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CROP SCIENCE

Adaptation of rapid multiplication method: cassava stem and root yield at different spacings and transplanting seasons

ANDRÉ SCHOFFEL, SIDINEI J. LOPES, JANA KOEFENDER, ALESSANDRO D. LÚCIO, JULIANE N. CAMERA & DIEGO P. GOLLE

Abstract: This study aimed to assess cassava root and stem yield at different spacings and four transplanting seasons of seedlings produced by an adaptation of the rapid multiplication method. The experimental design was a randomized block design with three replications in a factorial (4 × 5) arranged in strips. Treatments consisted of the combinations of growing seasons (November 9 and 24 and December 3 and 26) and spacings (0.6 × 0.6, 0.8 × 0.8, 0.8 × 0.6, 1.0 × 0.6, and 1.0 × 0.8 m). The percentage of survival, main stem branching height, number of branches, base, middle, and upper diameter, mean diameter, stem length, number of buds per stem and hectare, root length and diameter, root fresh matter per plant and hectare, and number of roots per plant were measured at harvest. Seedling transplanting performed up to November 24 favored the expression of stem and root yield. The spacing of 1.0 × 0.6 m was the most suitable for stem yield traits.

Key words: Growth and development, management techniques, *Manihot esculenta* Crantz, seedling production.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) belongs to the Euphorbiaceae family and stands out for its starchy tuberous roots, an important energy food that is a source of subsistence for human and animal food, especially in family farms (Schons et al. 2009). Grown in various regions of the world, it contributes to increased food security since it is an accessible source of carbohydrates, mainly from provincial communities (Salvador et al. 2014). Despite the high root yield potential, cassava mean yield is usually low, especially in family farms, which account for 87% of the national production and reach a mean yield below 6,000 kg ha^{-1} (Brasil 2009).

Despite the high rusticity and tolerance to drought and low soil fertility (Adeniji et al. 2011), several factors limit crop yield, including soil chemical and physical conditions, disease incidence, and improper management techniques. In most cases, cassava is grown in areas of low fertility levels and limiting physical conditions for root growth and development (Delaquis et al. 2018), especially in small farms (Pypers et al. 2012), which use more fertile areas for growing grain or vegetable crops. The occurrence of bacterial diseases is favored by the successive cultivation of cassava in the same area, in which the disease is spread by infected propagation material and survives in crop residues and soil, drastically limiting yield, being required the disposal of infected propagation material (Ishida et al. 2016).

Cassava crop is propagated vegetatively by planting stem cuttings. The predominant planting method is the traditional one, which consists of planting 4 to 6 buds in non-fertilized furrows and at varying populations and spacings, determined by cultivar characteristics, area size, and technological level. In this type of method, planting at the beginning of the recommended season accelerates starch accumulation and, in turn, its delay results in reduced stem yield, although it does not significantly influence root yield (Fagundes et al. 2010). One of the significant constraints on cassava yield is the quality of propagation material. The traditional planting method becomes a severe constraint in cases of shortage of propagation material due to the low multiplication rate and use of high-quality stems (Ceballos et al. 2015).

Cassava stems need to be stored during the winter in southern Brazil due to the low temperatures, allowing planting them in early spring when dormant buds begin to sprout. A high percentage of stem mortality occurs in cases of inadequate storage and frost occurrence, which drastically limits the availability of propagation material for planting in the traditional method. In these cases, the rapid multiplication method developed by the International Center for Tropical Agriculture (CIAT) is an alternative because it increases the multiplication rate by up to 17 times compared to the traditional planting method (Santos et al. 2009). Nevertheless, the study of adaptations to the method and management techniques that contribute to maximizing seedling survival and root and stem yield for the next crop is important.

The rapid multiplication method consists of planting two-bud stem cuttings in beds or rooting chambers covered with transparent plastic film to stimulate rooting. After reaching an approximate height of 15 cm, cuttings are collected, placed in containers with water to boost adventitious rooting, and planted in containers with a substrate for seedling production, being ready for the transplanting to production areas after an acclimation period. This method was adapted to the cultivation conditions of Northeast Brazil (Fukuda & Carvalho 2006) and Nigeria (Abass et al. 2014), but adaptations during seedling production and management techniques information after transplanting to production fields are scarce, especially for the cultivation conditions of southern Brazil.

It highlights the need to define management strategies for cassava cultivation propagated by adapting the rapid multiplication method for root and stem production. According to Santos et al. (2009), this method has limitations in the rooting of cuttings for seedling production, with production being incipient in the first year, with roots have a different format and low quantity compared to the traditional method. This study aimed to assess cassava root and stem yield at different spacings and four transplanting seasons of seedlings produced by an adaptation of the rapid multiplication method.

