academicJournals

Vol. 11(46), pp. 4810-4818, 17 November, 2016
DOI: 10.5897/AJAR2016.11761
Article Number: C67767061723
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Sweet potato cultivars grown and harvested at different times in semiarid Brazil

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Received 26 September, 2016; Accepted 8 November, 2016

Sweet potato constitutes a source of energy and nutrient which is very important economically, especially, for the poorest people in the world, supplies calories, vitamins and minerals in the diet. The determination of the harvest age has great influence on vegetative production, quality, productivity and root biomass. The planting season is determined by climatic elements, which have influence on the growth, development and crop productivity. The objective of this paper was to evaluate the agronomic performance of sweet potato cultivars, as a function of the age of harvest in two growing seasons. Two experiments were conducted, the first in the rainy season and the second in the dry season in semiarid Brazil. In both experiments, the experimental design was a randomized block with split plots with four replications, being the plot formed by three cultivars (ESAM 1, Paraná and Mãe de Família), and the subplot by 5 harvest times (90, 105, 120, 135 and 150 days after planting). The length and diameter of commercial roots, dry mass of roots and shoots, and fitomass production were determined. The diameter, total dry mass of roots, commercial and total productivities of roots showed increasing responses with increasing harvest age in both crop growing seasons. The Paraná cultivar showed the best productive performance among cultivars. The harvest age of 150 days after planting was more productive. The best time of cultivation was in the dry season. Considering the importance of sweet potatoes, further studies are recommended in order to solve some problems related to adaptability and cultural reproduction in other regions to elucidate the effects of harvesting ages and growing seasons at longer intervals.

Key words: *Ipomoea batatas*, productivity, roots, tuberous.

INTRODUCTION

The sweet potato is one of the most important foods in the world because of its high yield and nutritional value (Data and Eronico, 1987; Raemaekers, 2001). The United Nations Food and Agriculture Organization (FAO)

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(1990, 2011) reported that sweet potato (*Ipomoea batatas* (L.) Lam.) is a very important crop in the developing world and a traditional culture, but less important in some parts of the developed world. According to FAO (2011), sweet potato is one of the seven crops in the world that produce over 105 million tons of edible products annually. Only potato and cassava, among the roots and tubers produce more. Only China produced 80-85% of sweet potato in the world, while other Asian countries had the highest production, followed by Africa and Latin America (Centro Internacional de la Papa, 2009).

The main producing countries are China, Russia, India, Ukraine and the USA, with annual worldwide production of potatoes in 2009 of about 329,581 million tons (FAO, 2011). Sweet potato [*Ipomoea batatas* (L.) Lam] in Brazil, is considered the fourth most consumed vegetable crop; in 2014, it recorded a production of 525,140 tons in 39.705 ha with an average productivity of 13.2 t ha^{-1} of roots, highlighting the Rio Grande do Sul as the largest producer. In the Northeast, where culture has participation in the economic and social scenarios, the state of Sergipe stands out as the largest producer with an output of 40,271 tons in 2014 and yield of 12.9 t ha^{-1}, followed by Paraíba State with a production of 28,121 tons and yield of 7.56 t ha^{-1} (IBGE, 2015). In addition to the ease of cultivation, the species shows a rich germplasm, in which is found variability for various features, resulting in ample adaptation to different environments, cultivation methods as well as allows meeting different consumer markets, since coloring of the pulp is an important factor for selection of the market (Ritschel and Huaman, 2002).

The sweet potato, beside been a rich source of starch, contains proper amount of secondary metabolites and small molecules that play an important role in various processes (Friedman, 1997).

Sweet potato cultivars with coloring of purple, white and pink films, and cream and white pulps are well accepted in the consumer market. However, film cultivars and orange pulp are not common in the local market, even though they stand out as a source of carotenoids and vitamin C, and can act as antioxidants (Padmaja, 2009). The use of sweet potatoes with orange flesh is seen as a viable alternative to supply the vitamin A deficiency in poor populations, and is a source of low cost and abundant of β-carotene (Rodriguez-Amaya and Kymura, 2004).

The species has continuous tuberset and in general, the harvest season is determined by factors such as demand and market price (Queiroga et al., 2007). Thus, besides cultivars with suitable coloring at the consumer market demand, sweet potato cultivation lacks information to obtain a quality product and economically feasible. Among these informations can mention the growing season (Medeiros et al., 1990; Villordon et al., 2010), the used cultivar and the appropriate age to harvest the roots.

Thus, the determination of the best cultivar and harvest age associated with better growing season can provide guidance to farmers producing sweet potato crop in a particular region, contributing to the increase of the productive chain, making it more efficient and profitable, adapting always to supply the demand. In this sense, the objective of this study was to evaluate the agronomic performance of sweet potato cultivars, as a function of the age of harvest in two growing seasons.

