Development and fruit yield of strawberry plants as affected by crown diameter and plantlet growing period

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Abstract – The objective of this work was to evaluate the influence of crown diameter and growing period of runner tips in 128 cell-trays on growth and yield of strawberry in the field. Treatments consisted of three classes of runner tip crown diameters, between 2.0 to 3.9 mm; 4.0 to 5.5 mm and 5.6 to 7.0 mm, respectively, and four growing periods in trays, 24; 39; 54 and 69 days, respectively. Higher shoot dry mass of transplants at planting and earlier yield of plants in the field were obtained in transplants grown for 69 days in trays. Larger runner tips lead to more vigorous transplants at planting and plants with higher vegetative growth in the field, with minor impact on yield. Increasing the growing time of runner tips in trays improved early fruit yield and decreased plant vegetative growth in the field.

Index terms: *Fragaria x ananassa*, early yield, propagation, plug plants.

Desenvolvimento e produtividade do morangueiro influenciados pelo diâmetro da coroa e período de crescimento de mudas

Resumo – O objetivo deste trabalho foi avaliar a influência do diâmetro das pontas de estolão e do seu período de crescimento em bandejas sobre o crescimento da planta e produtividade do morangueiro Arazá. Os tratamentos consistiram em três classes de diâmetro das pontas de estolão: entre 2,0 e 3,9 mm; 4,0 e 5,5 mm e 5,6 e 7,0 mm, e quatro períodos de crescimento nas bandejas: 24; 39; 54 e 69 dias. Maior massa seca vegetativa das mudas no plantio e maior produção precoce das plantas foram obtidas com mudas que cresceram 69 dias nas bandejas. Pontas de estolão de maior diâmetro originaram mudas mais vigorosas no plantio e plantas com maior crescimento vegetativo no campo, sem efeito na produtividade de frutas. O aumento do período de crescimento das mudas nas bandejas aumentou a produção precoce de frutas e diminuiu o crescimento vegetativo das plantas no campo.

Termos para indexação: *Fragaria x ananassa*, precocidade, propagação, muda com torrão.

Introduction

In the propagation of strawberry plants, explants are harvested from a clonal garden and multiplied in vitro for several generations. After acclimatization, they are planted as stock plants for vegetative growth, emission of stolons and production of transplants. That later step is critical, since yield of the crop depends on the quality of the transplants.

Bare root is the traditional production method of strawberry transplants. It causes mechanical damage to the root system at planting and high risk of contamination by pathogens. As a consequence, several plants die in the first week after planting and vegetative growth is slow, delaying the onset of fruiting and reducing fruit yield and quality (Durner et al., 2002).

An alternative method for the production of strawberry transplants is that known as plug plants. In this method, runner tips are collected from stock plants at the emission of the first root primordia and rooted in trays with substrate. They are later shipped for sale with roots coated in the substrate, thus eliminating most of the disadvantages of bare root transplants. Plug transplants reach the conditions reported by Latimer (1998) for quality of transplant production in nurseries: 1) they withstand the stress of handling, transportation and transplanting, 2) they adapt quickly to the field environment, 3) they establish and resume active growth soon after transplanting, and 4) they produce acceptable yield without reduction or delay compared to other establishment methods. As to plug plants, survival after planting is enhanced and initial growth is faster, resulting in earlier (Fernandez & Ballington, 2003; Takeda & Hokanson, 2003) and higher fruit yield and quality (Hochmuth et al., 2006a, 2006b; Durner et al., 2002; Takeda & Hokanson, 2003; Giménez et al., 2009).

Strawberry yield is affected by the physiological quality of transplants. Young and vigorous transplants produce plants with higher vegetative growth and fruit yield than weak and old ones, and they also reduce management practices (Hicklenton & Reekie, 2002). A positive correlation between transplant crown diameter and total fruit yield has been reported in the literature (Faby, 1997). Large-crowned plants produced higher early season yield than small-crowned plants (Albregts, 1968; Durner et al., 2002). The main variable that has been used to identify the quality of strawberry transplants is the crown diameter, which must be over 8 mm (Durner et al., 2002).