MATERIALS AND METHODS

The experimental area belongs to the Laboratory of Plant Multiplication of the Higher Jacuí Technological Innovation Center located on the campus of the University of Cruz Alta (Unicruz), Cruz Alta, RS, Brazil, at the geographical coordinates 28°38’19” S and 53°36’23” W, with an average altitude of 452 m. The regional climate is subtropical, type Cfa according to the Köppen classification. The mean air temperature is 18.7 °C, with a mean minimum temperature of 9.2 °C in July and a mean maximum temperature of 30.8 °C in January (Pes et al. 2011). The soil is classified as a clay textured typic dystrophic Red Latosol (Embrapa 2013).

Planting of stem cuttings of the cultivar Apronta Mesa for collecting shoots was carried out from July to October in 15-cell black plastic trays with dimensions of 34 cm long × 21 cm wide × 7.8 cm high. Cells had 6.2 cm at the top × 5.0 cm at the bottom × 7.8 cm in height and five 6-mm holes to drain excess water applied by an irrigation system. Trays were filled with the commercial substrate Mec Plant®.

Seedlings were produced in a Van der Hoeven greenhouse with an automatic mist irrigation system and mean temperature of 25 °C. Each cutting was immediately planted after harvesting in 15-cell plastic trays filled with the commercial substrate Mec Plant® previously irrigated to prevent dehydration of tissues at planting. A one-centimeter deep furrow was opened, and one cutting was planted per cell. Planting was carried out in the morning, and the maximum allowed temperature was 25 °C to minimize the risk of dehydration of cuttings tissues. Seedlings were removed from this greenhouse and taken to an agricultural greenhouse at 30 DAP for a minimum 5-day acclimation, except for the last season, when seedlings went to acclimation at 23 DAP. Cassava seedlings with more than three visible leaves were selected for transplanting. Leaf was considered visible when the edges of one of the leaf lobes did not touch each other (Schons et al. 2007).

The experiment was conducted in the 2017/2018 crop at four seedling transplanting seasons (November 9 and 24 and December 3 and 26). A soil sample was taken from a depth of 0 to 20 cm to characterize soil fertility of the experimental area. Soil analysis showed the following values: pH in water = 5.5, clay = 50%, soil organic matter = 3.3%, phosphorus = 26.2 mg dm^{-3}, potassium = 96 mg dm^{-3}, calcium = 5.9 $cmol_c$ dm^{-3}, magnesium = 2.4 $cmol_c$ dm^{-3}, aluminum = 0.0 $cmol_c$ dm^{-3}, and base saturation = 68.7%.

Fertilization was based on the recommendations of the Comissão de Química e Fertilidade do Solo (2016) for cassava cultivation. The mineral fertilizer formula 5–20–20 was applied on the soil surface at a dose of 334 kg ha^{-1} during transplanting. Nitrogen fertilization consisted of urea (46–00–00) split into two applications of 70 kg ha^{-1} at 15 days after transplanting (DAT) and beginning of starch accumulation (BSA), which occurs when cassava plants has 21 visible leaves on the main stem, according to Schons et al. (2007). The data of precipitation, maximum and minimum air temperature, and maximum and minimum relative humidity were obtained from an automatic weather station located approximately 200 m from the experimental area.

The experimental design was a randomized block design with three replications in a factorial (4 × 5) arranged in strips, totaling 20 treatments. Treatments consisted of the combinations of growing seasons (November 9 and 24 and December 3 and 26) and spacings (0.6 × 0.6, 0.8 × 0.8, 0.8 × 0.6, 1.0 × 0.6, and 1.0 × 0.8 m, corresponding to transplanting densities of 27,778, 15,625, 20,833, 16,667, and 12,500 plants ha^{-1}, respectively).

The experimental units were composed of four rows with four plants per row and consisted of areas of 4.32, 5.76, 5.76, 7.2, and 7.2 m^2 for spacings of 0.6 × 0.6, 0.8 × 0.8, 0.8 × 0.6, 1.0 × 0.6, and 1.0 × 0.8 m, respectively. The winter crop, formed by the intercropping of cover crops (*Avena strigosa* Schreb. + *Raphanus sativus* L.), was desiccated using the herbicide glyphosate (3 L ha^{-1}) before the preparation of the experimental area. The soil was prepared conventionally, which consisted of plowing and harrowing.

Seedling transplanting was carried out in 15-cm deep unfertilized furrows according to each season. Weed control was carried out weekly by manual weeding until the complete closure of the interrows, which is extended up to three months after seedling transplanting and characterized as the period in which the crop is subject to competition with weeds (Oliveira Júnior et al. 2005). Sprinkling irrigation was performed daily up to the 15th day after transplanting for all seasons and when there was no precipitation. Irrigation management after transplanting was adopted because the water supply is important for the establishment of cassava seedlings produced by the rapid multiplication method (Santos et al. 2009).