MATERIALS AND METHODS

Two experiments were conducted at the Experimental Garden at Federal Rural University of Semi-Arid (UFERSA), geographically located at 5° 11 'S 37° 20' W and 18 m. The first experiment was carried out from February 10 to 10 July and the second from 29 June to 28 November 2015. The climate can be classified according to Köeppen in BShw as dry and very hot, with two defined seasons: a dry (June to January) and a rainy season (February to May) (Carmo Filho and Oliveira, 1989). The average meteorological data of the period of the experiments are presented in Figure 1.

The soil of the experimental area was classified as Ultisol Eutrophic Abrupt, with sandy texture (Embrapa, 1999), whose chemical analysis, in the depth of 0.20 m, prior to installation of each experiment are shown in Table 1. Two months prior to installation of each experiment, branches of the cultivars were planted with the purpose of multiplication.

The experimental design was a randomized block in split plot with four replications, with the plot formed by the three cultivars (ESAM 1, Paraná and Mãe de Família), and the subplot by the five harvest times (90, 105, 120, 135 and 150 days after planting).

Cultivars showed the following characteristics: ESAM 1, fusiform roots, pink outer skin, cortex and white pulp (Murilo et al., 1990); Paraná, rounded roots and orange pulp (Moreira et al., 2011); Mãe de Família has long roots irregular with cream outer film and white pulp (Albuquerque et al., 2015). Plowing, disking and soil collection were carried out for analysis. Windrows were raised at 30 cm height manually with the aid of a hoe.

The spacing used was 1.0 m between rows (windrows) and 0.30 m between plants. The experimental plots were composed of four lines 3.0 m long, totaling 12.0 m^2 of total area, with a harvest area of 4.8 m^2. In each hole, were planted two branches with six buds each, three buds been buried, totalizing a population of 80 plants per experimental plot.

The fertilization was carried out as recommended for culture (IPA, 2008) and the irrigation was located drip with daily parceled irrigation interval in two applications (morning and afternoon), as water requirement of the crop. Manual weeding was performed whenever needed.

At harvest, the following characteristics were evaluated: length (CRL) and diameter (DCR) of commercial roots in cm (Cavalcante et al., 2010); root dry mass (RDM) and dry mass of shoots (DMS), estimated in four plants in the harvest area of each plot after drying in an oven with forced air, with temperature set at 65°C until constant mass, and expressed in t ha^{-1} (Oliveira, 2013); fitomass production (FP), obtained from the harvest of branches, to 3.0 cm from the ground, of all plants of the harvest area of each plot, and expressed in t ha^{-1} (Cavalcante et al., 2010); commercial productivity of roots (CPR) and total of roots (TPR), obtained from the weighing of 28 plants roots of the harvest area of each plot and expressed in t ha^{-1} (Cavalcante et al., 2010). Roots weighing more than 80 g were considered commercial, and those outside this standard or with defects were classified as non-commercial

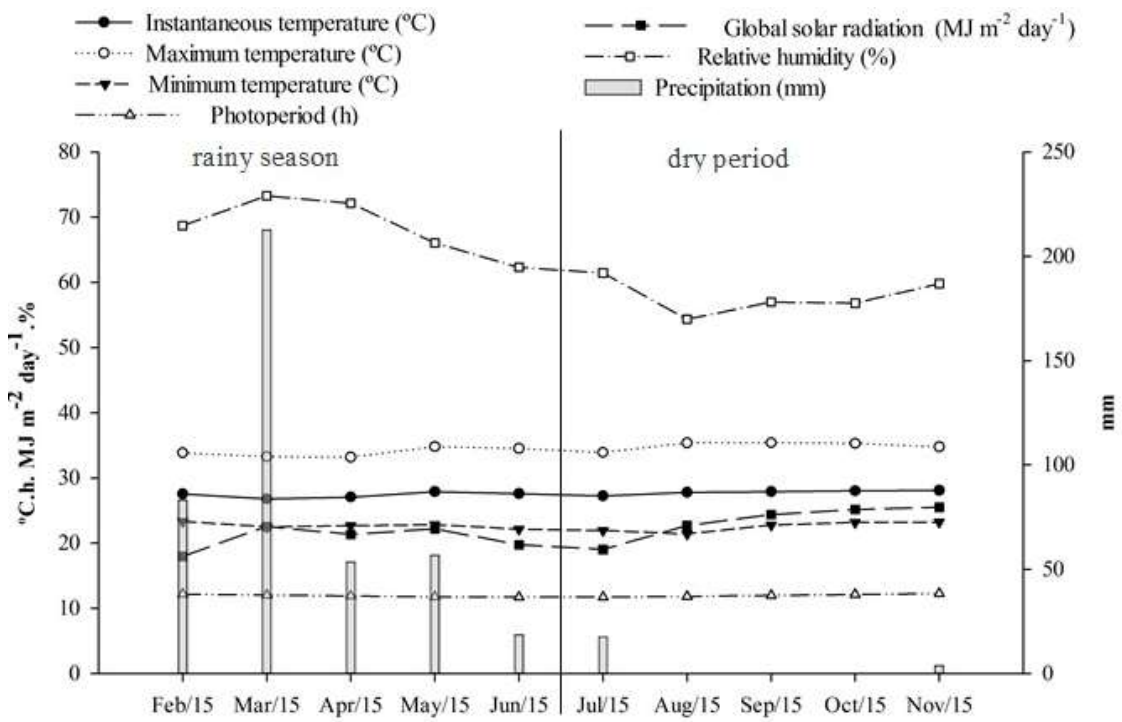

Figure 1. Average values of the instantaneous, maximum and minimum (C) temperatures, photoperiod (h), global solar radiation (MJ m^{-2} day^{-1}), relative humidity (%) and precipitation (mm) in each growing season of the sweet potato.

