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# Yam tubers yield and quality subjected to nitrogen doses and staking methods[1]

## Produção e qualidade de túberas do inhame submetido a doses de nitrogênio e tipos de tutoramento

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*HIGHLIGHTS:*
*The maximum marketable yield of the yam is obtained with staking.*
*Nitrogen provides tubers with commercial standard mass.*
*Nitrogen and the staking promotes the potential of cultivar Da Costa to produce more than 15 tons ha$^{-1}$ in Entisol.*

**ABSTRACT:** Adequate mineral fertilization and staking are necessary to obtain good productivity in yam cultivation. The objective of this study was to determine the increase in yield and quality of yams subjected to nitrogen doses and staking methods. This study was carried out under field conditions using a randomized block design in a 5 × 3 factorial scheme, with five nitrogen doses (0, 50, 100, 150 and 200 kg ha$^{-1}$) and three staking methods (wire trellises, single staking, and without staking) with four replicates. Nitrogen doses were applied in topdressing, and split into equal parts at 60 and 90 days after seed tuber planting. Tuber length and weight, starch and leaf nitrogen concentrations, and total and marketable yields were determined. Staking promoted higher total yield, mass, length, and leaf nitrogen concentration, but no changes were observed in starch concentration among the staking methods. Commercial productivity was higher with single staking. Planting yam with staking and a nitrogen dose of 120.70 kg ha$^{-1}$ is recommended to promote maximum productivity.

**Key words:** *Dioscorea cayennensis*, tuber, mineral nutrition, development

**RESUMO:** No cultivo do inhame a adubação mineral e o uso de tutoramento proporciona boa produção. O objetivo deste trabalho foi avaliar a produção e a qualidade do inhame submetidos a doses de nitrogênio e tipos de tutoramento. O trabalho foi realizado em condições de campo no delineamento experimental em blocos casualizados em esquema fatorial 5 × 3, com cinco doses de nitrogênio (0, 50, 100, 150 e 200 kg ha$^{-1}$) e três tipos de tutoramento (espaldeiramento, vara e sem tutor), com quatro repetições. Na adubação em cobertura foram aplicadas as doses de nitrogênio parceladas em partes iguais aos 60 e 90 dias após o plantio. Foram avaliados comprimento, massa média, teores de amido e N foliar, produtividades total e comercial de túberas. O tutoramento promoveu maior rendimento total, massa média, comprimento e teor de nitrogênio foliar, entretanto não foram observadas alterações no teor de amido entre os tipos de tutoramento. A produtividade comercial é maior com a utilização do tutor em vara. Recomenda-se o plantio do inhame com tutoramento e dose de nitrogênio de 120,70 kg ha$^{-1}$ para promover a máxima produtividade.

**Palavras-chave:** *Dioscorea cayennensis*, tubérculo, nutrição mineral, desenvolvimento

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## Introduction

Yam (*Dioscorea* spp.) cultivation in Brazil has great socio-economic importance because of its use in human consumption and profitability. The most widely cultivated species in the Northeast Region are yellow yam (*Dioscorea cayennensis* Lam.) and water yam (*Dioscorea* alata L.) (Lovera et al., 2020), both of which contribute to the economic development of the Paraíba, Pernambuco, Sergipe, Alagoas, Bahia, and Maranhão states, because of their participation in farmers' income and local commerce (Brito et al., 2011).

However, the expansion of yam agribusiness in producing states is still limited, mainly because of the lack of scientific information required to increase productivity. Thus, research aimed at technologies that favor cultivation and nutritional management is essential to increase the productivity of this crop (Oliveira et al., 2015).

Nitrogen is one of the most essential nutrients for plant growth and development, given its role in protein composition and metabolic processes (Filgueira, 2008; Leghari et al., 2016). During cultivation, yam plant staking promotes tuber production because it allows the yam leaves to be adequately positioned for greater photosynthetic efficiency (Saravaiya et al., 2013). However, single staking and wire trellises are the most frequently used staking methods during yam cultivation in the Northeast Region (Oliveira et al., 2015), because of the following two reasons: the cost and the traditional areas for planting yams being located in the vicinity of the Atlantic Forest. As a result, the producer chooses to use wood obtained from the forest to carry out the single staking of the plants, damaging local biodiversity when exploited constantly.