The time that plug transplants remain in trays may affect their growth and development. The period must be long enough for the emission of new roots and leaves and storage of assimilates before planting in the field. On the other hand, if this period is too long, competition for radiation may occur, and root growth may be restricted by the size of the container, with reduced growth and delay in the development, affecting the survival of transplants at planting and fruit yield of plants in the field, irrespective of the crown diameter of the transplants (Bish et al., 2002; Hochmuth et al., 2006a, 2006b).

The objective of this work was to evaluate the effect of crown diameter and period of transplants in trays on growth, development and fruit yield of 'Arazá' strawberry plants in the field.

Materials and Methods

The experiment was carried out in 2009 at Departamento de Fitotecnia, Universidade Federal de Santa Maria, Santa Maria, Rio Grande do Sul, Brazil (29º 42'S, 53º 42'W, altitude: 95 m). The climate is subtropical humid by Köppen's classification, with monthly average temperatures ranging between 3 and 22ºC and annual rainfall of about 1,769 mm (Moreno, 1961).

The strawberry cultivar used was Arazá (INIA, Uruguay). It is a short-day, intermediate vigor and early yield cultivar, derived from a cross between Uruguayan A07.04 (Oso Grande x Sweet Charlie) and C01.05 (Addie x Sweet Charlie) (Giménez et al., 2003). For the production of runner tips, explants were collected at the beginning of January of 2008, in the strawberry clonal garden. After four in vitro multiplications, they were acclimatized in a polyethylene greenhouse with 80% transmissivity, for 30 days between August, 31th and September, 30th, 2008, in a closed soilless system, using sand as substrate (Bisognin, 2007).

After acclimatization, they were transplanted as stock plants in 2.3 dm^3 polyethylene bags, filled with the organic substrate Plantmax HA and placed on top of a polyethylene film-covered-bed, 80 cm above the soil surface. The substrate bulk density was 0.405 kg dm^{-3} and the water retention capacity 0.466 L dm^{-3}. A distance of 0.27 m among rows and 0.30 m among bags was used, in a plant density of 12 plants m^{-2}. Water and nutrients were supplied daily by fertigation, using the nutrient solution adjusted by Andriolo (2007), in mmol L^{-1}: 10.6 NO_3^-; 0.43 NH_4^+; 2 H_2PO_4; 6.15 K^+; 3.0 Ca^{2+}; 1 Mg^{2+} and 1 SO_4^{2-}; and in mg L^{-1}: 0.03 Mo; 0.42 B; 0.06 Cu; 0.50 Mn; 0.22 Zn and 1.0 Fe. The pH and electrical conductivity were maintained between 5.5 and 6.5 and between 1.4 and 1.5 dS m^{-1}, respectively.

To obtain plants on different growing periods in trays, runner tips were collected from the stock plants on four dates: February 11 and 26th, March 13 and 28th, 2009, totalizing 24, 39, 54 and 69 days, respectively. They were separated by crown diameter into three classes: 2.0 to 3.9 mm (class 1); 4.0 to 5.5 mm (class 2) and 5.6 to 7.0 mm (class 3) (Durner et al., 2002). Runner tips of each class were rooted in separate 128 cell polystyrene trays filled with 62 cm^3 of the commercial substrate Plantmax HA and placed for one week in a moist chamber under sprinkler irrigation for 5 min eight times a day. Afterwards, trays were transferred to benches inside the polyethylene greenhouse, under the same conditions of sprinkler irrigation, and fertigated twice a week using the same nutrient solution as the stock plants.

Treatments were the three crown diameter classes of runner tips collected from the stock plants and four periods of transplants in trays, 24, 39, 54 and 69 days, in a 4x3 factorial randomized block design, with four replications and 16 plants per plot (2.60 m^{-2}).

Transplants of all treatments were planted in the field on April 20th, and the experiment was terminated on December 1st, 2009. Before planting, older leaves were removed. Roots longer than 10 cm were excised (Antunes & Duarte Filho, 2003). The remaining leaves were recorded, the crown diameter measured and shoot and root dry mass determined after drying at 65°C until constant mass was achieved. A sample of four plants in each treatment was used for determination.