Table 1. Soil chemical analyzes in each growing season, in the depth of 0.20 m.

Growing seasons	N (g kg^{-1})	OM (g kg^{-1})	K	P	Na	Ca	Mg (dm^3)	pH	EC
			mg dm^3			($cmol_c$)			(dS m^{-1})
I	0.28	11.5	172.6	135.56	15.94	2.89	1.30	8.25	8.25
II	1.54	29.2	62.90	211.5	5.51	6.00	1.85	7.67	7.67

(Embrapa, 1995).

Analysis of variance for the evaluated characteristics was performed through the application SISVAR 3:01 (Ferreira, 2003). When the homogeneity of variance was observed, a joint analysis was applied, considering the growing season as a new factor. In quantitative factors, the fitting procedure of response curve was performed using the program Table Curve 2D (Systat Software, 2002), as prepared in Sigma Plot graphics 12.0 (Systat Software, 2011). The Tukey test ($p<0.05$) was used to compare the averages between growing seasons.

RESULTS AND DISCUSSION

After accepting the homogeneity of variances for length (CRL) and diameter (DCR) of commercial roots, root dry matter (RDM), dry mass of shoot (DMS), fitomass production (FP) a joint analysis of experiments was done, and a triple interaction was observed for all these features. The largest CRL values were recorded in the second growing season. Regardless of the age of harvest and growing season, the cultivar Mãe de família was presented the highest CRL (19.70 cm) to 120 DAP in the second growing season (Figure 2B).

The cultivar ESAM 1 showed an increasing linear correlation with respect to harvesting age in the second growing season for CRL, reaching 15.27 cm at 150 DAP (Figure 2B), indicating that the increase of the field period promoted greater root growth, differing from that of the first growing season, where decrease in the length of commercial roots in the cultivar at 150 DAP (13.49 cm) was observed (Figure 2A).

For the diameter of commercial roots (DRC), the highest values were found in the second growing season, being that the cultivar Paraná was that presenting the highest DRC at the 150 DAP, reaching 6.38 cm in the first growing season (Figure 3A). The results of this study were higher than those of Queiroga et al. (2007), in which

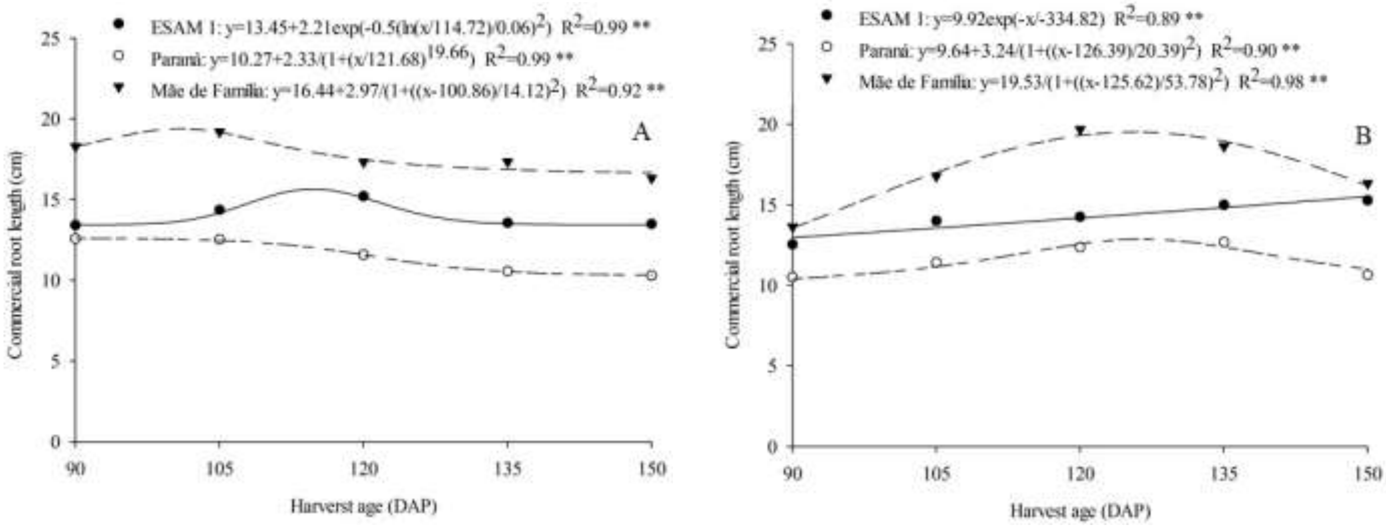

Figure 2. Commercial root length as a function of sweet potato cultivars and harvest ages in two growing seasons (rainy season A and the dry B).