Yam quality is directly related to the balanced nitrogen nutrition (Dantas et al., 2013). Thus, this study aimed to determine the increase in yield and quality of yam tubers subjected to nitrogen doses and staking methods.

## Material and Methods

The experiment was conducted under field conditions in the experimental area of the Centro de Ciências Agrárias, Universidade Federal da Paraíba, from February to December 2017.

The experimental area is located in the municipality of Areia, Paraíba, Brazil, in the Brejo Paraibano Microregion, at an altitude of 574.62 m, latitude 6° 57' 26" S and longitude 35° 45' 31" W. According to Köppen's classification, the predominant climate is As', characterized as hot and humid, with autumn-winter rains, and an average annual precipitation of 1.200 mm (Francisco et al., 2015). The soil of the experimental area is classified as Entisol, with a sandy loam texture (Santos et al., 2018). Meteorological data (INMET Automatic Weather Station of Areia, PB, Brazil) during the experimental period are presented in Figure 1.

The experimental design comprised randomized blocks, with treatments distributed in a 5 × 3 factorial scheme, with five nitrogen doses (0, 50, 100, 150 and 200 kg ha$^{-1}$), and three staking methods (wire trellises, single staking, and without staking), in four replicates. The experimental units were composed of 50 plants distributed in five rows at 1.20 × 0.60 m spacing. However, only the 24 plants in the three central rows were evaluated. Planting fertilization, 10 tons ha$^{-1}$ of cattle manure, 70 kg ha$^{-1}$ of $P_2O_5$ (simple superphosphate) and 60 kg ha$^{-1}$ of $K_2O$ (potassium chloride) were supplied (Cavalcante et al., 2008). The N doses were applied in topdressing in equal parts 60 and 90 days after yam planting, as described in the experimental design.

Soil samples were collected at 0-20 cm depth, before the experiment was set up for analyzing the chemical and physical attributes of the soil (Table 1).

Tuber seeds of Da Costa yam cultivar (approximately 200 g) were sown at a depth of 10 cm at the top of the soil mound. During cultivation, weeds were controlled with hoes, and in the period without precipitation, a supplemental drip

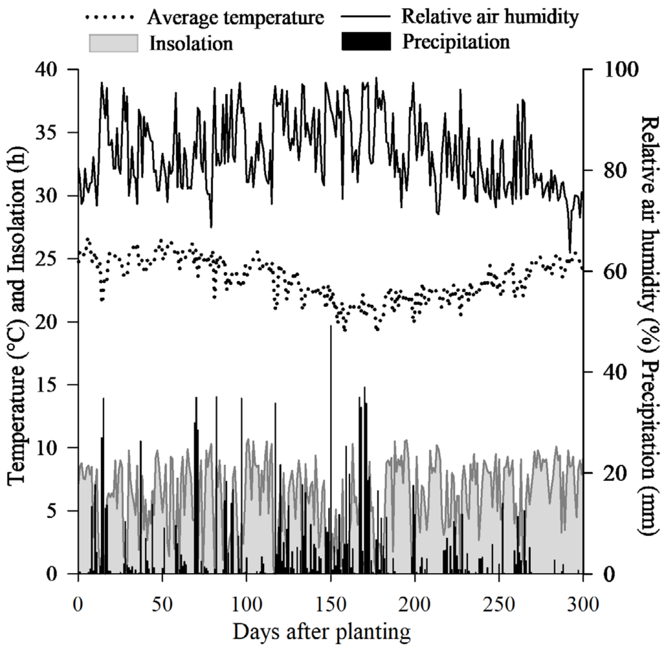



**Figure 1.** Average meteorological variables during cultivation of yam cultivar Da Costa

**Table 1.** Chemical and physical properties of the experimental area soil

| Chemical characteristics | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| pH $H_2O$ (1:2.5) | P (mg dm$^{-3}$) | $K^+$ | $Na^+$ (cmol$_c$ dm$^{-3}$) | $H^+ + Al^{3+}$ | $Al^{3+}$ | $Ca^{2+}$ | $Mg^{2+}$ | SB | CEC | OM (g kg$^{-1}$) |
| 6.3 | 32.04 | 79.14 | 0.06 | 1.65 | 0.00 | 1.48 | 1.18 | 2.92 | 4.57 | 12.49 |

| Physical characteristics | | | | | | |
|---|---|---|---|---|---|---|
| Coarse sand (g kg$^{-1}$) | Fine sand | Silt | Clay | Soil density (g cm$^{-3}$) | Particle density | Total porosity (m$^3$ m$^{-3}$) |
| 672 | 125 | 126 | 77 | 1.28 | 2.61 | 0.51 |