Planting in the field was performed on 1.10 m width polyethylene mulched raised beds, with a plant density of 6.6 plants m^{-2} (0.40x0.40 m), under 0.70 m high 100 µm polyethylene tunnels. In sunny days, tunnels were opened at sunrise and closed at sunset and kept closed on cloudy or rainy days. Water and nutrients were supplied by dripping according to recommendations of Santos & Medeiros (2003).

Number of days from planting to the beginning of flowering and to the first fruit harvest were recorded when 50% of the plants in the plot had at least one flower and one ripe fruit, respectively. Ripe fruits were harvested twice a week at 100% red epidermis, identified by the phenological stage 87 (Meier et al., 1994). They were counted, weighted and screened as marketable, when the fresh mass surpassed 10 g, and unmarketable when it was below 10 g. Early fruit production was considered from the beginning of the harvest to September 30th, 2009 and total fruit production, from the beginning of the harvest to December 1st, 2009. At the end of the experiment, four plants from each treatment were removed from the soil. The crown diameter, number of crowns and number of leaves were counted and dry mass of shoot and roots was determined after drying at 65ºC until constant mass was recorded.

The fulfillment of assumptions of the mathematical model for analysis of variance was verified by the error normality test. The variable number of fruits, leaves and crowns were transformed using the expression $(x + 0.05)^{0.5}$. All variables were submitted to analysis of variance and the significance of differences among means was determined by the Tukey's test at 5% probability or polynomial regression.

Results and Discussion

No significant interactions were found between crown diameters of runner tips and growing period of transplants in trays. The number of leaves of transplants at planting was similar among runner tip crown diameter classes, with an average of 4.5 leaves per transplant (Table 1). At planting, crown diameter, shoot and root dry mass were higher on transplants from class 3 runner tips. At the end of the experiment, number of leaves, shoot and root dry mass of plants were also higher in those originated from class 3 runner tips. Number of crowns did not differ among plants originated from the three runner tip classes and the crown diameter was lower on plants from class 1 runner tips. Earlier flowering and fruit harvest were recorded on plants from class 3 runner tips ($p>0.05$).

The time the transplants spent in the trays affected growth and development (Figure 1). At planting, a positive quadratic polynomial model was fitted for the number of leaves (Figure 1 A), showing a strong increase affected by the growing period in trays. The crown diameter did not differ significantly ($p>0.05$, F test) while shoot dry mass increased linearly (Figure 1 C). The number of days from planting to the beginning of flowering and fruit harvest decreased

Table 1. Number of leaves (NL), crown diameter (CD), shoot dry mass (SDM) and root dry mass (RDM) of strawberry transplants at planting and number of leaves (NL), crown diameter (CD), number of crowns (NC), shoot dry mass (SDM) and root dry mass (RDM) of plants at the end of the experiment[(1)].

Crown class	Diameter (mm)	Planting				End of experiment				
		NL	CD (mm)	SDM (g $plant^{-1}$)	RDM (g $plant^{-1}$)	NL	CD (mm)	CN	SDM (g $plant^{-1}$)	RDM (g $plant^{-1}$)
1	2.0-3.9	4.37a	5.18b	0.42b	0.15b	31.4b	13.1b	4.2a	14.02b	2.67b
2	4.0-5.5	4.43a	5.68b	0.52b	0.16b	30.6b	15.3a	3.9a	15.14b	2.99b
3	5.5-6.9	4.87a	7.47a	0.72a	0.29a	40.8a	15.5a	4.8a	19.62a	4.30a
CV (%)		21.3	14.5	27.2	40.3	8.7	8.8	10.8	20.9	26.6
DMS		0.84	0.77	0.13	0.07	5.42	1.11	0.88	2.92	0.81

[(1)]Means followed by same letter in column do not differ by Tukey test, at 5% probability.

linearly (Figure 1 D). At the end of the experiment, the effect of the time of transplants in trays on number of leaves on the plant was weak (Figure 1 A). Crown diameter (Figure 1 B) and shoot dry mass (Figure 1 C) follow a polynomial quadratic model.

