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PRODUCTION OF SWEET POTATO (*Ipomoea batatas* (L.) Lam) IN AGROFORESTRY SYSTEM: CASE STUDY OF AN EXPERIMENTAL UNIT IN SANTARÉM, PARÁ, BRAZIL

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Abstract

Agroforestry systems (AFS) play a key role in recovering degraded areas and restoring fragmented landscapes, enabling the diversification of species that can be cultivated simultaneously. In this context, the introduction of short-cycle crops, such as sweet potato (*Ipomoea batatas* (L.) Lam), in agroforestry systems is a viable and affordable option for income generation due to low production costs and the relatively short cycle of this crop. A species of the Convolvulaceae family, sweet potatoes are recommended for hot climates. In this scenario, the present study aims to evaluate the production of sweet potatoes in different agroforestry arrangements. The experiment was conducted at the Experimental Farm of the Federal University of Western Pará in Santarém, State of Pará, Brazil. Sweet potato was cultivated in agroforestry systems in a completely randomized design, with three plots in each treatment (full sun, African mahogany reforestation, and teak reforestation). The results showed that, in the specific conditions of this study, sweet potato did not adapt to cultivation in shaded areas. The highest production was in full sun, where the consortium with forest species still does not provide shading for cultivation. These findings highlight the importance of considering the specific characteristics of sweet potato and its sunlight needs when planning and implementing agroforestry systems. Understanding these results contributes to making informed decisions regarding the development of cultivation and management strategies aiming to optimize sweet potato production in agroforestry systems.

Keywords: intercropping; agricultural component; species diversification.

PRODUÇÃO DE BATATA-DOCE (*Ipomoea batatas* (L.) Lam) **EM SISTEMA AGROFLORESTAL: ESTUDO DE CASO EM UNIDADE EXPERIMENTAL EM SANTARÉM, PARÁ**

Resumo

Os sistemas agroflorestais (SAFs) podem contribuir para a recuperação de áreas degradadas ou para a restauração de paisagens fragmentadas, com destaque para a diversificação de espécies que podem ser produzidas simultaneamente. A introdução de culturas de ciclos curtos em sistemas agroflorestais, como a batata-doce (*Ipomoea batatas* (L.) Lam), é uma opção acessível de renda, pois demanda baixo custo de produção e possui um ciclo relativamente curto. A batata-doce é uma hortaliça pertencente à família Convolvulaceae e é indicada para climas quentes. Nesse sentido, o presente trabalho teve como objetivo avaliar a produção de batata-doce em diferentes arranjos agroflorestais. O experimento foi realizado na Fazenda Experimental da Universidade Federal do Oeste do Pará em Santarém, Pará. A batata-doce foi introduzida em sistemas agroflorestais, com delineamento inteiramente casualizado e utilizando-se de três parcelas em cada tratamento (pleno sol, mogno africano e teca). Os dados mostraram que, nas condições expostas pela pesquisa, a batata-doce não se mostrou adaptada ao cultivo em áreas sombreadas, apresentando a maior produção nas condições de pleno sol, onde o consórcio com espécies florestais ainda não gera sombreamento ao cultivo.

Palavras-chave: cultivo consorciado; componente agrícola; diversificação de espécies.

Introduction

Brazil has a vast territorial extension and, as a result, a great climatic diversity and landscape changes, which makes it possible to cultivate different crops (Guimarães *et al.,* 2020). Agriculture is one of the pillars of the Brazilian economy. It is internationally recognized for the production and export of products. This panorama is the result of large investments in the development of new technologies and creation of public policies, such as tax incentives, price adjustments, stimulus to exports, and trade (Gomes, 2019). However, some agricultural activities accelerate and cause environmental impacts, such as burning and excessive use of fertilizers on properties, in addition to causing problems to human health and worsening air quality (Guimarães *et al.,* 2011; Gomes, 2019).

In view of this, there is a need to seek measures that promote the maintenance of the production scale within sustainable boundaries, with emphasis on agroforestry systems (AFS) (Buttoud, 2013). This form of cultivation consists of deliberately combining, in a same area, agricultural crops with perennial forest species with or without the presence of animals (Silva, 2013; Righi; Bernardes, 2018; Rosa, 2021). AFS may contribute to the recovery of degraded areas and the restoration of fragmented landscapes, with emphasis on the diversification of species that can be cultivated simultaneously (Rodrigues *et al.*, 2008), providing greater profitability and food and nutritional security for families (Miccolis *et al.*, 2019).

