Effect of plant spacing on growth, development and yield of cassava in a subtropical environment

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Abstract

The objective of this study was to analyze the effect of different plant spacing on growth, development and stems and roots yield of cassava in a subtropical environment in Rio Grande do Sul State, Brazil. Treatments consisted of four spacings: 0.8x0.8 m, 1.0x1.0 m, 1.2x1.2 m, 1.5x1.5 m, corresponding to densities of 15,625 plants ha^{-1}, 10,000 plants ha^{-1}, 6.944,45 plants ha^{-1} and 4.444,45 plants ha^{-1}, respectively. The cultivar used was Fepagro – RS 13. The variables of growth and development analyzed were green leaf area, plant height, number of senescent leaves, internode length, final leaf number (FLN), number of lateral shoots, final leaf size, phyllochron and stem and root fresh and dry weight yield. The maximum leaf area index and phyllochron increased as plant density increased. The final leaf size and number of lateral shoots increased as plant density decreased. FLN differed only for the second sympodial branching, with the highest number of leaves at the 1.5x1.5m plant spacing. Stem yield of the cultivar Fepagro – RS 13 does not change with plant spacing, but tuber root yield per area is higher at higher densities, while yield per plant and per root is higher at lower densities.

Key words: *Manihot esculenta Crantz*, plant density, phyllochron, LAI.

Efeito do espaçamento de plantio no crescimento, desenvolvimento e produtividade da mandioca em ambiente subtropical

Resumo

O objetivo neste trabalho foi analisar o efeito de diferentes espaçamentos de plantio no crescimento, desenvolvimento e produtividade de hastes e raízes comerciais de mandioca cultivada em ambiente subtropical no Rio Grande do Sul, Brasil. Os tratamentos foram em quatro espaçamentos: 0,8x0,8 m; 1,0x1,0 m; 1,2x1,2 m e 1,5x1,5 m, que correspondem às densidades 15.625 plantas ha^{-1}, 10.000 plantas ha^{-1}, 6.944,45 plantas ha^{-1} e 4.444,45 plantas ha^{-1}, respectivamente. A cultivar usada foi a Fepagro – RS 13. As variáveis de crescimento e desenvolvimento analisadas foram área foliar verde, altura das plantas, número de folhas senescidas, comprimento de entrenó, número final de folhas (NFF), número de brotações laterais, tamanho final de folhas, filocrono e produtividade de haste e raiz em massa fresca e seca. O índice de área foliar máximo e o filocrono aumentam à medida que aumenta a densidade de plantio. O tamanho final de folha e o número de brotações laterais aumentaram à medida que diminuiu a densidade de plantio. O NFF diferiu apenas na segunda ramificação simpodial (RS2), com maior número de folhas nas plantas espaçadas a 1,5x1,5 m. A produtividade de hastes na cultivar Fepagro – RS 13 não varia com o espaçamento de plantio, mas a produtividade de raízes por área é maior nas densidades maiores, enquanto que a produtividade por planta e por raiz comercial é maior nas densidades menores.

Palavras-chave: *Manihot esculenta* Crantz, densidade de plantas, filocrono, IAF.

1. INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a perennial plant, but commercially the crop cycle may range from 6 to 24 months depending on the conditions of the growing region (Alves, 2006). Brazil is the second largest producer, behind Nigeria (FAO, 2014). In 2012, 23,044.557 t of roots were harvested in an area of 1,692.986 ha, with an average yield of 13.612 t ha^{-1}, and in the Rio Grande do Sul State average yield is 15.097 t ha^{-1} (IBGE, 2014), quite below the cassava

potential yield which is 25-60 t ha^{-1} (Cock, 1990). In experiments, yields reached 33-35 t ha^{-1} in Rio Grande do Sul State (Fagundes et al., 2009; Schons et al., 2009).

The cassava crop in the state of Rio Grande do Sul has great importance in family livelihood, given the good performance due to its plasticity and adaptability to low fertile soils (Fagundes et al., 2010; Lago et al., 2011). Besides the use of roots for food and feed, shoots of cassava can be used for feeding animals as fresh feed or

as hay and silage (Furlan et al., 2010). Apart from the use of edible tuber roots for food, cassava is also grown with industrial purpose; in Brazil, it represents raw material for various industries including food (starch mills), textile, alcohol, pharmaceutical, paper and cardboard industries (Cardoso et al., 2006).