At the end of the early yield period, number of leaves and fruit yield were lower on plants originated from class 1 runner tips (Table 2). Fruit weight did not differ among treatments, with an average of 11.4 g fruit^{-1}. At the end of the experiment, number of leaves, total fruit yield and fruit mass did not differ among plants originated from all runner tip classes and means were 48.8 fruit plant^{-1}, 461.9 g plant^{-1} and 9.5 g fruit^{-1}, respectively.

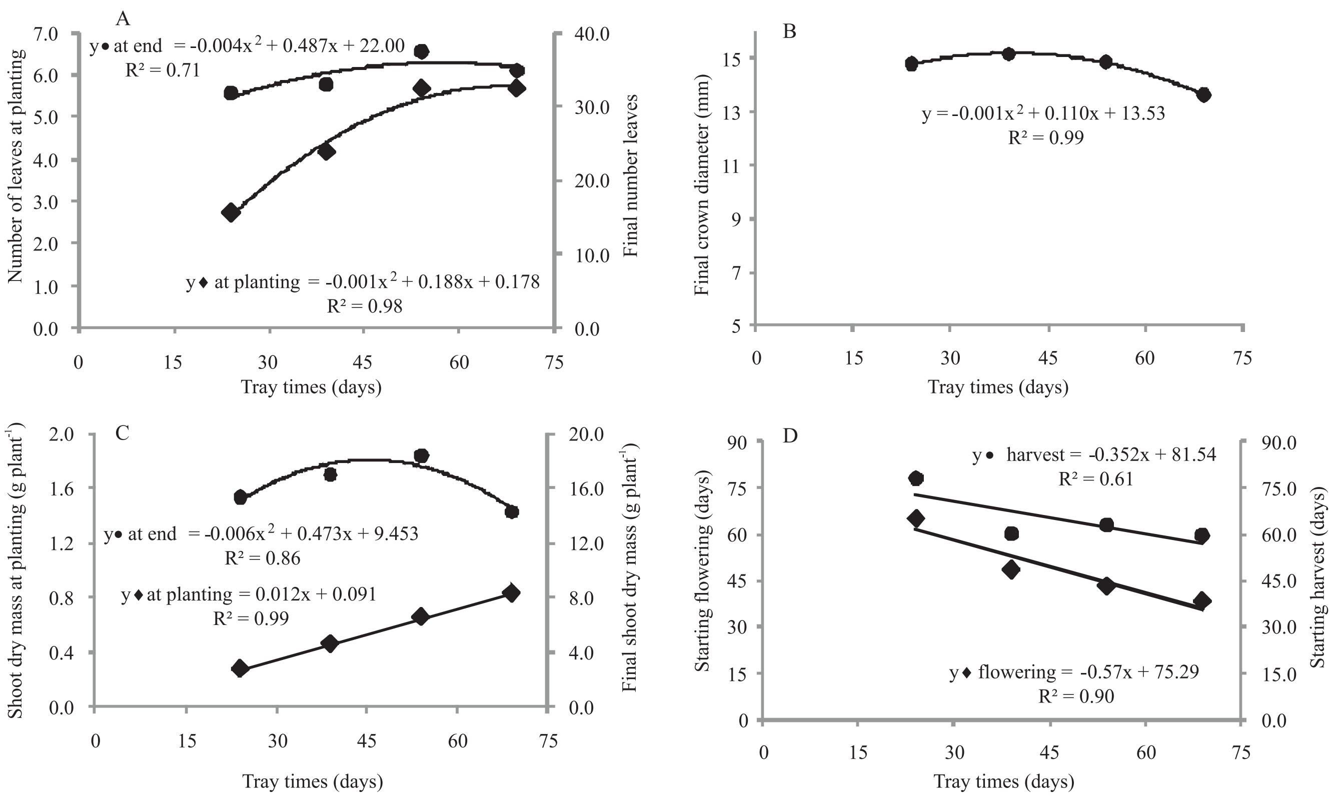

Figure 1. Number of leaves of transplants at planting and of plants at the end of the experiment (A), crown diameter of plants at the end of the experiment (B), shoot dry mass of transplants at planting and of plants at the end of the experiment (C) and number of days until onset of flowering and fruit harvest (D) on plants from 24, 39, 54 and 69 days as growing periods of transplants.