We measured the percentage of survival (S%) of stems and the following stem traits: main stem branching height (MSBH), number of branches (NB), base diameter (BD), middle diameter (MdD), upper diameter (UD), mean diameter (MD), stem length (SL), number of buds per stem (NBS), and number of buds per hectare (NBH) were measured. The following root traits were also measured: root length (RL), root diameter (RD), root fresh matter per plant (RFMP), root fresh matter per hectare (RFMH, kg ha^{-1}), and the number of roots per plant (NRP). Diameter measurements were performed with a digital caliper, with root diameter measured in the upper third of roots. Harvesting was carried out on May 30 and cycle duration for the transplantation seasons of November 9 and 24 and December 3 and 26 was 203, 188, 179, and 156 days, respectively.

The daily thermal summation (TSd, °C day) was calculated by three methods (Gilmore Jr & Rogers 1958, Arnold 1960), in which:

Method 1: TSd = (Tmean – Tb) × 1 day, if Tmean < Tb then Tmean = Tb (1).

Method 2: TSd = (Tmean – Tb) × 1 day, if Tmean < Tb then Tmean = Tb and if Tmean > Topt then Tmean = Topt (2).

Method 3: TSd = (Tmean – Tb) × 1 day when Tb < Tmean ≤ Topt and TSd = (Topt – Tb) × (Tmax – Tmean)/(Tmax – Topt) when Topt < Tmean ≤ Tmax (3), where Tmean is the mean daily air temperature, Tb is the base temperature, Topt is the optimum temperature, and Tmax is the maximum temperature for cassava crop development. The base temperature was 14 °C (Schons et al. 2007), while optimum and maximum temperatures were 30 and 42 °C, respectively (Matthews & Hunt 1994). The accumulated thermal summation (TSa, °C day) at different stages (transplanting to BSA, BSA to harvest, and transplanting to harvest) was calculated by the sum of TSd values.

The assumptions of the mathematical model were verified before the analysis of variance by the homogeneity of treatment variances and normality of errors by applying the Bartlett and Shapiro-Wilk tests, respectively, at 0.05 error probability. The box-cox procedure was used when the assumptions were not met in order to verify the appropriate transformation to the obtained data using the software Action (Equipe Estatcamp 2014). Results were submitted to analysis of variance, and the means were compared by the Scott-Knott test at 0.05 probability by the statistical package Sisvar 5.6 (Ferreira 2011).

RESULTS AND DISCUSSION

The data were transformed to meet the assumptions of normality of errors (percentage of survival) and homogeneity of variances (number of branches, number of buds per plant, and number of buds per hectare). No significant interaction was observed between factors (seasons and spacing) for traits measured in stems and, therefore, the main effect of each factor was studied. Only the percentage of survival, main stem branching height, and stem length showed no significant effects. The number of branches, stem base diameter, stem middle diameter, stem upper diameter, stem mean diameter, number of buds per stem, and number of buds per hectare had a significant effect for the factor transplanting seasons. Base diameter, middle diameter, upper diameter, mean diameter, and number of buds per hectare showed a significant effect for the factor spacings.

No significant interaction was observed for root traits. The data of root fresh matter per plant were transformed because they did not meet the assumptions. The number of roots per plant showed a significant effect on the factors seasons and spacings. Root fresh matter per plant and hectare, root length, and root diameter had a significant effect only for the factor transplanting seasons.

The percentage of plant survival was higher than 90% after transplanting to the production field at all seasons, and no significant difference was observed between transplanting seasons (Table I). The percentage of survival between seasons ranged from 91% at the transplanting carried out on December 26 to 98.40% on December 3. The restriction on growth and development of the shoot and root system of pre-transplanting seedlings related to the delay at the transplanting season possibly influenced the percentage of survival in the production field. This result of the percentage of survival reflected the physiological and health quality of the produced seedlings and the rapid multiplication method offered the possibility of discarding seedlings with suspected disease incidence before transplanting to the production field.

A percentage of survival of 91.87% was verified in the transplanting carried out on November 9 due to heat canker. This disturbance was caused by the high temperature of the soil surface, which led to the disruption of cell membranes and dehydration and necrosis of collar tissues, which prevented the transport of water and nutrients from roots to the shoots, resulting in plant death. This type of damage is identified by shoot tipping over and strangulation lesions in the collar region of plants and can affect different crops after emergence (Neumaier et al. 2000) or cassava seedling transplanting, as observed in this study.

Table I. Percentage of survival (S%), main stem branching height (MSBH), number of branches (NB), stem base diameter (BD), stem middle diameter (MdD), stem upper diameter (UD), mean stem diameter (MD), stem length (SL), number of buds per stem (NBS), and number of buds per hectare (NBH) of cassava plants transplanted on November 9 and 24 and December 3 and 26.