P, $K^+$, $Na^+$ - Extractor mehlich 1; $H^+ + Al^{3+}$ - Extractor calcium acetate 0.5M pH 7.0; $Al^{3+}$, $Ca^{2+}$, $Mg^{2+}$ - Extractor KCl 1M; SB - Sum of bases; CEC - Cation exchange capacity; OM - Organic matter (Walkley - Black) irrigation system was used in a two-day irrigation shift, with water depths of 5 mm per day and a flow rate of 2 L hour$^{-1}$, with space between tapes and emitters, according to the experimental spacing.

Stakes of *Mimosa caesalpiniaefolia* (L.) 1.50 m in length were purchased and inserted alongside the plants at the tuber emergence time as the single staking method. The wire trellises staking method was also composed of *M. caesalpiniaefolia* canes 2.0 to 2.20 m in length and buried at 0.50 m depth. During seedling development, a string was tied around the basal stem up to the espalier wire, as described by Oliveira et al. (2015).

The harvest occurred 210 days after tuber seeds were sown, when the tubers were immature, which is characterized by the end of flowering and senescence of the flowers, called the first harvest or "milking." The tuber length and mass, total and marketable tuber yield, tuber starch, and leaf nitrogen concentration were determined.

The length was obtained by measuring all marketable tubers with a ruler, and the values were expressed in centimeters. The marketable tuber mass was obtained by dividing the plot production by the number of marketable tubers, and the results were expressed in kilograms. Total yield corresponded to the weight of all harvested tubers, and marketable yield corresponded to the weight of tubers ranging from 0.7 to 3.0 kg, as described by Santos (1996), with data expressed in tons per hectare (tons ha$^{-1}$).

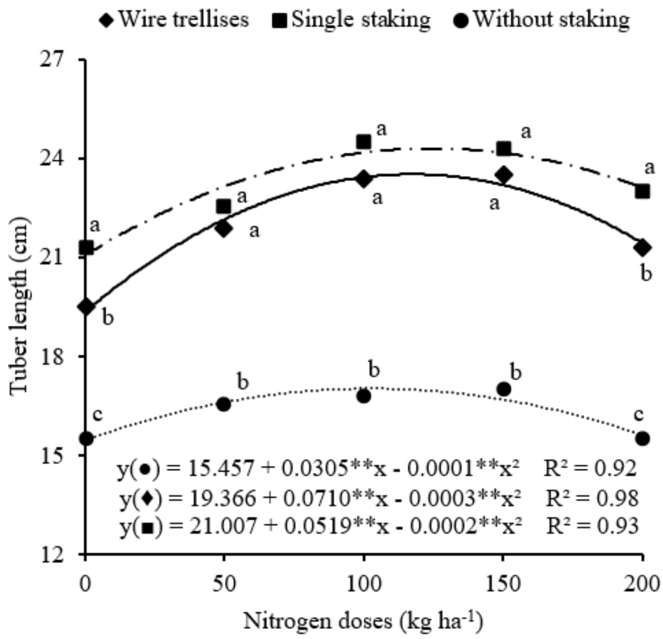
Fresh tuber samples (1.0 kg) were randomly collected to assess the starch content, according to the analytical standards of the Adolfo Lutz Institute (2005). At 150 days after planting, 20 leaves from the middle portion of shoots were collected from each treatment and replicated, to evaluate the leaf N concentration, according to the methodology described by Tedesco et al. (1995).

The results were subjected to analysis of variance (ANOVA) and polynomial regression to test the linear and quadratic models. The values of each staking method were compared at each nitrogen dose level by the Tukey test ($p \leq 0.05$). The criteria for choosing the model were the significance of the F test ($p \leq 0.05$) and a coefficient of determination ($R^2$) greater than 0.60. Statistical analyses were performed using the statistical program R (R Core Team, 2021).