Most studies in the literature have quantified the effect of plant on the production of tuberous roots (Aguiar et al., 2011; Cock et al., 1977), but are lacking studies, especially in subtropical regions such as the Rio Grande do Sul State, investigating the effect of different spacing on growth and development, which are determinants of root yield in cassava. Such studies are also important, for example, to provide data of growth and development to validate dynamic mechanistic models such as the GUMCAS model (Gabriel et al., 2014; Matthews and Hunt, 1994). Examples of growth variables include leaf area and plant height whereas of development variables, the cumulative number of leaves per stem and the phyllochron, defined as the time interval for the appearance of successive leaves on a stem (Schons et al., 2007; Wilhelm and McMaster, 1995).

In this context, this study analyzed the effect of different plant spacing on growth, development and yield of stems and roots of commercial cassava grown in a subtropical environment in Rio Grande do Sul State (RS), Brazil.

2. MATERIAL AND METHODS

The experiment was conducted during the 2009/2010 growing season in Santa Maria, RS, Brazil (29°43'S, 53°43'W, 95 m). The climate is Cfa according to Köppen system, i.e., subtropical humid with hot summers and no dry season (Kuinchtner and Buriol, 2001). The soil is classified as Rhodic Paleudalf – Argissolo Bruno Acinzentado alítico típico (EMBRAPA, 2006). The cassava cultivar used was Fepagro - RS 13, a genotype suitable for forage and tuberous roots production, adapted and widely grown in Rio Grande do Sul State (Lago et al., 2011).

The treatments consisted of four equidistant spacing between rows and between plants: 0.8x0.8 m; 1.0x1.0 m; 1.2x1.2m and 1.5x1.5 m, corresponding to densities of 15,625 plants ha^{-1}, 10,000 plants ha^{-1}, 6,944.45 plants ha^{-1} and 4,444.45 plants ha^{-1}, respectively. Each plot consisted of five rows with eight plants per row, totaling 40 plants per plot. The experiment was a randomized block design with five replications.

The fertilization was performed according to technical indications for cassava crops (SBCS and CQFS, 2004). The planting was performed on 24 September 2009 in 0.20 m deep pits, using vegetative propagules (cuttings) with 0.20 m in length. Rainfall was the only source of water for the crop during the development cycle, that is, there is no

supplemental irrigation. Weeds were controlled by hand weeding to avoid interference by interspecific competition.

The crop emergence was on 24 October 2009 when 50% of plants in each plot were visible above the ground. Six plants per plot were randomly selected and tagged with colored wires. On the main stem (MS), and on a first sympodial branching stem (SB1) and on a second sympodial branching stem (SB2) of the selected plants, we determined the following development variables: the cumulative number of leaves (CNL) once a week, final number of leaves (FLN) and the date of each sympodial branching. The criterion for considering a leaf as visible was when at least one of the lobes of the leaf was open (Schons et al., 2009). In the six marked plants, we measured plant height (distance from ground level to the highest meristematic apex) every 15 days. In one plant per plot, also in a 15 day-interval, we measured the length of the longest lobe of all the leaves of the plant, except for the lateral shoots. The internode length was estimated by the plant height:CNL ratio.

Measurements of length of the largest lobe were used to estimate the individual leaf area using the equation calibrated for this cultivar, using 50 leaves: Leaf Area (cm^2) = 0.1774 (x)$^{2.4539}$; where x is the length of the largest lobe (cm); the leaf area in the stem was calculated as the sum of the area of individual leaves (Gabriel et al., 2014). For sympodial branching, we considered the leaf area of stems from the same branching as identical, multiplying the leaf area of the stem by the number of stems in each branch. The green leaf area index was obtained from the ratio between the leaf area and the ground area occupied by each plant in each plant spacing. The number of lateral shoots was counted on axillary buds on the main stem one day before harvest.

The harvesting of plants (roots and shoots) was on 9 June 2010. In the tagged plants, we determined the fresh weight (FM) and dry weight (DM) of commercial roots (RC) and of branches per area, per plant and per root, and the number of commercial roots per plant. A root was considered as commercial when had length greater than 10 cm and diameter greater than 2 cm (Schons et al., 2009)

Accumulated thermal time (STa) was calculated by the equation STa =Σ(Tm – Tb) (Schons et al., 2007), where Tm is the mean daily air temperature, calculated by the arithmetic mean between the minimum and the maximum daily temperature, measured in the Principal Climatological Station of the UFSM, and Tb is the base temperature estimated to the cultivar Fepagro –RS 13 at 14 °C (Schons et al., 2009). Phyllochron (°C day leaf^{-1}) was estimated as the inverse of the slope of the linear regression (Xue et al., 2004) between the number of leaves on the stems of the cassava plant (NF HP, NF SB1 and NF SB2) and STa from the date of emergence and from the dates of appearance of sympodial branches in the plant (Samboranha et al., 2013). Data were subjected to

analysis of variance and means were compared by Tukey test (p<0.05) using the SAS statistical software (SAS, 2002). The variable phyllochron was analyzed considering a 4x4 factorial arrangement, with the factor A being the stems (main stem - MS, first sympodial branching - SB1, second sympodial branching - SB2 and full - MS + SB1 + SB2) and the factor B being the spacings.