	Season				
Traits	**November 9**	**November 24**	**December 3**	**December 26**	**CV (%)**
S (%)	91.87* a	97.20 a	98.40 a	91.00 a	24.03
MSBH (cm)	1.41 a	1.36 a	1.48 a	1.19 a	18.60
NB (plant)	3.00 a	3.00 a	3.00 a	2.67 b	23.53
BD (mm)	23.33 a	24.13 a	22.73 a	18.33 b	7.21
MdB (mm)	21.60 a	22.20 a	20.67 a	16.47 b	10.05
UD (mm)	18.40 a	18.47 a	16.87 b	13.20 c	9.80
MD (mm)	21.20 a	21.67 a	20.13 a	15.93 b	8.82
SL (mm)	1.23 a	1.19 a	1.30 a	1.01 a	20.99
NBS	38.73 a	38.93 a	37.93 a	28.27 b	14.62
NBH	721968.60 a	728647.73 a	706088.20 a	521961.27 b	12.13

***Means followed by different letters differ from each other by the Scott-Knott test at 0.05 probability (P<0.05).**

The mean number of branches in the main stem was three at the first three transplanting seasons, differing significantly from the last season, as the cultivar Apronta Mesa had a trichotomous branching habit (Koefender et al. 2015). Despite being governed mainly by intrinsic genetic factors to cultivar, the mean number of branches was 2.67 on December 26, with the influence of environmental conditions on this trait. This result was caused by a delay at the transplanting season, which is out of the period recommended by the climate risk zoning for cassava cultivation in Cruz Alta. Planting by the traditional method in Cruz Alta should occur between September 11 and November 30 (Mapa 2011), as it is a period that offers adequate climate conditions for crop growth and development.

No significant difference was verified between transplanting seasons for main stem branching height and stem length. This result can be considered normal, considering the relationship between these traits. However, for the production of stems that will be used for the implantation of the next crop, the transplanting of late produced seedlings can be carried out until the third ten-day period of December and stem length will not be reduced.

In general, stem diameter decreased as transplanting seasons delayed. The best means for basal and middle diameters were observed at the transplanting seasons of November 9 and 24 and December 3, in which diameter ranged from 22.73 to 24.13 mm and 20.67 to 22.20 mm, respectively. The best means for upper diameter were verified on November 9 and 24, with values of 18.40 and 18.47, respectively. Stem cuttings from the upper third of the stem have restrictions for cassava planting by the traditional method due to the reduced survival capacity after emergence. However, their use may be an alternative under situations of the shortage of propagation material, especially for seedling production through the implementation of the rapid multiplication method in a controlled environment.

The season of December 26 had the worst result for mean diameter (15.93 mm). Although it did not negatively influence stem length, stem diameter was smaller and led to a reduction in the contribution of reserve substances and water in stems, being important for survival and ensuring stem viability during storage. Photosynthesis products, especially carbohydrates, are stored in the stems, conferring the physiological quality of the propagation material (Alves 2006). Stems are stored for extended periods under the late planting situation in southern Brazil. In early spring, as temperature increases, stem begins to sprout, triggering the degradation and consumption of reserve substances, a process that is attenuated with a delay of the growing season. Thus, the use of stems for planting and implementation of the rapid multiplication method is compromised, mainly for stem cuttings from the upper third of stems. According to FAO (2013), the low quality of propagation material is one of the main causes of the low yield of cassava roots.

The best means for the number of buds per stem and number of buds per hectare were observed in the first three transplanting seasons, with values ranging from 706,088.20 to 728,647.73, which represented approximately 38 to 39 buds per stem. The mean number of buds per stem in the last season was 28.27 and represented 521,961.27 buds per hectare. Although not negatively affecting stem length, the delay in seedling transplanting was a limiting factor to the number of buds produced per unit area. Fagundes et al. (2010) verified that stem yield of the cultivar Fepagro RS 13 reduced in late November growing seasons when compared to September and October using the traditional planting method. Reduction of shoot growth and development occurs gradually with a delayed planting season, which reduces leaf emission, photoassimilate production, and dry matter accumulation in drains (stems and roots).

No significant difference of spacings was observed on the percentage of survival, main stem branching height, number of branches, stem length, and number of buds per stem (Table II). These traits were influenced mainly by genetic factors and environmental effects. Plant growth and the influence of internal and external factors are controlled by genetics, and the supply of water, oxygen, carbon dioxide, nutrients, solar radiation, and temperature are important. Cell turgidity is necessary for cell growth and, therefore, water supply is essential for plant growth and development (Floss 2011). Silva et al. (2013) studied planting densities ranging from 5,000 to 21,000 plants ha^{-1} at 2,000-plant intervals and found that the increased planting density caused an increase in the main stem branching height. This result may be related to competition between plants at higher densities and the need to search for essential elements for development, especially solar radiation, in this case.