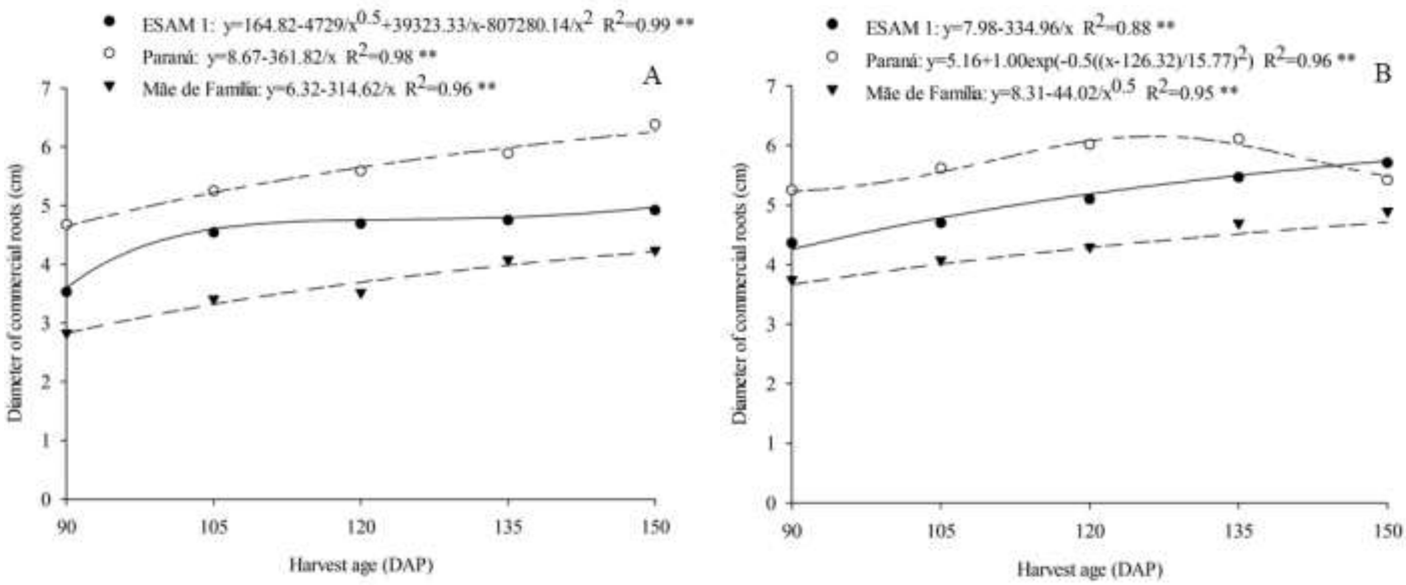

Figure 3. Diameter of commercial roots as a function of sweet potato cultivars and harvest ages in two growing seasons (rainy season A and the dry B).

three sweet potato cultivars (ESAM 1, ESAM 2 and ESAM 3) were studied as a function of the harvest season, in the rainy season of the conditions of Mossoro, where diameters varying of 4.59 to 5.29 cm were observed. These results show that the conditions and cultivation site are crucial in the development of tuberous roots.

Increased growth and diameter of sweet potato commercial roots allow infer that according to the cultivar studied and the conditions in which it is subjected are extremely important to define the material to be grown. According to Miranda et al. (1995), the tuberous roots of sweet potato of best rating (extra A) must have diameter between 5 and 8 cm and length ranging between 12 and 16 cm.

In the second growing season, the sweet potato trade roots showed higher growth and diameter of commercial roots as a function of the age of harvest. These positive results are due probably to the temperature increase in the second semester of the year, with variation of 33-