3. RESULTS AND DISCUSSION

Minimum and maximum temperatures for most of the development cycle were above 10 °C and 30 °C respectively, and higher than 35 °C during three heat waves, with the highest maximum temperature of 38.4 °C on 03 February 2010, and the lowest minimum temperature of 4.1 °C on 01 June 2010 (Figure 1a). Low temperatures and solar radiation at the beginning and end of the growing season, and the high temperatures and solar radiation in December and January (Figures 1a,b) are typical weather conditions during the growing season of cassava in subtropical regions. The 2009/2010 growing season was characterized as an El Niño year, with high rainfall and low radiation from September to December (Figure 1b). Excess moisture caused mild soil temperatures, which delayed sprouting and plant emergence. From January 2010 onwards, rainfall was lower, but evenly distributed throughout the cycle, and no symptoms of water deficit were observed.

The evolution of the Leaf Area Index (LAI) for each treatment during the growing season is shown in figure 2a. Treatments with smaller spacing had higher LAI throughout the development cycle, and the maximum LAI (7.6) was observed at the 0.8m spacing, followed by 1.0 m, 1.2 m and 1.5 m spacings, with LAI of 5.3; 4.6 and 3.3, respectively (Table 1). The canopy closure occurred more rapidly at the beginning of the growing season in treatments with smaller spacing, which aided weed control. Peressin (2010) reports that at greater densities of cassava there is the most effective weed control.

The green leaf area (LA) per plant, unlike the LAI, was higher in treatments with greater spacing (Figure 2b). The 1.5x1.5 m treatment plants had larger photosynthetic leaf area per plant throughout the crop cycle, followed by treatments 1.2x1.2 m, 1.0x1.0 m and 0.8x0.8 m, respectively. The highest LA per plant for the treatment of larger spacing was due to the larger leaf size at the first sympodial branching (Figure 2b) and at the second sympodial branching (Figure 2c). Leaf size on the main stem was similar between the smallest (0.8x0.8m) and the largest (1.5x1.5m) spacing (Figure 2a). The smaller size of leaves in the treatment with smaller spacing is related to higher intraspecific competition among individuals in this treatment, once the final number of leaves was not different between treatments (Table 1).

The competition between cassava plants caused differences in the average number of lateral shoots from the main stem. The 1.5x1.5 m treatment had the highest number of shoots (Table 1), because the plants grow and develop under reduced competition for environmental resources, especially light. In turn, by reducing the plant spacing, the plants showed a stronger apical dominance in search of solar radiation, thus presenting fewer lateral shoots (Table 1). However, the plant height was similar during the entire growing season (Figure 2c), without significant difference for the maximum plant height (Table 1). Also, in the 0.8x0.8m treatment the lower number of leaves offset the greater length between nodes (Figure 2e).

The evolution of leaf senescence was similar between treatments (Figure 2d). The almost linear relationship in figure 2d indicates a constant rate of leaf senescence at the end of the cycle of cultivation of cassava, typical physiological response of cassava grown in subtropical regions, such as Rio Grande do Sul State due to decreased air temperature and solar radiation in autumn (Gabriel et al., 2014; Matthews and Hunt, 1994). Therefore, senescence is a factor contributing to the decrease in growth rates of LAI and green leaf area per plant, which started to decline close to 150 DAE (Figure 2a,b). The internode length also had a reduced growth rate close to the day 150 after emergence (DAE) for the four treatments (Figure 2e), possibly because of reduced photosynthetic rate of the canopy by reducing the availability of solar radiation from the second half of February 2010 (Figure 1).