On the other hand, a significant difference was found for diameter measurements and number of buds per hectare, corroborating the results observed by Rojas et al. (2007) for stem diameter. This result showed that the content of reserve substances, water, and bud yield are influenced by spacings. The definition of this management technique is important to obtain stems with adequate quality and viability for use in the next crop. Despite the economic and social importance, researches to improve management techniques to achieve increased cassava yield has been little addressed (Silveira et al. 2012).

In general, diameter measurements presented the best results at larger spacings, i.e., at lower plant densities. The spacings 1.0 × 0.6 and 1.0 × 0.8 m presented the best means for the base, middle, and upper diameters, except for upper diameter, in which the spacing 1.0 × 0.6 m presented the best result, as well

Table II. Percentage of survival (S%), main stem branching height (MSBH), number of branches (NB), stem base diameter (BD), stem middle diameter (MdD), stem upper diameter (UD), mean stem diameter (MD), stem length (SL), number of buds per stem (NBS), and number of buds per hectare (NBH) of cassava plants at spacings of 0.6 × 0.6, 0.8 × 0.8, 0.8 × 0.6, 1.0 × 0.6, and 1.0 × 0.8 m.

	Spacing					
Traits	**0.6 x 0.6 m**	**0.8 x 0.8 m**	**0.8 x 0.6 m**	**1.0 x 0.6 m**	**1.0 x 0.8 m**	**CV (%)**
S (%)	91.75* a	94.42 a	95.50 a	94.42 a	97.00 a	11.96
MSBH (cm)	1.41 a	1.34 a	1.38 a	1.36 a	1.32 a	13.64
NB (plant)	2.92 a	2.92 a	2.83 a	3.00 a	2.92 a	11.91
BD (mm)	21.50 b	21.75 b	21.25 b	23.42 a	22.75 a	5.98
MdB (mm)	19.50 b	19.75 b	19.50 b	21.42 a	21.00 a	5.10
UD (mm)	16.08 b	16.42 b	16.08 b	18.17 a	16.92 b	6.41
MD (mm)	18.92 b	19.00 b	19.33 b	21.17 a	20.25 b	6.01
SL (mm)	1.22 a	1.16 a	1.21 a	1.18 a	1.15 a	15.11
NBS	34.75 a	35.50 a	35.67 a	36.83 a	37.08 a	17.16
NBH	969392.92 a	557611.75 c	743379.75 b	613618.50 b	464329.33 d	6.85

***Means followed by different letters differ from each other by the Scott-Knott test at 0.05 probability (P<0.05).**

as observed for mean diameter. It shows that intraspecific competition is attenuated in smaller spacings, and larger plant populations negatively influence the absorption capacity and accumulation of reserves in stem tissues, which caused a reduction in diameter.

Although the number of buds per stem showed no significant difference for spacings, the number of buds per hectare was higher at the smallest spacing due to a higher plant population. This result needs to be carefully interpreted since despite having a higher number of buds per unit area, diameter assessments, which are more informative on stem quality, were lower, i.e., there was less accumulation of water and reserve substances, mainly for stem cuttings from the middle and basal thirds, which are the most used. This information is important due to a recent increase in the trade of stems, emerging as an alternative for diversification and profitability for farmers (Edet et al. 2015).

Root fresh matter per plant and unit area were higher when seedlings were transplanted in November. Also, yield decreased with a delay of the transplanting season (Table III). Root fresh matter was 21,755.07 kg ha^{-1} when transplanting was carried out on November 9, while yield was 8,708.07 kg ha^{-1} when transplanting was carried out on December 26, which represents a reduction of approximately 60% in relation to the first transplanting season. This result is similar to that found by Fagundes et al. (2010), who worked at four seasons of cassava planting by the traditional method and observed that a delay in growing season until November 28 did not result in reduced root yield. This result is an indication that seedling transplanting should be performed by the end of November to achieve higher cassava root yield using the adaptation of the rapid multiplication method.

The maximum yield of root fresh matter was lower than that observed by Silva et al. (2016), who obtained a mean yield of approximately 30 t ha^{-1} when using the traditional planting method and cassava intercropped with grain production species in Diamantina, Minas Gerais. These authors found yields of 40.75 and 42.25 t ha^{-1} for the cultivars Cacau-UFV and IAC-2, respectively, under single cultivation and with weed control. On the other hand, yield at transplanting carried out on November 9 is within the production range of cassava cultivars in the traditional planting method in Santa Maria, Rio Grande do Sul (Tironi et al. 2015).