This model easily adapts to family production, improving the use of available labor and diversifying crops (Rodrigues *et al.*, 2007). AFS may bring financial return to the producer in the long term due to the cutting of trees. Therefore, it is relevant to introduce short cycle crops to obtain income throughout the development of the system (Graça *et al.*, 2000; Zanin; Meyer, 2018).

The introduction of crops with short cycles, such as sweet potato (*Ipomoea batatas* (L.) Lam), in intercropping is an income option, as it demands low production costs and has a relatively short cycle of 90 to 150 days until harvest (Silva; Lopes; Magalhães, 2008, Aguirre *et al.*, 2020, Coelho *et al.*, 2022). Sweet potato cultivation stands out for its profitability due to its simplicity of cultivation and low operational cost of development (Oloniyo *et al.*, 2021).

Sweet potato is a vegetable native to Central and South America. Its use dates back more than ten thousand years (Oliveira *et al.*, 2013). Although it is a perennial plant, its cultivation is carried out annually through different forms of planting, such as botanical seeds, branches, seedlings, or other plant tissues (Silva; Lopes, 1997). Sweet potato belongs to the Convolvulaceae family and is suitable for hot climates with average temperatures of 24 ºC (Silva; Lopes; Magalhães, 2008; Neumann *et al.*, 2017). Therefore, aiming to investigate alternative incomes to minimize the costs of perennial plantings in agroforestry systems, the present study aims to evaluate the production of sweet potatoes in a unit in Santarém, State of Pará, Brazil.

Material and Methods

The experiment was carried out at the Experimental Farm of the Federal University of Western Pará - UFOPA, located on the PA-370 highway (Santarém/Curuá-Una), in the municipality of Santarém, western region of Pará. It consisted of planting sweet potatoes in different agroforestry arrangements.

The region has a hot and humid climate, with rainfalls concentrated in the first half of the year. The average temperature ranges from 25 °C to 27 °C, and the average relative humidity is 86%. The average annual rainfall is 1,920 mm, with a monthly average of 60 mm. This climate is classified as Am3 (Martorano; Nechet; Pereira, 1993; Alvares *et al.*, 2013). The soil in the experimental area was classified as an Argisolic dystrophic yellow Oxisol, with sand contents between 439 and 679 g/kg, silica from 64 to 99 g/kg, and clay between 234 and 479 g/kg, according to Almada *et al.* (2021).

The area used for the project has a history of cattle ranching for more than 20 years, followed by natural regeneration and predominance of secondary vegetation (Pauletto *et al.*, 2022). In two areas of the experiment, the vegetation was manually cut and burned in 2016, and later teak (*Tectona grandis* Lf) and African mahogany (*Khaya grandifoliola*) plantations were introduced in 2017. In the third area, after the 2016 intervention, there was a period of natural regeneration for three years. In 2019, there was another removal of vegetation using agricultural equipment, followed by soil harrowing. In this area, legumes such as sunn hemp (*Crotalaria juncea* L.), jack bean (*Canavalia ensiformis*) and velvet bean (*Mucuna pruriens* (L.) D.C. var. utilis) were grown in 2020 and 2021 with the aim of improving soil conditions.

The experimental design was completely randomized, with three plots 1 m wide and 5 m long, totaling 15 m² of cultivation for each treatment. The preparation of the experiment area took place in November 2021 with the choice of two shaded areas (reforestation) and a control treatment with cultivation under full sun. The experiment consisted of intercropping sweet potato with teak (treatment 1) and African mahogany (treatment 2), both forest species cultivated in a spacing of 3 x 2 m, with five years of age (planting in March 2017).

In treatment 3, sweet potato was planted between tonka seedlings (*Dipteryx* sp.), spaced 6 x 3 m, with one year of cultivation (planted in February 2021), so as not to shade the plants grown nearby.