The distribution of the final leaf area in different positions at MS, in SB1 and SB2 of treatments 0.8x0.8 m and 1.5x1.5 m indicates no difference in leaf area along MS for both treatments, pointing out no competition between cassava plants in the beginning of the growing season (Figure 3a). Still at the MS, leaf area increases from lower leaves upwards, reaching the maximum size in portions 28 and 33, and decreasing again in the upper leaves. The largest difference in leaf size between plants of the treatments was found in the SB1 (Figure 3b). While the 0.8 m spaced plants formed leaves with areas from about 200 cm^2 to 270 cm^2, plants at the highest spacing had leaves with areas of 300 cm^2 to 460 cm^2 in the middle portion of the SB1 canopy. Just like the main stem, the leaf size in SB1 was higher in the middle portion of the canopy, with smaller sizes of the leaves approaching the second branch (SB2). The leaves on the SB2 also had a profile with a maximum in the upper portion, being smaller than the MS and SB1, and differences between the two treatments as in SB1 (Figure 3c). As well as in the main stem, the leaf size in SB1 was larger in the middle portion, with smaller sizes when approaching the second branch (SB2). The leaves in the
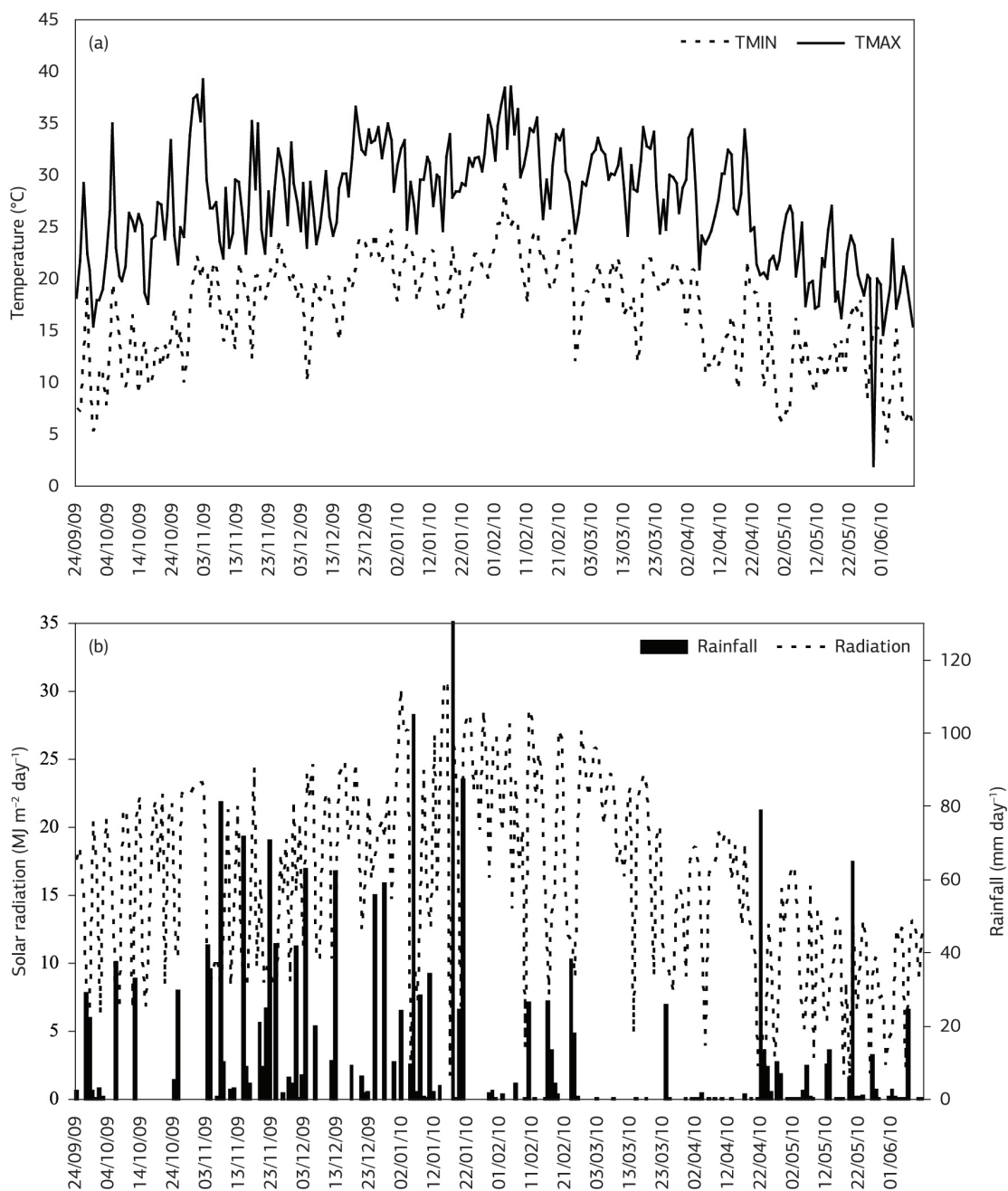
Figure 1. Daily values of minimum (Tmin) and maximum (Tmax) air temperature (a), rainfall and solar radiation (b) during the growing season (dd/mm/yy) from planting to harvest. Santa Maria (RS), Brazil, 2009/2010.