## Results and Dicussion

There was a significant interaction effect ($p \leq 0.05$) on the length, marketable tuber mass, and marketable yield, with isolated effects of the factors on total yield, leaf nitrogen, and starch concentration of the yam cultivar Da Costa (Table 2).

Nitrogen doses of 118.33 and 129.75 kg ha$^{-1}$ promoted the production of yam tubers with 23.6 and 24.37 cm in length, on wire trellises and single staking, respectively (Figure 2). When the plants were not staked, the tubers reached only 15.5 cm, at a dose of 118.75 kg ha$^{-1}$. Staking promoted greater tuber length, regardless of the nitrogen dose applied, with emphasis on single




** - Significant at $p \leq 0.01$ by F test. Means of staking methods at each nitrogen dose followed by the same letters are the same by Tukey test at $p \geq 0.05$

**Figure 2.** Yam marketable tubers length in function of nitrogen doses in three staking methods

**Table 2.** Summary of the analysis of variance for tuber length (TL), marketable tuber mass (TM), starch concentration (SC), leaf nitrogen concentration (NC), total yield (TY) and marketable yield (MY) of yam cv. Da Costa, fertilized with nitrogen and different methods of staking

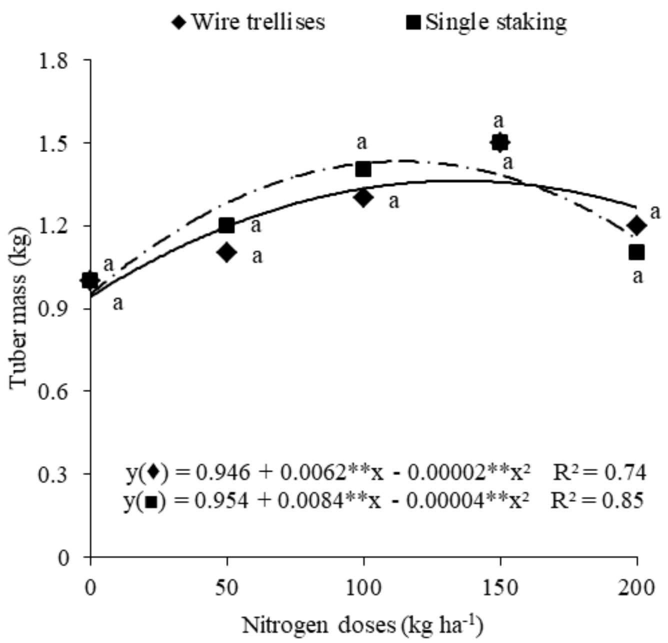
| Source of variation | DF | Mean squares | | | | | |
|---|---|---|---|---|---|---|---|
| | | TL | TM | TY | MY | NC | SC |
| Doses of nitrogen (D) | 4 | 11.116** | 0.275** | 60.704** | 46.622** | 99.035** | 20.505** |
| Methods of staking (M) | 2 | 118.866** | 0.778** | 135.931** | 232.724** | 27.707** | 18.520ns |
| Interaction (D x M) | 8 | 0.616** | 0.048** | 2.813ns | 7.285** | 0.951ns | 0.13ns |
| Nitrogen/Wire trellises | | | | | | | |
| Linear regression | 1 | 2.133** | 0.192** | 18.096** | 18.723** | 252.880** | – |
| Quadratic regression | 1 | 13.714** | 0.077** | 109.771** | 73.868** | 10.802ns | – |
| Nitrogen/Single staking | | | | | | | |
| Linear regression | 1 | 6.533** | 0.507** | 11.907* | 19.683** | 96.123** | – |
| Quadratic regression | 1 | 11.523** | 0.482** | 91.819** | 78.720** | 0.148ns | – |
| Nitrogen/Without staking | | | | | | | |
| Linear regression | 1 | 7.500** | 0.065** | 18.723** | 17.328ns | 69.616** | – |
| Quadratic regression | 1 | 20.023** | 0.009ns | 28.339** | 27.523ns | 0.228ns | – |
| Blocks | 3 | 0.466ns | 0.004ns | 2.354ns | 3.670ns | 4.501ns | 13.006ns |
| Residue | 42 | 0.195 | 0.005 | 1.683 | 1.081 | 3.160 | 0.549 |
| CV (%) | | 2.41 | 7.44 | 8.58 | 10.33 | 1.90 | 1.99 |