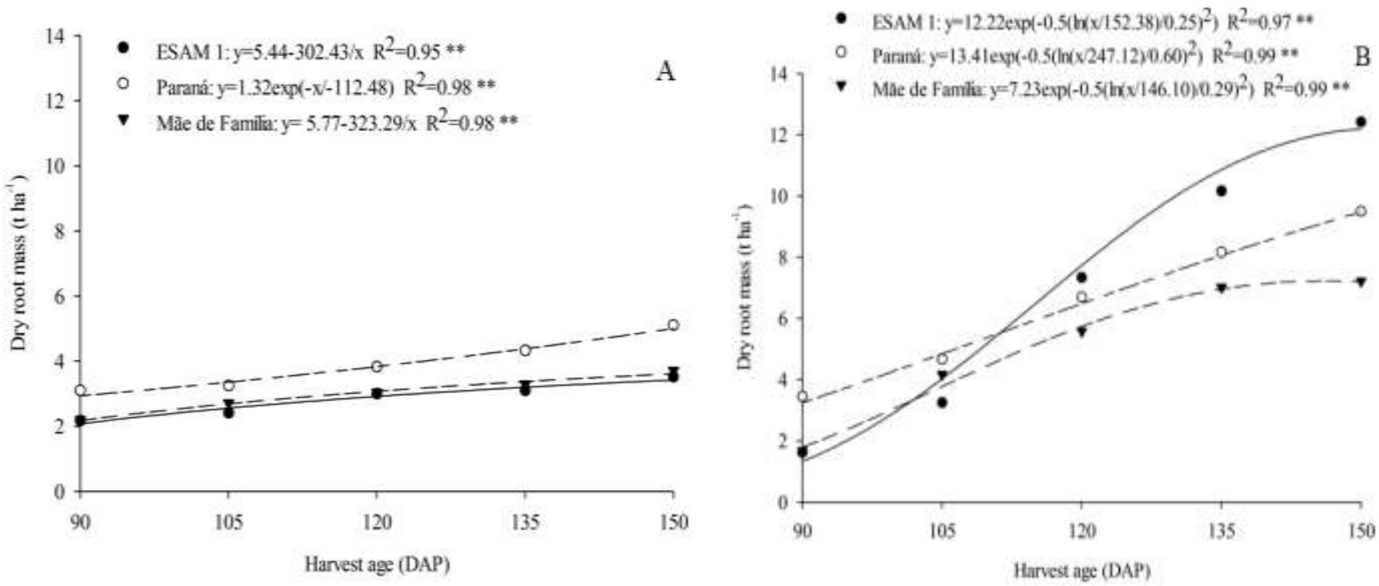

Figure 4. Dry root mass as a function of sweet potato cultivars and harvest dates in two growing seasons (rainy season A and the dry B).

35°C (Figure 1). The optimum temperature for growth of sweet potato roots is about 25°C, with standstill of growth occurring at temperatures below 15°C and above 35°C (Ravi et al., 2009; Spence and Humphries, 1972; Villavicencio et al., 2007). Although, there was temperature of 35°C (Figure 1) during the development of the work, the cultivars showed good performance which may be indicative of good adaptation to growing conditions.

Length and diameter of tuberous roots are among the most important characteristics for good marketing of sweet potato, because the consumer is increasingly demanding with regard to the visual quality of the product, making this a decisive factor when buying.

For producer, these characteristics are fundamental to the choice of material to be produced, given that according to the demand of the consumer market, standards of cultivars to be commercialized can be set.

Thus, the results observed for the cultivars studied shows the potential for improvement in the cultivation of sweet potato in semiarid conditions. It is worth noting that the cultivation at the appropriate time and with appropriate cultivars, not only bring an increase in production but also in the quality of the obtained roots.

In the dry mass of roots (MSR) of sweet potato, it was found that, as the harvest age increased, there was a dry mass increment for all cultivars evaluated in both growing seasons (Figure 4). However, the best time of cultivation was observed in the dry season. It was also observed that the cultivar ESAM 1 expressed higher values of MSR, when compared with the other cultivars in the second growing season, reaching 12.42 t ha^{-1} at 150 DAP (Figure 4B).

The increase of the dry mass of roots in the second growing season may have been caused by the higher incidence of solar radiation, which suffered variation from 27 to 28 MJ m^{-2} day^{-1} (Figure 1). According to Conceição et al. (2004), during the growth period of tuberous roots, high levels of solar radiation combined with suitable temperatures contribute to greater production of total dry matter, and consequently, the highest yield of tuberous roots.

The sweet potato cultivation in the hottest time of year can serve as an alternative for producers who own infrastructure and resources such as water, adding value to the product being offered and getting a higher market value of the marketed product.

The higher values of dry mass of shoots (DMS) were recorded in the first growing season for all cultivars (Figure 5). Regardless of the age of harvest and growing season, the cultivar Mãe de família presented the highest DMS content, reaching 4.20 and 3.20 t ha^{-1} at 90 DAP in the first and second growing season, respectively (Figure 6).

There was still a decreasing linear response for all cultivars, independent of harvest age and growing season (Figure 5). Erpen et al. (2013), evaluating the growing of sweet potato Princess as a function of four planting dates in subtropical climate in the spring summer season, found values close to those found in this work, which ranged from 3.1 to 5.4 t ha^{-1}.