Table 2. Beginning of flowering and fruiting, number of fruits (NF), fruit yield (FY) and fruit mass (FW) in early and total yield at the end of the experiment with strawberry plants originated from three crown diameter classes of runner tips[(1)].

Crown class	Diameter	Flowering	Fruiting	Early yield			Total yield		
				NF	FY	FW	NF	FY	FW
	(mm)	(days)	(days)		(g plant^{-1})	(g fruit^{-1})		(g plant^{-1})	(g fruit^{-1})
1	2.0-3.9	57.4a	69.5a	14.3b	164.2b	11.6a	46.5a	440.0a	9.4a
2	4.0-5.5	43.4b	63.2b	17.1a	192.9ab	11.3a	48.9a	470.1a	9.6a
3	5.5-6.9	45.6b	62.8b	18.8a	208.5a	11.2a	51.0a	475.8a	9.4a
CV (%)		15.1	6.7	19.6	19.0	11.1	18.1	20.1	8.0
DMS		6.4	3.9	2.8	31.1	1.1	7.7	80.7	0.6

[(1)]Means followed by same letter in column do not differ by Tukey test, at 5% probability. Early yield, from the beginning of the harvest to September 30th; total yield, from the beginning of the harvest to December, 1st.

Number and early fruit yield were affected by the period of transplants in trays (Figure 2). Older transplants produced more fruit and higher yield of plants in the field, at a rate of 0.13 fruits day^{-1} and 1.17 g day^{-1}, respectively. A similar linear relationship was found between early fruit yield of plants in the field and shoot dry mass of transplants at planting (Figure 3).

Results show that larger runner tips (class 3) produce more vigorous transplants at planting and plants with higher vegetative growth in the field (Table 1). This is in agreement with recommendations of Durner et al. (2002) for using strawberry transplants with a crown diameter over 8 mm. Nevertheless, it is surprising that the effect of plant vigor on fruit yield was of minor importance. In fact, only the smallest runner tips (class 1) reduced early number and fruit yield of plants in the field, without any significant effect on total yield (Table 1). A hypothesis that may explain this apparent discrepancy is the indirect influence of growth on plant development. Although plant developmental stages have been associated with thermal units (Andriolo et al., 2003; Streck et al., 2005), plants have to attain a minimum size in their current development stage before going to the next one, regardless of favorable environmental conditions.

In this sense, more vigorous transplants at planting could produce and store assimilates in a shorter time, reaching the physiological conditions for flowering before less vigorous transplants. This is supported by the early flowering and fruit harvest recorded on plants from class 3 transplants. Nevertheless, this effect would be buffered onwards, as vegetative growth, flowering and fruit growth in the strawberry plant are simultaneous and indeterminate processes that continue while environmental conditions are favorable. As a consequence, the effect of transplant vigor at planting on further early yield of plants in the field becomes diluted on the scale of total yield.

The above hypothesis could also explain the effect of the time growing period in trays on number of leaves of transplants at planting and of plants in the field (Figure 1 A). More time in the trays led to higher number of leaves at planting. Nevertheless, the relationship was polynomial, as transplants at times 54 and 69 did not differ significantly by the t test ($p>0.05$). However, during these times in trays, shoot growth of transplants did not show any tendency of reduction (Figure 1 C). This implies that growth was not affected by restrictions in root growth induced by the small volume of the tray cells, as reported in the literature (Hamann & Poling, 1997).