Table 1. Height and maximum leaf area index (LAI $_{MAX}$), final leaf number (FLN) on the main stem (MS), on the first sympodial branching (SB1), on the second sympodial branching (SB2) and total (MS+SB1+SB2) and number of lateral shoots emitted by cassava plants, cultivar Fepagro - RS 13, in four plant spacing. Santa Maria (RS), Brazil, 2009/2010

Growth and development variables	Spacing (m)				CV (%)
	0.8x0.8	**1.0x1.0**	**1.2x1.2**	**1.5x1.5**	
Height $_{MAX}$ (cm)	225 a*	243 a	238 a	250 a	5.34
LAI $_{MAX}$	7.62 a	5.00 b	4.29 bc	3.30 c	13.80
FLN MS	41 a	42 a	40 a	41 a	4.42
FLN SB1	35 a	40 a	40 a	40 a	7.58
FLN SB2	21 b	24 ab	27 ab	31 a	10.5
Total FLN	102 a	108 a	110 a	115 a	7.8
Number of lateral shoots	1.2 b	2 ab	1.75 ab	3.2 a	33.38

*Means followed by the same letter in the row are not significantly different by Tukey test at 5% probability.
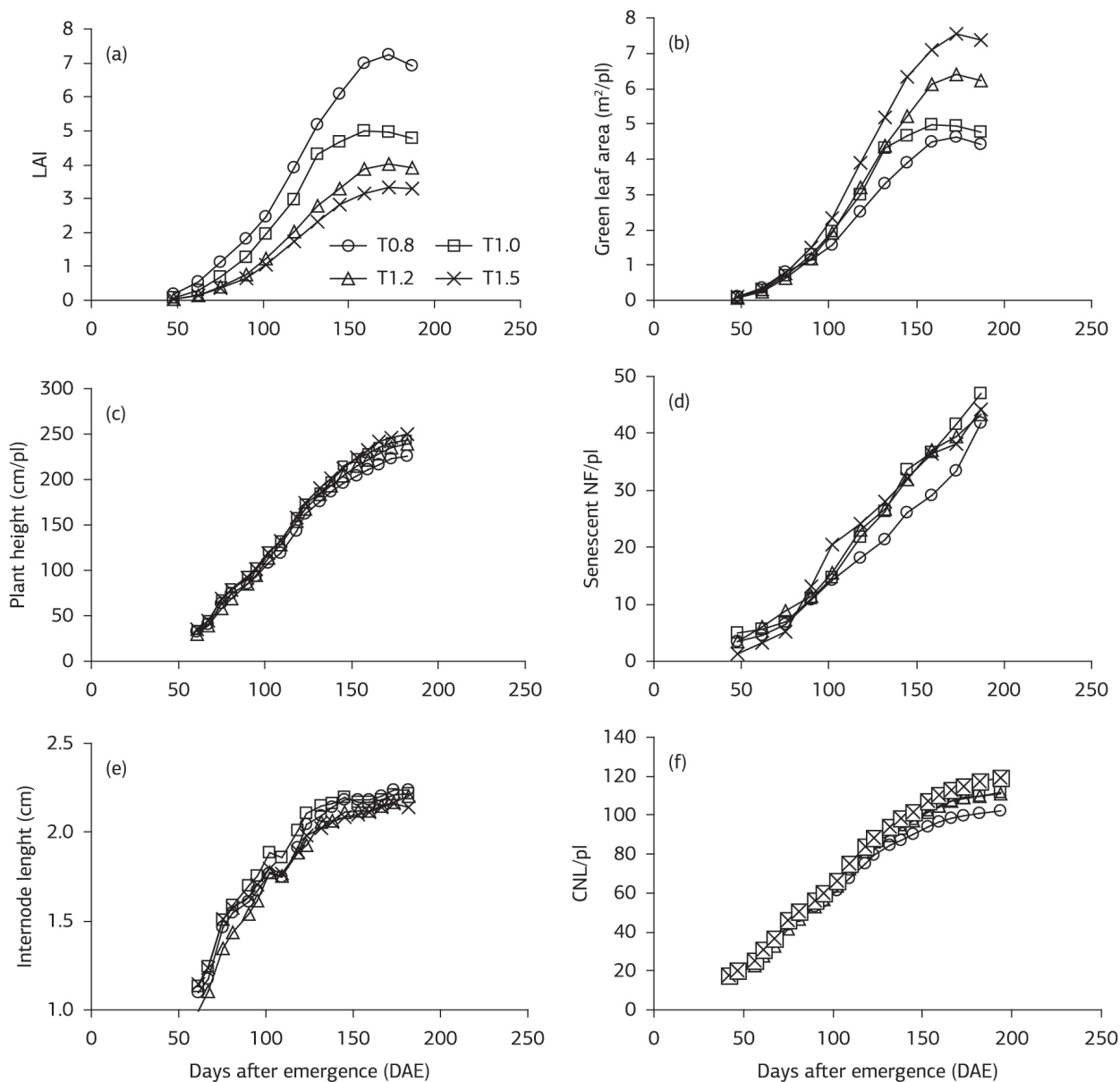
Figure 2. Evolution of leaf area index (a), green leaf area per plant (b), height (c), leaf senescence (d), internode length (e) and cumulative number of leaves (f) in cassava plants, cultivar Fepagro - RS 13, as a function of days after emergence (DAE) for four plant spacings: 0.8x0.8m (T 0.8); 1.0x1.0m (T 1.0); 1.2x1.2m (T 1.2) and 1.5x1.5m (T 1.5). Santa Maria (RS), Brazil, 2009/2010.

