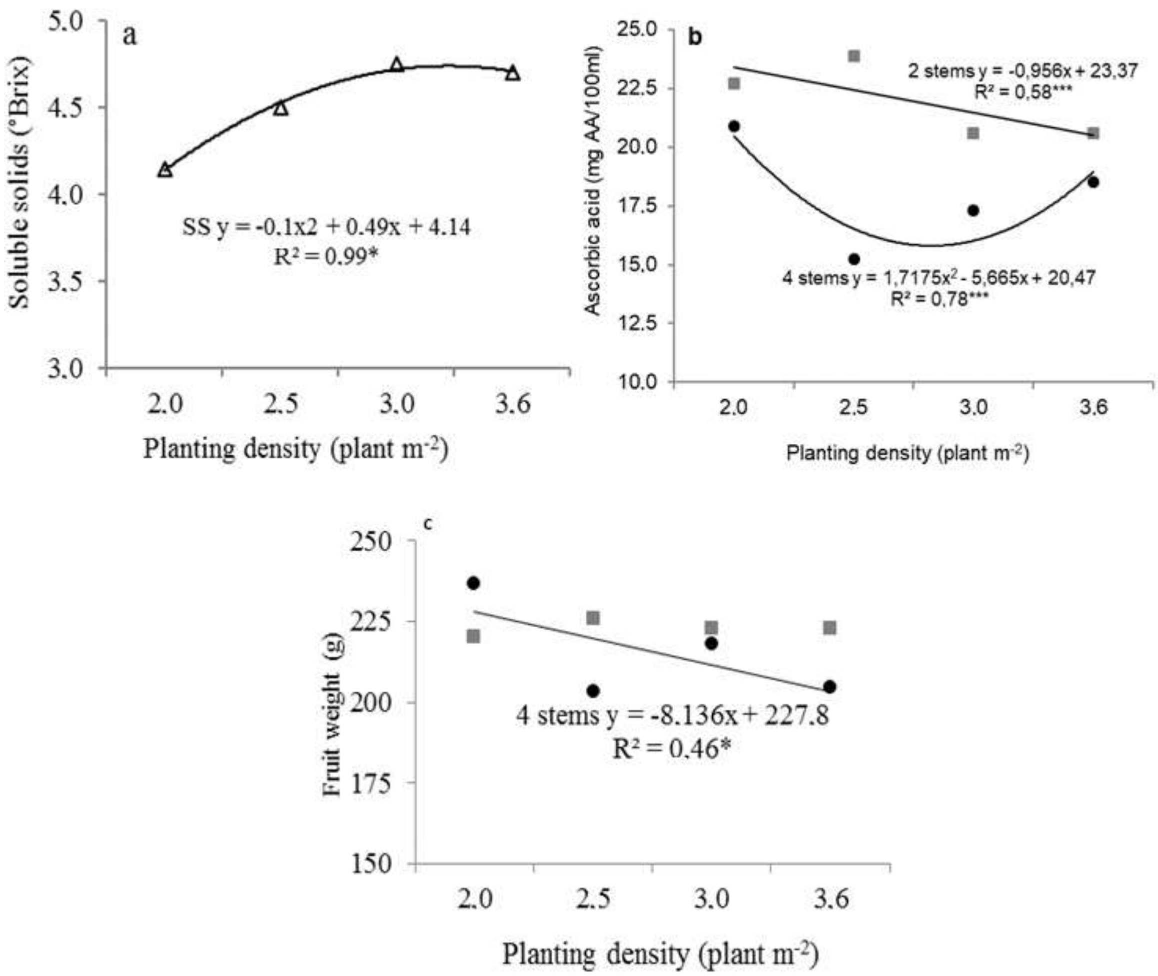


Figure 3. Soluble solids (a), ascorbic acid (b), and fruit weight (c) of tomato Floradade in Spring-summer crop season as a function of plant density and number of shoots per plant in ecological production system.

raceme.

In agreement with this information, it was observed that the plant leaf area index (LAI) in the SF period was 50% lower than that in the SS cultivation, when the same planting densities and number of stems per plant (2.47 for the SS cultivation and 1.21 for the SF cultivation) are compared. As light interception is an important plant productivity determinant, when the leaf area is reduced, there is solar radiation interception reduction and photoassimilate production which, together with the lower solar radiation of the period, contribute to reduced summer-fall cycle productivity. Furthermore, an aggravating factor in the SF cultivation was the late blight (*Phytophthora infestans*) occurrence in the plants at the end of the cycle, which caused fast plant leaf area loss. Lower LAI values for SF cultivation as compared to SS cultivation were found for this same variety under Rio Grande do Sul State conditions (Radin et al., 2003).