For planting, the soil was turned over in the entire length of the plots using a hoe. This portion of land was used to open furrows, with the shape of a mound, higher than the terrain, reaching approximately 30 cm in height. In each plot, 1.25 kg of dolomitic limestone and 3.75 kg of substrate composed of organic elements, such as chicken litter, black earth with burning residues, tanned sawdust, crushed charcoal and tanned rice straw, were added, in addition to chemical components, such as corrective fertilizer (nitrogen, phosphorus, potassium, and limestone) and potassium chloride. These inputs were incorporated into the furrow one month before planting for activation in the soil until the planting date.

The planting of sweet potato tuberous roots was carried out in December 2021, with the opening of five holes per plot, spaced one meter apart. This spacing was adopted based on the literature (Miranda *et al.*, 1995; Soares; Melo; Matias, 2002), which recommends cultivation with a spacing of 0.80 to one meter. For propagation, two sweet potatoes were introduced into each hole at a depth of approximately 15 cm and subsequently covered with soil.

Although it is possible to plant this species using branches (Rodrigues; Assunção, 2018), this method was chosen to standardize the propagation system since this study is part of a project that evaluates several species that produce tuberous roots and tubers.

During the experiment period (December 2021 to May 2022), monthly cultural treatments were carried out, such as manual weeding in the furrows and mechanical mowing around the cultivation area, aiming to control possible spontaneous plants competing with sweet potato. In an exceptional moment, in the plots of treatment 3, a herbicide (Select 240 EC) was applied three months after planting, on the side of the experiment and at a distance of one meter from the rows with the planted tubers, in order to minimize the occurrence of Mombasa grass (*Panicum maximum*).

In treatments with shading, it was not necessary to apply herbicides or carry out mechanical mowing due to the low occurrence of spontaneous plants in this area of the experiment. Manual weeding proved to be sufficient to control and clean competing plants.

The harvest was carried out 138 days after planting (May 2022), as there is no specific time to harvest sweet potato roots, which may be carried out 120 to 150 days after planting (Rezende, 2000); the greater productivity is obtained if done at 150 days (Coelho *et al.*, 2022). The roots were harvested manually, turning the soil with a hoe and machete to locate all tubers in the plots. Branches, leaves, and roots of plants were also collected for later determination of biomass (green matter and dry matter).

The harvested potatoes went through a process of washing and drying in open air for one day. Then, to evaluate production, all tubers of each plot/treatment were counted, weighed, and measured (length and diameter). All procedures were carried out at the facilities of the Laboratory of Forest Seeds of UFOPA with the aid of a caliper and a semi-analytical balance.

To account for shoot biomass, all leaves and branches harvested in the plots were initially weighed in field using a scale with a mechanical platform and plastic bags to avoid water loss and obtain more accurate data. Considering this biomass, three samples from each plot were taken, which were placed in closed plastic bags and weighed on the same day of harvest. Another weighing was carried out in laboratory with a semi-analytical scale (precision of 0.01 g) to account for the weight of the green matter. Then, the samples were placed in paper bags in an oven at 70 ºC for 48 hours until reaching a constant weight, indicating the complete extraction of water from the material (Petruzzi *et al.*, 2005).

The morphometric data of potatoes (weight, length, and diameter) were submitted to Lilliefors normality test. As most of the data did not present a normal distribution, a linear transformation was performed. To verify differences between treatments, an ANOVA was performed and the means were tested by Tukey test, adopting a significance level of 95%. All statistical analyses were performed using the Bioestat Program (Ayres *et al.*, 2007).

Results and Discussion

The results revealed variation in the production of sweet potato in the experimental area. Table 1 shows the descriptive data for each treatment, highlighting the performance of this crop in different agroforestry modalities. The comparison between treatments revealed a statistically significant difference (p<0.0001) in the weight of sweet potatoes, especially showing a difference between cultivation in full sun (treatment 3) and the other treatments. The same response pattern was observed in the statistical analysis of potato length and diameter. The results indicate that the partial luminosity offered to treatments with shading was insufficient to reach the same production levels obtained in full sun cultivation. This is probably because sweet potato is a species that requires high light incidence and long photoperiods (Silva; Lopes,1997; Mortley *et al.*, 2009).