Root length and diameter are important traits used as a parameter for commercialization. Root length and diameter were favored when transplanting was performed on November 9 and 24. Root growth began after transplanting and, according to Figueiredo et al. (2014), occurs until

Table III. Root fresh matter per plant (RFMP (g plant^{-1}) and hectare (RFMH, kg ha^{-1}), root length (RL), root diameter (RD), and number of roots per plant (NRP) in cassava plants transplanted on November 9 and 24 and December 3 and 26.

	Season				
Traits	**November 9**	**November 24**	**December 3**	**December 26**	**CV (%)**
RFMP (g plant^{-1})	1206.87 a	1210.80 a	787.53 b	483.60 c	12.22
RFMH (kg ha^{-1})	21755.07 a	21504.20 a	13736.40 b	8708.07 c	12.02
RL (cm)	22.20 a	22.87 a	20.13 b	19.27 b	8.26
RD (mm)	30.33 a	31.00 a	26.47 b	26.60 b	7.20
NRP (plant)	8.53 a	8.40 a	8.26 a	5.20 b	16.61

***Means followed by different letters differ from each other by the Scott-Knott test at 0.05 probability (P<0.05).**

root diameter increase begins. In this context, shoot growth and development are important and served to synthesize and translocate photoassimilates for storage in reserve roots. A high net photosynthesis rate and a significant increase in root diameter are observed after shoot establishment (Figueiredo et al. 2014).

The delay of the transplanting season led to a longer duration of the seedling establishment stage, i.e., until the beginning of starch accumulation (Table V). On the other hand, a reduction was observed from the transplanting stage to harvest, characterized mainly by a gradual reduction at the stage from the beginning of starch accumulation to harvest. This stage is important for shoot growth, development, and production of photoassimilates, and its reduction led to a lower translocation and accumulation of root fresh matter.

The number of roots was higher in the first three transplanting seasons, ranging from 8.26 to 8.53 roots plant^{-1}. This result was higher when compared to that found by Aguiar et al. (2011), who did not observe significant differences in relation to the control (without pruning) for the trait number of roots, which ranged from 5.40 to 7.58 roots plant^{-1}. The number of roots was 5.20 roots plant^{-1} for seedlings transplanted on December 26. Thus, this result, associated with root length and diameter, contributed to a low yield, considering that these traits are important yield components and directly influence root fresh matter (Figueiredo et al. 2014). Nevertheless, root yield was higher than that of the national average on family farms (5,770 kg ha^{-1}) (Brasil 2009), indicating that the adaptation of the rapid multiplication method is an alternative for increasing national cassava yield, in addition to contributing to the subsistence and financial support of these families, as well as food security of the population.

No significant difference was observed for traits measured in roots at different spacings (Table IV). Akpan & Ikeh (2018) found that cassava yield in Nigeria varied at different spacings and that the spacing 1.0 × 0.8 m provided the best results for the cultivars TMS 30572 and TME 419. Silva et al. (2013) found that planting density influenced fresh matter and the number and length of roots, but did not affect root diameter. These authors observed a beneficial effect for fresh matter and number of roots up to densities of 14,416 and 16,436 plants ha^{-1}, respectively, being these traits negatively affected from these densities, with a reduction in root length as plant density increased. Higher availability of resources, such as water, and reduced competition for nutrients and solar radiation are observed under a reduced plant density and, consequently, plants are exposed

Table IV. Root fresh matter per plant RFMP (g plant^{-1}) and hectare (RFMH, kg ha^{-1}), root length (RL), root diameter (RD), and number of roots per plant (NRP) in cassava plants at spacings of 0.6 × 0.6, 0.8 × 0.8, 0.8 × 0.6, 1.0 × 0.6, and 1.0 × 0.8 m.

	Spacing					
Traits	**0.6 x 0.6 m**	**0.8 x 0.8 m**	**0.8 x 0.6 m**	**1.0 x 0.6 m**	**1.0 x 0.8 m**	**CV (%)**
RFMP (g plant^{-1})	711.25 a	878.42 a	723.83 a	1163.58 a	1133.92 a	24.02
RFMH (kg ha^{-1})	19755.33 a	13726.25 a	15080.67 a	19393.42 a	14174.00 a	22.77
RL (cm)	19.92 a	20.33 a	20.75 a	21.58 a	23.00 a	10.50
RD (mm)	28.08 a	28.50 a	27.42 a	29.42 a	29.58 a	7.48
NRP (plant)	6.67 a	7.67 a	7.00 a	8.75 a	7.92 a	18.72

***Means followed by different letters differ from each other by the Scott-Knott test at 0.05 probability (P<0.05).**

to better conditions to express their production potential of the shoot and root traits. Above the mentioned densities, the authors reported increased competition for essential resources and hence a reduction in trait values.