The reduction to shoot dry mass in the first growing season can be attributed to decreased fitomass (Figure 6) at the same season as they are proportional characteristics. According to Spence and Humphries (1972) higher dry matter accumulation occur in the leaf (blade and petiole) per unit area before the formation of the tuberous roots of sweet potato. The activity of the source depends on the demand of assimilates of the drain, there is an interrelationship between the

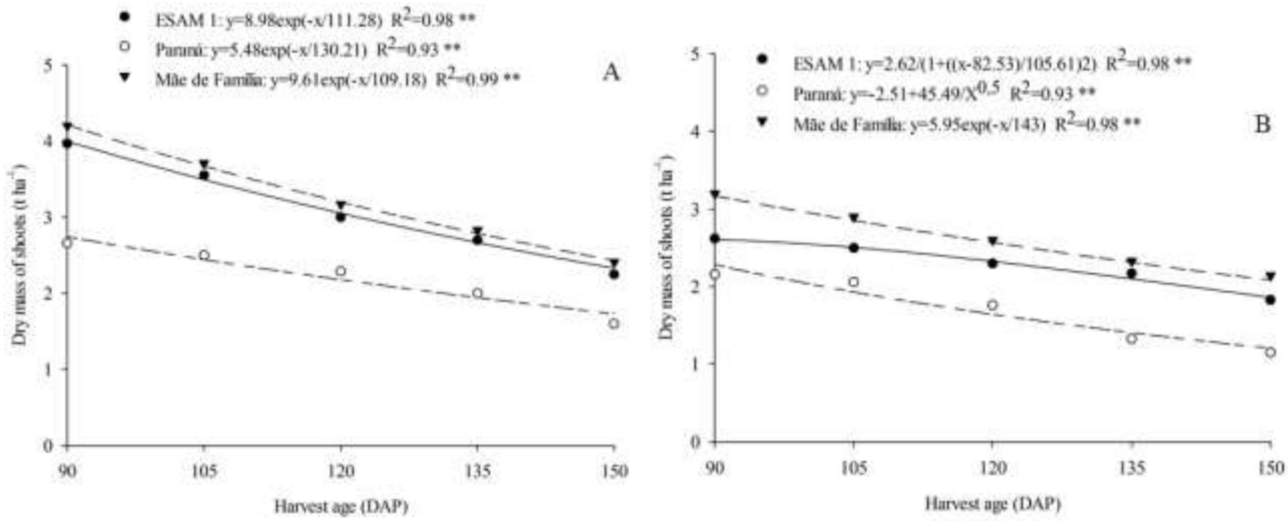

Figure 5. Dry mass of shoots as a function of sweet potato cultivars and harvest ages in two growing seasons (rainy season A and the dry B).

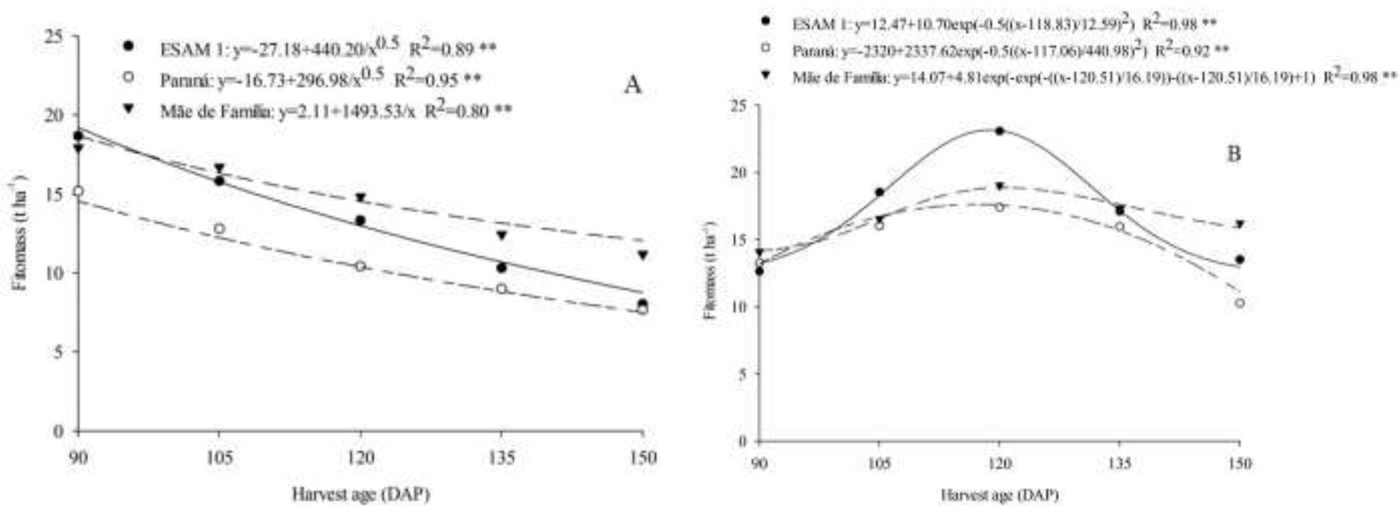

Figure 6. Fitomass as a function of sweet potato cultivars and harvest ages in two growing seasons (rainy season A and the dry B).

photosynthetic rate in the leaf and the storage of assimilated tuberous roots of sweet potato (Hozyo and Park, 1971; Spence and Humphries, 1972).