Table 1. Descriptive statistics of morphometric characteristics of sweet potato (*Ipomoea batatas* (L.) Lam) cultivated in different agroforestry systems at the Experimental Farm of UFOPA, Santarém, Pará, Brazil.

Variable	Full sun (T3)			African mahogany (T2)			Teak (T1)		
	PW g	PL cm	PD cm	PW g	PL cm	PD cm	PW g	PL cm	PD cm
No. of potatoes		93			19			13	
Minimum	4.9	3.9	1.3	2.0	2.1	1.1	2.1	3.8	1.0
Maximum	884.1	24	7.9	89.9	14.1	3.6	107.9	12	4.2
Arithmetic mean	122.0a	12.6 a	3.6 a	30.0b	7.5b	2.3b	18.6b	6.5b	1.9b
Standard deviation	133.3	4.4	1.2	28.8	3.4	0.8	27.6	2.3	0.83
CV (%)	109.3	34.7	34.4	96.1	45.5	34.2	148.7	35.8	45.1

Different letters on a same line, for the same variable, differ statistically by Tukey test. PW=potato weight, PL=potato length, PD=potato diameter. CV: Coefficient of variation.

In the three plots of the African mahogany treatment, a total of 19 potatoes were obtained, while in the teak area 13 potatoes were obtained. The production in full sun was 93 harvested potatoes (Table 1), so that there is a favorable influence of luminosity on production.

Still regarding the data of Table 1, one can note the discrepancy between the maximum value of the variables diameter, weight and length, highlighting the treatment in full sun, while in the treatments with shading the values are mathematically similar. As for the behavior of data in relation to the coefficient of variation, the greatest variability between treatments occurred for the potato weight data (96.1% to 148.7%). Furthermore, it is clear that the other two variables (length and diameter) also show high data variability (CV >30%), indicating a high heterogeneity in production.

The results show that, in this experiment, the main limiting factor for sweet potato production was light since in the area in full sun, there was a greater amount of tubers in relation to shaded areas (teak and mahogany). Even so, edaphic conditions, such as root arrangement and competition for water and nutrients resulting from intercropping, may also have influenced the data. The studies of Carter, Sanderson and Peters (2009) and Gordon *et al.* (2011) indicate that the forms of soil preparation do not affect sweet potato productivity when comparing a conservationist system and a system prepared with little turning.

Although the production in shading treatments showed lower production rates, it is noteworthy that the cleaning cost was lower compared to maintenance with land clearing in the full sun area. For the full sun system, monthly weeding (close to planting) and mowing (one-meter radius from the windrows) were necessary throughout the experiment, generating a cost of 1.5 days/month of manual labor. In the treatments with shading, only manual pulling (weeding) of spontaneous weeds was carried out; weeds were little expressive, totaling approximately two hours of work per month in each treatment. This confirms that the shading promoted by agroforestry systems requires low capital requirements for its maintenance (Lopes, 2001).

Evaluating the two shaded treatments, both with elliptical canopies, even though teak has a greater deposition of leaves in the ground as it is a deciduous species (Verhaegen *et al.*, 2010), it did not affect production, as in the areas with this species the weight was 38% higher than for teak. Aspects related to the branching of both species should also be considered. Teak results in a broader canopy, leading to a greater shading in intercropping. It should be noted that during the experiment (December to May), there was no deposition of leaves by the deciduous species, as this condition occurs in the months with less rainfalls (September to November).

To assess which production values would be destined for commercial use, the minimum values adopted were potatoes with a diameter greater than 6 cm and a weight greater than 80 g. For this decision, the acceptance of sweet potato as commercial roots consists of a uniform format and mass that may vary between 80 g and 400 g (Filgueira, 2008). According to Resende (2000), consumer market acceptance varies, with values ranging from 151 g to 800 g. However, such markets can be considered as less demanding. Table 2 shows values of sweet potato weight considered commercially acceptable per plot (kg), per hectare (kg/ha), and percentage.

Table 1. Average yield of commercially acceptable sweet potato cultivated in different agroforestry systems at the UFOPA Experimental Farm, Santarém, Pará, Brazil.

Treatment	Potato weight per plot (kg)		Estimate per hectare
	>80 g	Total	Commercial weight (kg)
Full sun	3.1	3.8	2,049.0
African mahogany	0.1	0.2	39.4
Teak	0.0	0.1	24.0

Source: Prepared by the authors.