Despite the difference in spacing and plant population, the absence of statistically significant differences is possibly due to reduced intraspecific and interspecific competition, as weed control was performed weekly until the closure of crop interrows. It favored crop establishment and consequently influenced root yield. A fast initial cassava growth is important to reduce weed competition due to the rapid soil shading in the crop area, contributing to integrated weed management (Rangel et al. 2018).

In addition, nitrogen, phosphorus, and potassium are the most important nutrients for root tuberization (Odedina et al. 2015). The addition of these nutrients in micronutrient formulations may contribute to increased yield (Howeler 2014). Munyahali et al. (2017) found that application of NPK-formulated fertilizer resulted in increased cassava stem and root yield, emphasizing that application in areas with low nutrient levels can generate a satisfactory economic return for producers. Ezui et al. (2016) demonstrated that nutritional supplementation was able to increase cassava yield.

Base and topdressing fertilization, irrigation after transplanting, and climate conditions favored crop growth and development, mainly due to the absence of long periods without precipitation (Figure 1). Despite the resistance to stress conditions caused by water restriction (Egesi et al. 2007) and high adaptive capacity to different environmental conditions (Delaquis et al. 2018), according to FAO (2013), cassava can be grown in regions with approximately 400 mm rainfall during its growing cycle. Higher accumulated precipitation, preferably well distributed over the first three months of cultivation to avoid a drastic reduction of sprout emission, root growth, and subsequent development of accumulation roots, is required for high yields. A good water distribution during the cycle and the consequent maintenance of turgid cells is preponderant for plant growth and development although cassava is capable

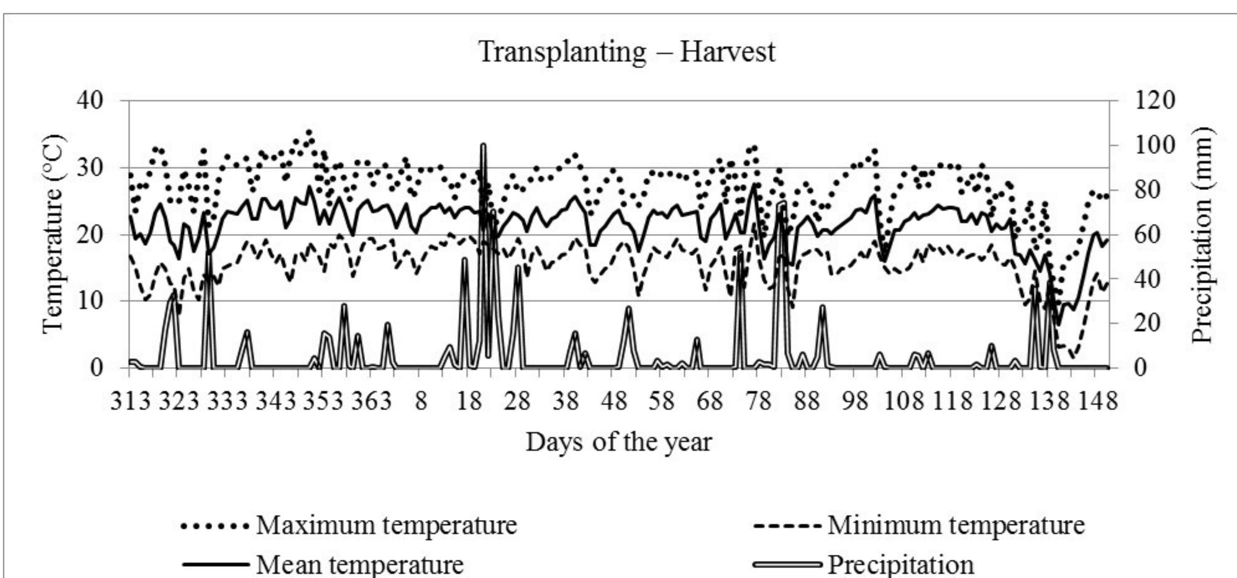

Figure 1. Minimum, mean, maximum temperatures and daily precipitation of seedling transplanting until the harvest of stems and roots.

of maintaining turgor even under drought conditions (Polthanee & Wongpichet 2017).

Also, night and daytime temperature variation within ranges close to the optimum temperature favors development (Floss 2011). This variation close to the optimum temperature for the crop was observed in most of the cycle, with daytime temperatures above 30 °C and nighttime temperatures below it. Cassava requires a temperature close to 25 °C and a high incidence of solar radiation for maximum growth and yield (Cock & Rosas 1975).