ns, *, ** - Not significant, significant at $p \leq 0.05$, and at $p \leq 0.01$ by F test, respectively. CV: Coefficient of variation staking, which resulted in higher lengths at doses of 0 and 200 kg $ha^{-1}$ nitrogen. Similar results were reported by Carvalho et al. (2014), who found a positive effect of staking methods on marketable tuber length.

Nitrogen fertilization associated with staking promoted greater tuber length because this nutrient helps increase chlorophyll concentration, resulting in a greater net rate of photosynthesis, as well as increasing plant metabolism enzymes. Consequently, nitrogen fertilization improves the exposure of plants to sunlight and provides a higher photosynthetic rate (Nunes et al., 2016; Binang et al., 2017; Abas et al., 2020). In the absence of staking, self-shading may have occurred, making it difficult for plants to absorb solar radiation, resulting in reduced photosynthesis and less starch storage in tubers. Further, self-shading also forms a microclimate favorable for the development of fungal diseases, which indirectly affects tuber growth (Carvalho et al., 2014; Norman et al., 2015).

Tuber mass presented a quadratic behavior, and the nitrogen doses of 105 and 155 kg $ha^{-1}$ promoted mean tuber mass of 1.39 and 1.43 kg, under single staking and wire trellises, respectively, with mean tuber mass of 0.8 kg in the method without staking (Figure 3). The staking methods showed no difference in the nitrogen doses applied. The tubers in all staking methods showed a commercial standard, due to their weight ranging from 0.7 to 3.0 kg, as described by Santos et al. (1996). In contrast to the results obtained by Ennin et al. (2014), the use of staking promoted greater accumulation of tuber mass.

The shortest tuber length was obtained using methods without staking, probably due to the contact of plant meristematic regions with the soil, causing blighting, in addition to inadequate disposition of leaves, which affected photosynthesis and resulted in low storage of plant photoassimilates (Saravaiya et al., 2013; Carvalho et al., 2014).