As for commercial weight, the average of potatoes per plot was 3.1 kg for full sun and 0.1 kg for African mahogany. The teak treatment failed to produce any commercially acceptable potatoes, resulting in an average of 0.0 kg per plot. Thus, the results showed that 76.9% of the total weight, in the full sun treatment, is commercially acceptable. Based on productivity estimates per hectare, 2,049.0 kg/ha were obtained in the full sun treatment, 39.0 kg/ha in African mahogany, and 24.0 kg/ha in the teak treatment (Table 2).

Several factors may affect sweet potato productivity. The study of Câmara *et al.* (2017) indicated that plants from tissue cultures showed a greater growth in mass and root production than that of the conventional cultivation. In addition, sweet potato crop responds to fertilization using chicken manure and mineral fertilizers (Rós; Narita; Hirata, 2014), as well as the addition of nitrogen, which increases the productivity of this species (Santos Neto *et al.*, 2017).

As for biomass, the percentage of water and dry mass did not present significant differences between treatments (Table 3). However, the sweet potato dry mass weight per plot and per hectare differs between treatments. It is higher in the full sun treatment. When comparing shaded areas (mahogany and teak), there was no difference in biomass results, even in the case of forest species with different characteristics. The biomass of sweet potato plants showed, after drying, that the average percentage of water contained in this material is 76.4% to 81%.

Table 2. Dry mass, fresh mass, and percentage of water in the shoot biomass, after drying, of sweet potato cultivated in different agroforestry systems at the Experimental Farm of UFOPA, Santarém, Pará, Brazil.

Treatment	Water	Dry mass	Dry mass	Dry mass	Fresh mass
	%	kg/plot		tons/hectare	
Full sun	79.8 a	20.2 a	3.0 a	6.0 a	31.0 a
African mahogany	81.0 a	19.0 a	0.2 b	0.5 b	2.4 b
Teak	76.4 a	23.6 a	0.3 b	0.5 b	2.2 b

Source: Prepared by the authors.

According to Lima Filho *et al.* (2014), green manure allows the soil to exert positive effects, such as minimization of erosion and the ability to produce phytomass for nutrient cycling, especially carbon (C) and nitrogen (N). The biomass of sweet potato shoots responds to N doses (Santos Neto *et al.*, 2017). Therefore, it offers an increase in aggregation, infiltration, and water storage in the soil. In addition, sweet potatoes have branches rich in starch, sugars, and vitamins. Sweet potato vines also have high levels of crude protein and nutrient contents, in addition to good dry matter indexes. This makes them suitable for animal feed, especially for ruminants (Monteiro, 2007; Capinus *et al.*, 2018), and can be used as good quality silage when additives are added to fresh matter (Valadares *et al.*, 2019). It can also be an alternative for use in times of scarcity (Pereira *et al.*, 2021).

Covering the soil with low-lying species such as sweet potato can protect the soil and add organic matter to it. The study of Lima (2022) with sweet potato cultivars reports a trend towards accumulation of dry mass in the shoots and maintenance of dry mass in the leaves even after 174 days of planting, which denotes the importance of this crop for the addition of material plant that could contribute to soil quality. However, the need for phosphate fertilization is emphasized to replace the amount of P exported by the harvested tuberous roots, thus avoiding loss of soil fertility (Cordeiro *et al.*, 2023).

The amount of dry matter in full sun (6.0 t/ha) was higher compared to that of some crops, such as forage peanut (*Arachis pintoi*), which has a dry matter rate of 3-4 t/ha, and Calopogonium (*Calopogonium mucunoides*), with 4-5 t/ha. This shows that sweet potato is a species with great potential for dry mass production when grown in full sun since in shaded treatments the dry mass estimates were lower (2.2 and 2.4 t/ha).

Conclusions

From the results obtained, it is concluded that the production of sweet potato has a low adaptation to shaded areas, taking into account the production data of tuberous roots. Planting in areas with full sun, despite requiring greater efforts for maintenance, is more efficient for the production of this species. Therefore, it is recommended to prioritize growing sweet potatoes in direct sunlight conditions to obtain better production results.

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