The number of stems did not affect the number of fruit and productivity of the tomato plant in the SF cycle due to the low solar radiation available and the great competition for photoassimilates between the stems under this condition, which resulted in a lower fruit fixation index. Therefore, there was four-stemmed plant superiority in relation to two-stemmed ones.

The higher number of fruit and higher yield per area with higher planting densities and the increase in the number of stems in the SS cultivation cycle are possibly related to an increase in LAI (on average 3.08 for a 3.6 m^{-2} plant density and 2.93 for 4 stemmed plants) and, consequently, a greater canopy efficiency at interception (Heuvelink, 1995; Papadopoulos and Pararajasingham, 1997) and the use of the abundant solar radiation available in the SS period. Candian et al. (2017) and Charlo et al. (2009) also found a higher number of fruit when the plants had a greater number of stems.

For both crop cycles, the density factor had no significant effect on the number of non-commercial fruit per area, 4.0 and 3.5 m^{-2} fruit on average in the SS and SF crops, respectively. Thus, there were no significant differences in fruit yield, with an average of 5.25 and 3.12 t ha^{-1} for the SS and SF crops, respectively.

The higher number of non-commercial fruit in four-stemmed plants was due to corn-earworm (*Helicoverpa zea*) and tomato pinworm (*Neoleucinodes elegantalis*) attack, in addition to soft rot occurrence. This bacterium (*Erwinia* sp) penetrates through wounds caused by insects that perforate the fruit. The greater damage by fruit borer caterpillars in four-stemmed plants may be related to the greater difficulty of natural enemies, such as egg parasitoids and *B. thuringiensis* applications, in reaching the target, due to a greater stem density per area.

Fruit of four-stemmed plants showed AA levels below 23 mg/100 ml, believed to be the minimum value of this acid in the fruit, whereas fruit of two stemmed plants showed AA levels above 20 mg/100 ml pulp, which was close to ideal levels (Crawford, 1996). A higher two-stemmed plant density, in spite of increasing light interception and the canopy photosynthetic rate, also reduces the penetration of light inside, decreasing the plant individual photosynthetic rate and, consequently, the ascorbic acid biosynthesis.

The total soluble solids content determines fruit taste, which is an important index for commercial tomato quality analysis (Jiang et al., 2017). The higher soluble solids content with higher planting density and the increase in productivity were due to the fact that the photosynthetic activity increase in the total plant set can be a way of obtaining high productivity without negatively affecting fruit quality, since a direct relation between fruit yield and soluble solids content is obtained (Guimarães et al., 2007). However, this is not in agreement with the results obtained by Agbna et al. (2017), who found that the soluble solid content and ascorbic acid is inversely proportional to tomato productivity under irrigation.

For both soluble solids (Figure 2b) and productivity (Figure 1b) variables, there were no numerical gains as the population increased from 3.0 to 3.6 plants m^{-2} in the SS cycle. In addition, one must consider the greater handling difficulty and the additional demand for labor as a consequence of a greater number of plants per cultivated area unit.

In both higher and lower plant density four-stemmed plants, there was an increase in ascorbic acid (Figure 1b). This can be attributed to stress caused by competition between plants in high densities and protection against UV radiation at low densities (Taiz et al., 2017). Previous research on the relationship between light irradiation and fruit ascorbic acid content has shown that ascorbate synthesis and metabolism in fruit are significantly affected by fruit irradiation in addition to leaf irradiation (Gautier et al., 2009).

The average fruit mass decrease in higher planting density four-stemmed plants can be attributed to the lower penetration of solar radiation in the canopy, the greater competition between plants for water and nutrients and, consequently, the lower production of photoassimilates, thus decreasing the average fruit mass (Wamser et al., 2009; Wamser et al., 2012). In the SS cycle, because of the high solar radiation availability, the average fruit mass was not altered for two-stemmed plants, even when planting density increased. This indicates that with two stems per plant, the increase in planting density did not affect the penetration of solar radiation in the canopy, without affecting fruit growth. The results of this study show that variations in plant and stem density per area alter solar radiation penetration in the canopy.

Conclusions

1. The yield components and chemical characteristics of

the tomato depend on the growing season for both planting density and the number of stems per plant.
2. In the spring-summer crop, the density of 3.0 plants m^{-2} with two stems per plant is recommended for 'Floradade' tomato in an ecologically based production system.
3. For summer-fall cycle crops, new studies should be carried out, testing other population arrangements and crop productive x economic feasibility under field conditions.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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