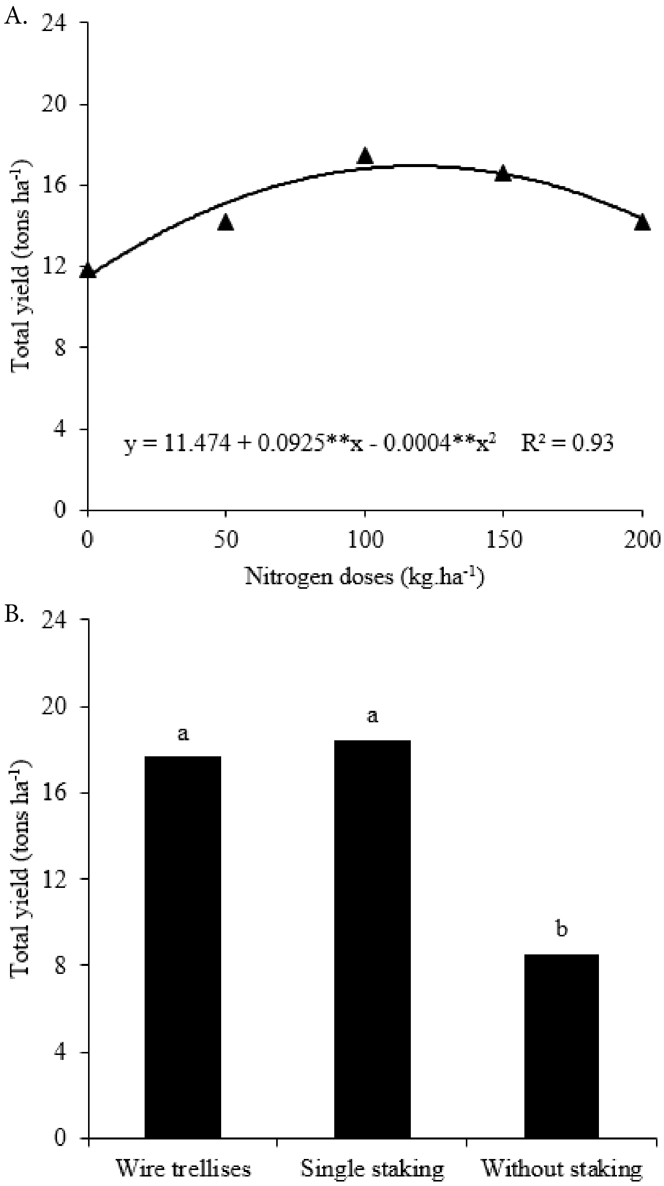

** - Significant at $p \leq 0.01$ by F test. Means of staking methods at each nitrogen dose followed by the same letters are the same by Tukey test at $p \geq 0.05$

**Figure 3.** Marketable yam tuber mass in function of nitrogen doses in two staking methods

Regardless of the staking method, the increase in the weight of tubers in response to nitrogen can be attributed to its influence on the concentration of chlorophyll, where it absorbs light energy to oxidize water, releasing oxygen, and producing NADPH and ATP; these are used to reduce carbon dioxide to form sugars, as well as to promote an increase in the starch enzyme synthetase in plants, promoting the rate of starch accumulation in tubers (Abas et al., 2020; Du et al., 2020).

Staking promoted a greater total yield regardless of the dose applied (Figure 4B). The maximum total productivity of 16.8 tons $ha^{-1}$ was obtained at a dose of 115.63 kg $ha^{-1}$, regardless of the staking method (Figure 4A). The simple staking method promoted higher marketable yield of tubers at all nitrogen doses, except for the application of 50 and 150 kg $ha^{-1}$, which was statistically similar to wire trellises.

The two staking methods, in the same order together with the nitrogen doses of 111.58 and 120.70 kg $ha^{-1}$, promoted the highest marketable yields of 15.5 and 16.6 tons $ha^{-1}$, whereas, without staking, only 7.1 tons $ha^{-1}$ was obtained (Figure 5).




** - Significant at $p \leq 0.01$ by F test. Means of staking methods followed by the same letters are the same by Tukey test at $p \geq 0.05$

**Figure 4.** Total yield of yam tubers in function of nitrogen doses (A) and at each staking methods (B)

Single staking provided increments of 3.4% and 28% in total yield, and 6.6% and 57% in marketable productivity, compared to staking with wire trellises and without staking. The marketable yields of staked yam in this study were above the average yield in the state of the Northeast region, with an average productivity of 9.6 tons $ha^{-1}$ (Garrido et al., 2017).

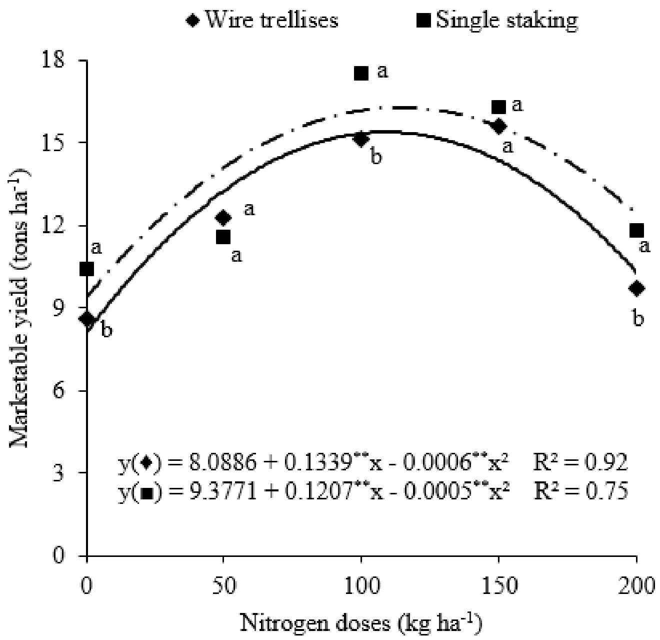
Although the highest yields were obtained with single staking, according to Oliveira et al. (2015), this method caused problems to the ecosystem in some yam producer states of the Northeast region, since they are usually taken from native species of the Atlantic Forest, causing an environmental disequilibrium. According to the same authors, the use of stakes obtained from species are from areas under management, such as the sabiá tree (*Mimosa caesalpiniaefolia* L.) or common bamboo (*Bambusa vulgaris*).