SB2 also showed maximum size in the upper portion, being smaller than in MS and SB1, and with differences between the two treatments, as in SB1 (Figure 3c). According to Tan and Cock (1979), the smaller the number of active shoot tips in the plant, the larger the individual leaf size, i.e., fully expanded leaves of cassava tend to reduce area with increasing the number of branching, because assimilates have to be distributed into a larger number of sinks due to enhanced intraspecific competition after the appearance of SB1.

The FLN differed only in SB2, with the highest number of leaves in plants spaced 1.5x1.5m and fewer leaves in the

0.8x0.8m spacing treatment (Table 1). For phyllochron, the interaction stem x spacing was significant, and therefore the statistical analysis was broken down within each factor. The total phyllochron (considering the leaves of all stems (MS, SB1 and SB2) was different between the treatments, with higher phyllochron in plants with narrower spacing (0.8x0.8 and 1.0x1.0 m) and lower phyllochron in plants with wider spacing (1.2x1.2 and 1.5x1.5 m) (Table 2). Phyllochron values in MS were similar, indicating no difference in the leaf emission rate between different plant spacings (Table 2) at the beginning of the development cycle. In the SB1, phylllochron was different, showing that in plants with
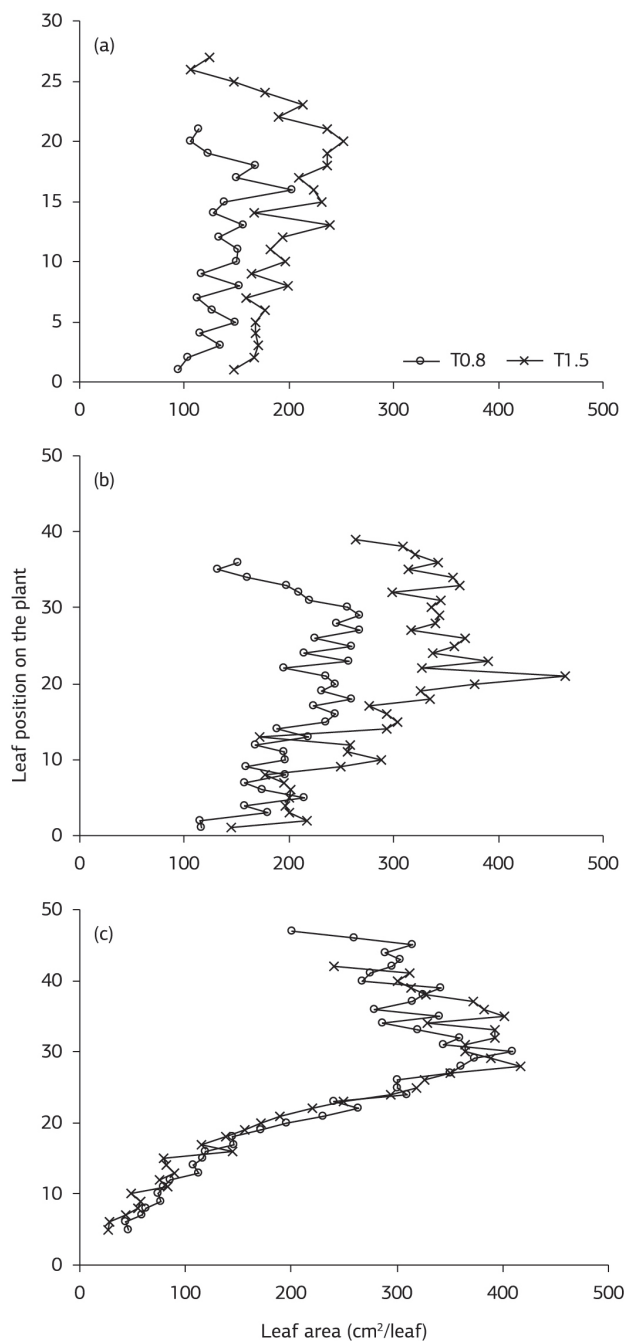
Figure 3. Final area of expanded leaves as a function of the position on the plant in the second sympodial branching (a), in the first sympodial branching (b) and on the main stem (c) of cassava plants, cultivar Fepagro - SR 13, for the plant spacings of 0.8x0.8 m and 1.5x1.5 m. Santa Maria (RS), Brazil, 2009/2010.