No difference was found between methods of estimating the accumulated thermal summation for stages from transplanting to the beginning of starch accumulation, beginning of starch accumulation to harvest, and transplanting to harvest (Table V). It occurred because the mean daily air temperature during these stages did not exceed the optimum temperature for cassava cultivation, which was 30 °C (Figure 1). Trentin et al. (2008) observed a similar result in a study whose objective was to determine the thermal summation of sub-periods of watermelon development by different methods.

In general, the duration of the stage from transplanting to the beginning of starch accumulation in thermal summation accumulation and days increased with a delay of the transplanting season and ranged from 355.25 to 432.40 °C day and 43 to 49 days, respectively. On the other hand, the duration of the stage from the beginning of starch accumulation to harvest and transplanting to harvest showed a reduction in the accumulated thermal summation as the growing season was delayed. The accumulated thermal summation ranged from 714.15 to 1178.95 °C day and 107 to 159 days from the beginning of starch accumulation to harvest for transplanting seasons performed on December 26 and November 9, respectively. Similarly, the accumulated thermal summation for the total transplanting cycle until harvest ranged from 1146.55 to 1534.20 °C day, corresponding to 155 to 203 days.

Table V. Accumulated thermal summation (°C day) and in days of stages from transplanting to the beginning of starch accumulation (BSA), BSA to harvest, and transplanting to harvest of cassava plants at four transplanting seasons (November 9 and 24 and December 3 and 26).

Transplanting – BSA		
	(°C day)	**Days**
November 9	355.25	43
November 24	411.10	45
December 3	379.90	45
December 26	432.40	49
BSA – Harvest		
	(°C day)	Days
November 9	1178.95	159
November 24	1027.70	142
December 3	987.80	138
December 26	714.15	107
Transplanting – Harvest		
	(°C day)	Days
November 9	1534.20	203
November 24	1438.80	187
December 3	1367.70	175
December 26	1146.55	155

The reduction in root fresh matter at the transplanting season of December 26 was mainly due to the shorter root tuberization time. Adventitious roots are replaced over the cycle by fibrous roots, which have the function of breaking deep soil layers, as well as absorbing water and nutrients. The number of fibrous roots that become storage roots is variable, and tuberization gradually increases over the crop cycle until the stage in which the partition of photoassimilates produced by the shoot is accelerated, with an increased translocation and accumulation of carbohydrates and soluble solids in reserve roots (Alves 2006). The beginning of this important period that defines root yield is marked by the beginning of starch accumulation in the roots, and the decrease in the stage from the beginning of starch accumulation to harvest caused by the transplanting carried out on December 26 resulted in a drastic reduction in root yield.

These results suggest that the highest root fresh matter, diameter, and length observed at the first two transplanting seasons are related to the accumulated thermal summation. A higher heat unit accumulation was observed at these times and, consequently, plant growth and development was favored mainly at the stage that defines root yield. The shorter the transplanting stage at the beginning of starch accumulation was, the longer the period of root starch accumulation until harvest, resulting in higher root yield and quality. On the other hand, the delay of the transplanting period demands a longer period of seedling establishment and to start the starch accumulation and, consequently, there was a shorter time for shoot development and starch deposition until harvesting, which significantly reduced yield and root quality. Photoperiod also influences crop development and long days favor shoot development, while short days promote a higher development of reserve roots (Alves 2006).

CONCLUSIONS

Seedling transplanting performed up to November 24 favored the expression of stem and root yield. The spacing 1.0 × 0.6 m showed the best results for stem yield traits.

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ANDRÉ SCHOFFEL[1]
https://orcid.org/0000-0002-2501-4834

SIDINEI J. LOPES[1]
https://orcid.org/ 0000-0002-7117-541X

JANA KOEFENDER[2]
https://orcid.org/0000-0002-5882-9669

ALESSANDRO D. LÚCIO[1]
https://orcid.org/0000-0003-0761-4200

JULIANE N. CAMERA[2]
https://orcid.org/0000-0001-7182-5788

DIEGO P. GOLLE[2]
https://orcid.org/0000-0002-5264-8007

[1]Universidade Federal de Santa Maria, Avenida Roraima, 1000, 97105-900 Santa Maria, RS, Brazil

[2]Universidade de Cruz Alta, Rodovia Jacob Della Méa, Km 5.6, 98005-972 Cruz Alta, RS, Brazil

Correspondence to: **André Schoffel**
E-mail: andre-schoffel@hotmail.com

Author contributions

André Schoffel contributed with project, experimental planning, experimental research, data analysis, data interpretation, revision and final review. Sidinei José Lopes contributed with project, experimental planning, data analysis, data interpretation and revision. Jana Koefender contributed with project, experimental planning, experimental research, data interpretation and revision. Alessandro Dal'Col Lúcio, Juliane Nicolodi Camera and Diego Pascoal Golle contributed with data interpretation and revision.