It is possible that the lower number of leaves at time period 69 was an artifact derived from the competition for light. Theoretical models used to explain the absorption of radiation by plant canopies state that the stabilization of the leaf area index (LAI) is a consequence of senescence and death of basal leaves caused by a shut-down of the photosynthetic rate below the compensation level (Gautier et al., 2001). Thus, the number of leaves on transplants at time period 69 did not increase, while the growth of young leaves did, without reduction in shoot growth.

The time of transplants in trays only improved early fruit yield and, at the end of the experiment, lower vegetative growth was recorded on plants originated from older transplants (Figure 1 B, C). This was

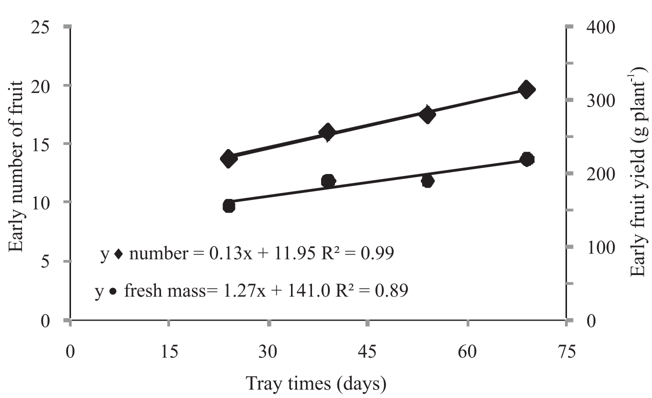

Figure 2. Relationship between early number and early fruit yield of strawberry plants and the time growing period of transplants in trays.

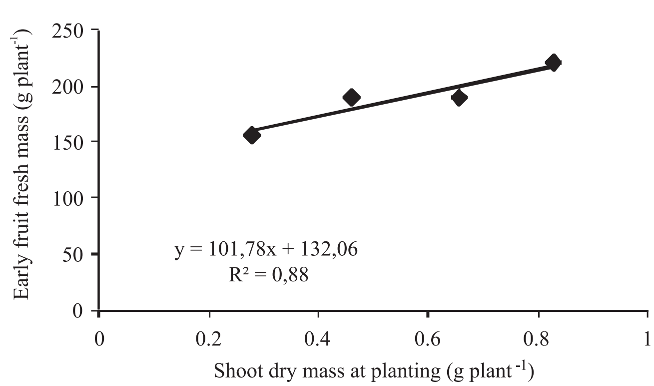

Figure 3. Relationship between early fruit yield of plants and shoot dry mass of strawberry plants and the time growing period of transplants in trays.

surprising, as higher vegetative growth and total fruit yield was expected in plants originated from these more vigorous transplants. The hormonal balance of stock plants and runner tips may be the reason. More vigorous older transplants were obtained from runner tips collected in February, under middle summer conditions, when flowering is inhibited by high temperatures and emission of stolons is stimulated by hormonal plant effects. Runner tips grown in summer possibly have some inhibitors that delay flowering and harvesting on plants in the field. Although this is supported by data in Figure 1 D, further research is necessary.

Results of this research show technological implications. Firstly, the crown diameter itself is not an efficient quality descriptor of strawberry transplants. It should be used together with other variables such as number of leaves or size of the transplant. Secondly, the environmental conditions at the time runner tips are collected should be considered. This imposes additional practical difficulties for nurseries in the commercial production of strawberry plug transplants. They search for extending the production time period of transplant production by collecting runner tips early in summer and rooting them in big tray cells or containers. In face of the present results, when this is accomplished, the inhibitory effect of high temperatures on flowering should be considered. Conditioning by artificial chilling, as in Unites States (Bish et al., 1997, 2002; Durner et al., 2002) and Europe (Faby, 1997; Lieten, 2000) for glasshouse forcing in winter, may be an alternative, but further research is needed to evaluate local conditions.

Conclusions

1. Larger runner tips lead to more vigorous strawberry transplants at planting, early yield and plants with higher vegetative growth in the field, with minor influence on fruit yield.
2. Increasing the growing time of runner tips in trays improves early fruit yield and decreases strawberry plant vegetative growth.

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