Nitrogen fertilization promoted yield increment regardless of the staking method, an effect already reported by Dantas et al. (2013) and Rezaei et al. (2017). The yam yield increment provided by nitrogen fertilization via topdressing was also reported by Oliveira et al. (2007) and Santos et al. (2015), with production ranging from 120 to 154.3 kg $ha^{-1}$.

The nitrogen doses recommended for yam cultivation in the Northeast region are between 50 and 100 kg $ha^{-1}$ (Filgueira, 2008). Thus, nitrogen doses that promoted the maximum yields were slightly above these intervals, demonstrating that in the edaphoclimatic conditions of Areia - PB, this nutrient must be supplied above the dose recommendations.

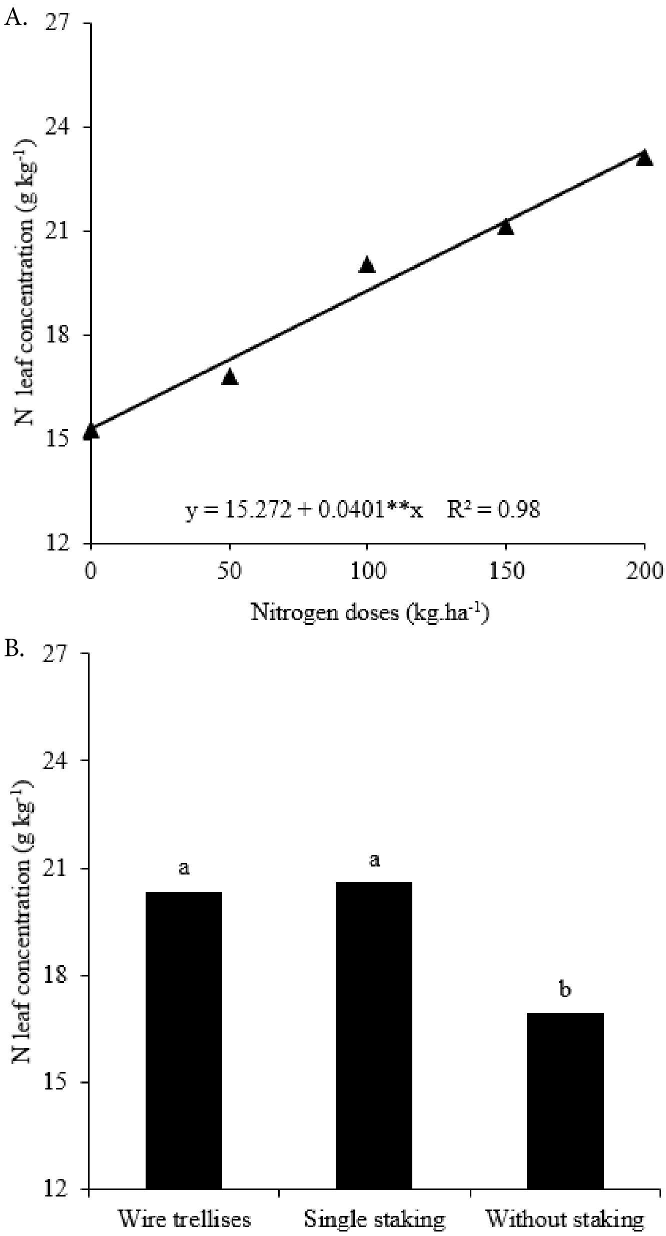
Recommendations for nitrogen fertilization in yams are complex. This can be attributed to the dynamics of nitrogen transformations in the soil, its mobility, and the factors that influence its absorption by plants (Malavolta et al., 2006; Silva et al., 2017). However, reductions in total and marketable yields at doses above those responsible for maximum yields may indicate that the excess of this nutrient is harmful to plant development. Moreover, how it produces intense dynamics in the soil can be attributed to many reasons, such as toxicity due to excess ammonium, as this favors the formation of reactive oxygen species and unbalances the cell pH, as well as, due to the source used (ammonia), it promotes a reduction in the absorption of metallic micronutrients; on the other hand, as it is a soil with low acidity and aerated, there is the possibility that this ammonium was oxidized to nitrate by nitrification and, in this case, decreased the absorption of phosphorus, sulfur, boron, and molybdenum (Miller & Cramer, 2005; Malavolta, 2006; Liu et al., 2017; Abas et al., 2020).