Evaluating the production of fitomass, maximum value of 120 DAP was observed for all cultivars in the second growing season (Figure 6). It was found that in the first growing season, there was a decrease in the production of fitomass for all cultivars (Figure 6A). The cultivar Paraná showed the lower fitomass production values in both croppings, reaching 7.67 and 10.27 t ha^{-1} in 150 DAP in the first and second growing seasons, respectively (Figure 6).

In this sense, the leaf area (source) is a determinant factor of the production, because its reduction means less absorption of radiant energy and less intense photosynthesis, reducing thus the production of biomass (Oliveira et al., 2010). The production of fitomass is directly reflected in the production; so, the producer can define the best age and harvest time to sell sweet potatoes, and significant gains in income, giving you greater flexibility on the demand and price marketplace. Additionally, you can also use fitomass as animal feed.

It is believed that the decrease in fitomass production is linked to senescence and leaf abscission and death of plants. Whereas harvest ages, with the increase of plant cycle, usually occur with reduction of leaf area due to senescence, and leaf abscission, but with favorable conditions for vegetative development of fitomass

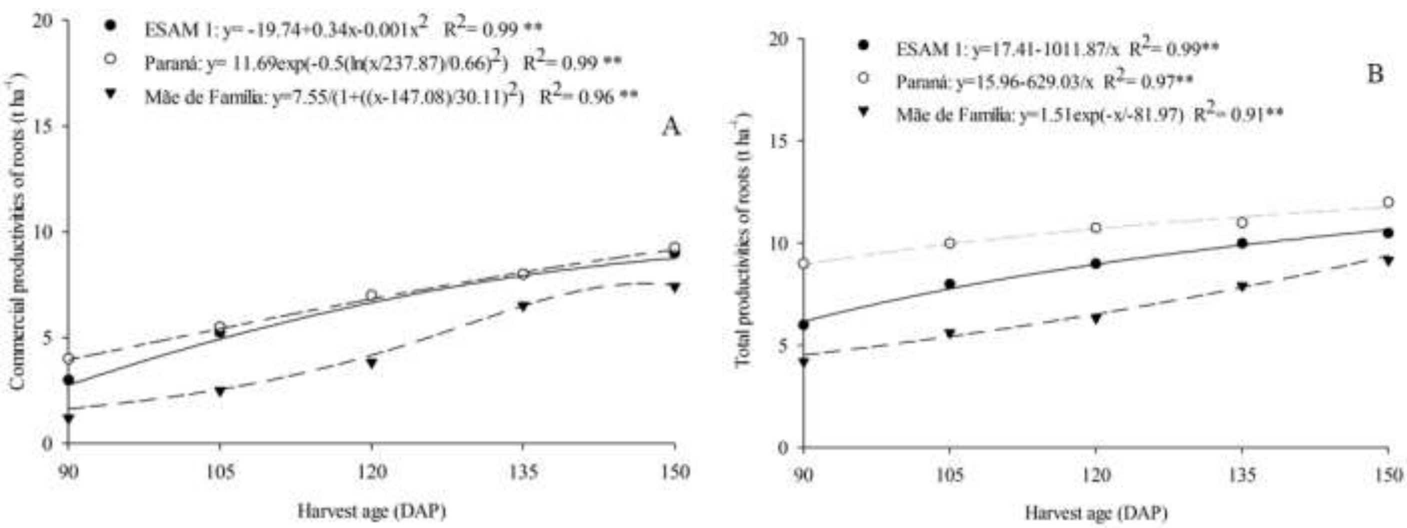

Figure 7. Commercial and total productivities of roots as a function of sweet potato cultivars and harvest ages in the rainy season.