wider spacings the time between the appearance of two successive leaves is shorter, and this difference remained in the SB2, thereby producing the highest FLN in the SB2 (Table 1). This difference can be attributed to the higher level of intraspecific competition in plants with narrower spacing, in which the phyllochron is higher (Table 1).

In all treatments, we observed an increase in phyllochron at higher sympodial branches, with higher phyllochron in the SB2. Fagundes et al. (2009) also observed an increase in the phyllochron with increasing number of branches.

Stem yield (t ha⁻¹), in fresh and dry weight, was not significantly different between treatments (Table 3). Stem yield per plant (kg plant⁻¹), in fresh and dry weight, was higher in the 1.5x1.5m pacing (Table 3), indicating a compensation of yield per plant at each spacing. The 0.8x0.8 spacing treatment had the highest root yield, 36.44 t ha⁻¹, differing from the treatments 1.2x1.2 m and 1.5x1.5 m (Table 4), indicating that the increased density (narrow spacing) increased yield per area in this cultivar. The results of dry weight (DM) of roots per hectare followed the same trend of the MF.

Tuberous roots and shoots are two sinks that compete during the plant life cycle (Alves, 2006). Data of weight per plant and weight per root in table 4 can be explained by the hypothesis of Aguiar et al. (2011) who found that, under conditions of lower densities (wide spacing), the sink of tuberous roots exceeds that of shoot tips. Thus, wider spaced plants (1.5x1.5 m) showed the highest weight per plant and per root (5.64 kg plant⁻¹ and 0.429 kg root⁻¹), followed by 1.2x1.2 m spaced plants (4.25 kg plant⁻¹ and 0.323 kg root⁻¹) and plants of 1.0x1.0 m and 0.8x0.8 m spacing treatments, which did not statistically differ (Table 4). This result confirms the individual advantage for plants with larger area for exploration and is according to Barros et al. (1978) who reported that the yield per cassava plant is greater in plants with wider plant spacing, but yield per area is higher with narrower spaced plants.

To result in a good root yield, the cassava plant should reach LAI of 3.0 as quickly as possible and remain as long as possible in the range between 3.0 and 3.5 (Cock et al., 1979). Figure 2 illustrates that the slopes of growth curves of LAI are higher in treatments 0.8x0.8m and 1.0x1.0m and lower in treatments 1.2x1.2m and 1.5x1.5m. Consequently, in the treatments with narrower spacing, the optimum range of LAI (3-3.5) is reached more rapidly, but the period in which the LAI remains in the optimum range was shorter than in treatments with wider spacing. For example, in the treatment 0.8x0.8m, the LAI was in the optimal range in the period from 02 February 2010 to 18 February 2010 (16 days) while in the treatment with wider spacing (1.5 m) the LAI of 3.0 was reached on 25 March 2010 and did not reach the upper limit of LAI (3.5), but remaining above 3.0 until the last day of the measurement, that is, for at least 42 days. In this way, a possible management tool to optimize the yield of roots under high plant density is the green pruning when LAI reaches 3.5.