The use of staking methods, regardless of the applied nitrogen dose, promoted greater nitrogen leaf content (Figure 6B). Leaf N concentration increased linearly in response to the nitrogen doses, reaching a maximum value of 23.1 g $kg^{-1}$ at the highest dose (Figure 6A). These values are below the variation range (40–45 g $kg^{-1}$), described as




** - Significant at $p \leq 0.01$ by F test. Means of staking methods at each nitrogen dose followed by the same letters are the same by Tukey test at $p \geq 0.05$

**Figure 5.** Total and marketable yield of yam tubers in function of nitrogen doses at each staking methods



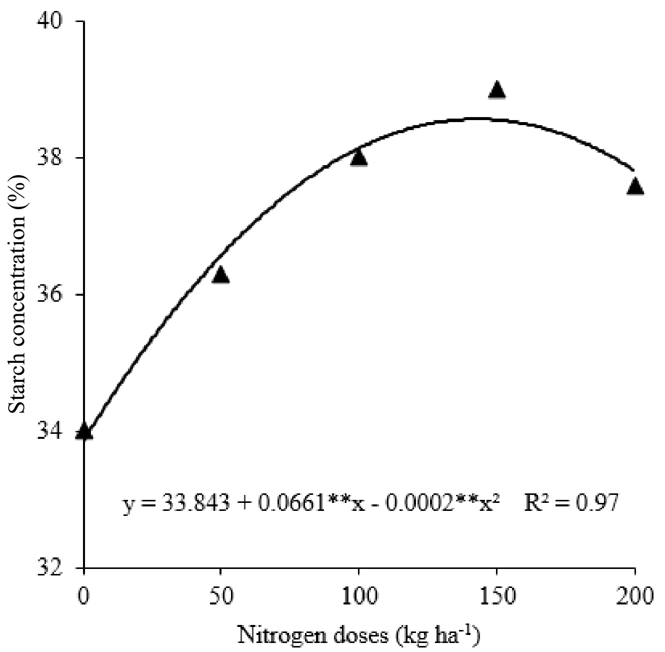

** - Significant at $p \leq 0.01$ by F test. Means of staking methods followed by the same letters are the same by Tukey test at $p \geq 0.05$

**Figure 6.** Nitrogen leaf concentration of yam plants in function of nitrogen doses (A) and at each staking methods (B)

normal for this crop, according to Malavolta et al. (2006). However, visual difference was observed only in the plants without staking.

The linear behavior of N concentrations in leaves indicated that the nitrogen doses did not reach the saturation level of absorption by plants, a fact also described by Oliveira et al. (2007) with the same yam cultivar. Thus, it demonstrates that increasing N concentration is necessary because nitrogen is one of the essential nutrients absorbed by yam plants (Oliveira et al., 2015).

The maximum starch concentration in yam tubers (39.3%) was obtained at a dose of 165.2 kg ha$^{-1}$ of nitrogen, decreasing its concentrations at doses above that level (Figure 7). This percentage indicates that starch accumulation in yam was not related to the staking method but was influenced by nitrogen, because it is a component of the starch synthetase enzyme and chlorophyll, which directly influences starch accumulation (Abas et al., 2020; Du et al., 2020). The decrease in starch concentrations with the nitrogen doses above those responsible for the maximum concentrations may indicate a nutritional imbalance in plants, which decreased starch biosynthesis in the tubers (Oliveira et al., 2002).




** - Significant at $p \leq 0.01$ by F test

**Figure 7.** Starch concentration in yam tubers in function of nitrogen doses

## Conclusions

1. Yam cultivation must be carried out with staking to promote its agronomic performance.

2. The single staking method and nitrogen dose of 120.70 kg ha$^{-1}$ are recommended to promote the maximum marketable yield of the yam cultivar Da Costa.

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