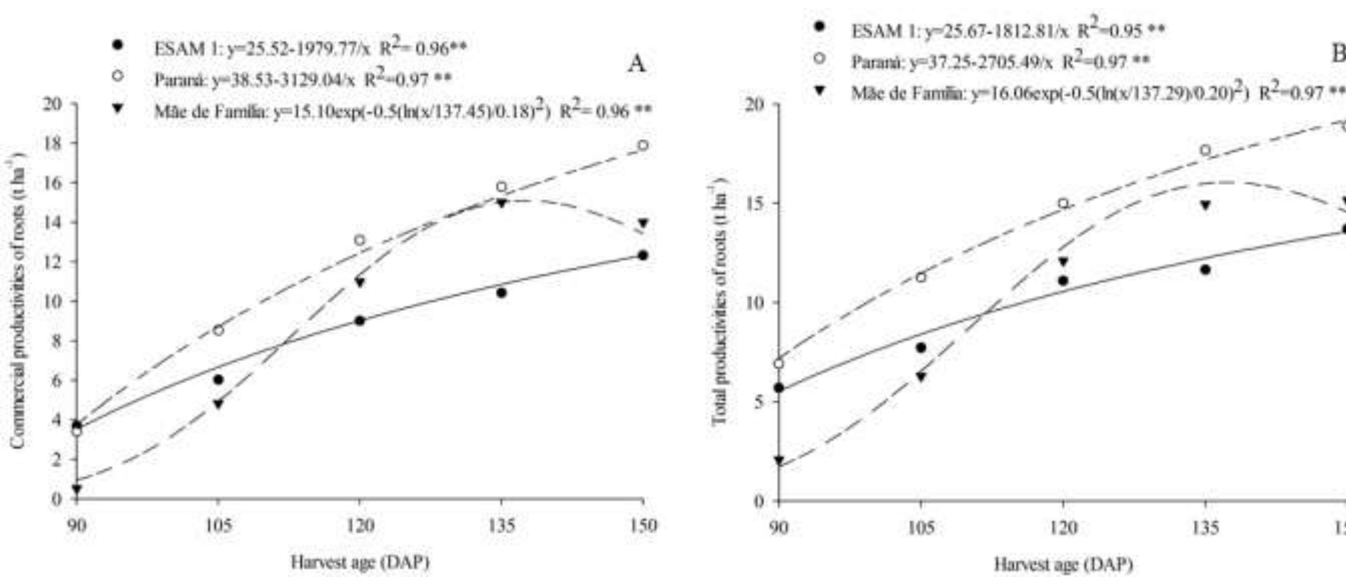

Figure 8. Commercial and total productivities of roots as a function of sweet potato cultivars and harvest ages in the dry season.

production can be maintained at high levels (Figueiredo, 1993).

The fitomass production values found in this work can be justified also by higher productivity index obtained at 150 DAP (ESAM 1 9.0 t ha^{-1}, Paraná 9.25 t ha^{-1} and Mãe de família 7.50 t ha^{-1}) for all cultivars, demonstrating that in this time, the preferred metabolic drain were the tuberous roots and not the shoot.

For the commercial productivity of roots (CPR) and total root productivity (TRP) in the homogeneity of variances was not accepted, thus performing a separate analysis of the experiments. From these results, there was a significant interaction (age x cultivar) in both croppings.

In the first growing season, regardless of the harvest age, the cultivar Paraná showed the greater commercial and total productivities roots, reaching 9.25 and 12.0 t ha^{-1} at 150 DAP, respectively (Figure 7A and B). It was also observed that all cultivars expressed an increasing linear response with respect to harvesting age.

In the second growing season, regardless of the harvest age, the cultivar Paraná showed the greater commercial and total productivities roots, reaching 17.67 and 18.89 t ha^{-1} at 150 DAP, respectively (Figures 8A and B). The cultivar Mãe de família showed a decreasing in the commercial productivity as from 135 DAP. It was also observed that all cultivars showed an increasing linear response with respect to harvesting age for full productivity.

Evaluating five sweet potato cultivars and two harvest seasons (150 and 200 days after planting) in the North of Minas Gerais, in the summer-autumn, Resende (2000) obtained an increase in productivity of all cultivars at 200 DAP, attributing the results to the longest period of crop permanency in the field. Queiroga et al. (2007) obtained an increase in the productivity at 155 DAP.

The source-drain relationship may also have been decisive in this respect, with the reduction of the shoots occurring in the largest production of tuberous roots. The production of the tuberous root is a function of the drain capacity and the potential of the source (Conceição et al., 2004). The sweet potato is a perennial crop, tuberosity continuously under favorable conditions, so that the longer the duration, the start of tuberosity-harvest allows more time for the accumulation of assimilates in the roots (Erpen et al., 2013).

After the beginning of the tuberosity initiation, productivity depends on the capacity of shoots to produce assimilated ones and translocate them to the roots (Somasundaram and Mithra, 2008). Consequently, high levels of solar radiation positively affect productivity of roots, since this variable is the energy source for photosynthesis.

Similar behavior was observed in both growing seasons, showing thus, positive responses with increasing harvest age. These positive results are due probably to the greater accumulation of assimilates in the tuberous roots due to longer time of the plant in field.

Thus, the producer can anticipate the harvest in 20 days without loss, or put it off for an equal time with significant gains in income, giving it greater flexibility on the demand and market price (Queiroga et al., 2007). In addition, the cultivar, Paraná was efficient in the absorption of resources, resulting in a good production, showing its productive potential in the region.

Conclusions

The sweet potato cultivar, Paraná showed the largest diameter of commercial roots, with the lowest increments of shoots and the highest commercial productivity of roots. At the age of harvest of 150 days after planting, the best agronomic results was observed for diameter of commercial roots, total dry mass of roots, commercial and total productivities of roots. The best cultivation season was observed in the 'dry' period. This work can be reproduced anywhere in the world, since the producers or researchers have knowledge of the agro-meteorological factors involved in the productive system, which can directly influence the productivity of the culture.

Considering the importance of sweet potatoes, further studies are recommended in order to solve some problems related to adaptability and cultural reproduction in other regions to elucidate the effects of harvesting ages and growing seasons at longer intervals.

Conflict of Interests

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The Federal Rural University of Semi-Arid, Federal Rural University of Pernambuco-Academic Unit of Serra Talhada and Higher Education Personnel Improvement Coordination are acknowledged.

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