Root yield per area is important when production has industrial purpose, while root yield per plant and per root are important when production is aimed for consumption (fresh or processed). Therefore, for this cultivar, when the

Table 2. Phyllochron (°C day leaf^{-1}) in the main stem (MS) in the first sympodial branching (SB1), in the second sympodial branching (SB2) and total (MS+SB1+SB2) in the cassava plant, cultivar Fepagro - SR 13, in four different plant spacings. Santa Maria (RS), Brazil, 2009/2010

| Spacing (m) | Stem on the plant | | | | CV% |
	MS	SB1	SB2	TOTAL	
0.8x0.8	15.86 b A*	18.60 b A	24.36 a A	17.07 b A	11.62
1.0x1.0	15.39 b A	16.31 b AB	24.55 a A	15.94 b AB	7.37
1.2x1.2	15.92 b A	14.91 b B	20.21 a AB	14.84 b BC	11.40
1.5x1.5	15.46 b A	14.96 b B	18.50 a B	14.35 b C	5.67
CV (%)	6.82	9.52	14.88	3.98	

*Means followed by the same lowercase letter in the row and by the same uppercase letter in the column are not significantly different by Tukey test at 5% probability.

Table 3. Fresh and dry weight of stems per area and per plant of cassava cultivar Fepagro - RS 13 in different plant spacings. Santa Maria (RS), Brazil, 2009/2010

| Variable | Plant spacing | | | | CV (%) |
	0.8x0.8m	1.0x1.0m	1.2x1.2m	1.5x1.5m	
	- - - - yield per area (t/ha) - - - -				
Fresh weight	26.18a*	26.43a	20.97a	21.30a	18.72
Dry weight	6.97a	6.39a	4.61a	5.63a	22.68
	- - - - yield per plant (kg/plant) - - - -				
Fresh weight	1.68b	2.64b	3.02b	4.79a	18.78
Dry weight	0.45b	0.64b	0.66b	1.27a	23.15

*Means followed by the same letter in the row are not significantly different by Tukey test at 5% probability.

Table 4. Fresh weight, dry weight and number of commercial roots per area, per plant and per root of cassava cultivar Fepagro - RS 13 in different plant spacings. Santa Maria (RS), Brazil, 2009/2010

| Variable | Plant spacing | | | | CV (%) |
	0.8x0.8m	1.0x1.0m	1.2x1.2m	1.5x1.5m	
	- - - - yield per area (t/ha)- - - -				
Fresh weight (t/ha)	36.44 a*	29.51 ab	27.85 b	25.09 b	10.73
Dry weight (t/ha)	13.08 a	9.87 b	10.05 b	8.39 b	9.07
Number of roots/ha	169271 a	125833 b	91435 c	58607 d	9.81
	- - - - yield per plant (kg/plant) - - - -				
Fresh weight (kg/plant)	2.33 c	2.78 c	4.25 b	5.64 a	14.20
Dry weight (kg/plant)	0.84 b	1.35 ab	1.34 ab	1.89 a	23.75
Number of roots/plant	10.78 a	12.70 a	13.14 a	13.20 a	12.65
	- - - - yield per commercial root (kg/root) - - - -				
Fresh weight (kg/root)	0.216 c	0.221 c	0.323 b	0.429 a	9.89
Dry weight (kg/root)	0.078 c	0.078 c	0.110 b	0.144 a	8.00

*Means followed by the same letter in the row are not significantly different by Tukey test at 5% probability.

production is for consumption, it is recommended a plant spacing wider than 0.8x0.8m and according to the results obtained in this experiment, it can be concluded that both the spacing 1.2x1.2 m and 1.5x1.5 m are those with greater weight per plant and per commercial root (Table 4). The cultivar Fepagro - RS13 showed high biomass production in shoots, thus it is also recommended for forage production. For this purpose, as there was no difference in stem yield per hectare (Table 3), we recommend narrow spacing (0.8x0.8m or 1.0x1.0m), which produce thinner stems than in wide spacing.

This study provides important results on the effect of plant spacing on the growth and development of shoots and roots of cassava, beyond root yield. The results can be extended to other cultivars, which have high shoot production, such as the cultivar Fepagro - RS 14.

4. CONCLUSION

The maximum leaf area index and the leaf development (phyllochron) increase with decreasing plant spacing in

cassava. The final leaf size and the number of lateral shoots increase with increasing plant spacing. The FLN differs only in the SB2, with the highest number of leaves in plants spaced 1.5x1.5m.

In the cultivar Fepagro - RS 13, the stem yield does not change with plant spacing, but the root yield per area is greater under narrow plant spacing, while the plant yield and per commercial root is greater at wide plant spacing.

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