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*Full Length Research Paper*

# Effect of nitrogen and potassium fertilization on morpho-agronomic traits of three elephant grass (*Pennisetum purpureum* Schum.) genotypes for biomass production

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**Elephant grass has been proposed for the energy sector as a possible source of renewable energy, because of its high biomass production. The aim of this study was to evaluate the effect of the mineral nutrients nitrogen and potassium on the morpho-agronomic traits (dry mater yield (DMY), percentage of DM (%DM), number of tillers per linear meter (NT), plant height (PH), stem diameter (SD) and leaf blade width (LW)) in different elephant grass genotypes in a randomized-block experimental treatment in a split-plot arrangement with three replications, in which the genotype factor ('Cuban Pinda' - G1; 'IAC Campinas' - G2; and 'Cameroon' - G3) was randomized in the plot, and the N and K factor was randomized in the sub-plot. The increase in nitrogen and potassium doses utilized influenced very little or almost did not influence the response of the three genotypes for the different morpho-agronomic traits assessed. The three genotypes had high number of tillers, height, and stem diameter at the lowest N and K doses, demonstrating a possible trend of high doses not providing a highly significant increase in these traits. The study of DMY showed that under a low nitrogen dose and with increase in potassium concentrations, dry matter yield increased; however, as the nitrogen dose increased in associated with potassium doses, dry matter yield did not augment, but was rather suppressed. The three elephant grass genotypes: 'Cuban Pinda', 'IAC Campinas', and 'Cameroon', had average dry yields of 52.66, 50.60, and 48.57 t ha$^{-1}$, respectively. Results are highly promising and prove the possibility of using elephant grass as an alternative source for biomass production.**

**Key words:** Renewable energy, mineral nutrients, production capacity.

## INTRODUCTION

The tropical-climate conditions of Brazil have characteristics that facilitate production of biomass such as sugarcane bagasse, charcoal, and wood (Rocha et al., 2015). The tropical climate is very favorable, especially to

C4 plants, which have a high plant mass accumulation in a short period, making the use of solar energy efficient. In this regard, the Poaceae family stands out for their greater plant mass production in relation to other plants. Elephant grass is species with great photosynthetic (C4 metabolism) and dry matter accumulation capacities, which make it comparable to sugarcane (Daher et al., 2014). This grass has shown tremendous advantages in relation to the other energy sources in research conducted so far (Oliveira et al., 2013). Elephant grass is highly productive in smaller areas, has a lower production, allows total mechanization, and provides renewable energy, greater carbon assimilation, and increased productivity by increasing the applications of nitrogen and potassium (Santos et al., 2014; Woodard and Sollenberger, 2015).

Nitrogen is one of the nutrients that most limits the development and biomass production of most Brazilian crops. The adequate management of fertilizers, especially those containing nitrogen, given the deficient availability of this nutrient in the soil, is fundamental for obtaining gains in productivity (Flores et al., 2013). Thus, it is important to adequate the use of nutrients in the elephant-grass production system so as to optimize the gains in renewable energy. Today, because of the elevated biomass production potential of elephant grass, it is being used in the form of direct combustion, in heat supply, replacing wood or charcoal. This energy source will be able to replace the man-made coal extracted in a predatory manner from native forests, which has caused environmental damage, like siltation and consequent death of several rivers.

Potassium is the second most widely required mineral in quantity by plant species, after nitrogen. It is highly mobile in the plant at any concentration, and it in the cell, in the plant tissue, in the xylem, or in the phloem. Potassium is not metabolized in the plants and binds to easily-reversible organic molecules. Furthermore, it is the most abundant ion in plant cells (Marschner, 1995). The potassium occurs in ground in two forms: as component of solid phase and as $K^+$ ion in the liquid phase, (Meurer, 2006). Potassium is a macronutrient present in the plants in similar amounts to the nitrogen. The adequate levels for the great growth are between 2 and 5% of the dry weight, depending on the species, the stage of development and the plant's organ. It has a mobility broad in the plant, as much as between the individual cells, the tissues and in the transportation to long distances too by way of xylem and phloem. It is common for potassium to be redistributed from old leaves to new ones.

Potassium is the second most widely required mineral in quantity by plant 56 species, after nitrogen. It is highly mobile in the plant at any concentration, be it in the 57 cell, in the plant tissue, in the xylem, or in the phloem. Potassium is not metabolized in the 58 plants and binds to easily-reversible organic molecules. Furthermore, it is the most 59 abundant ion in plant cells (Marschner, 1995).

In plant breeding, associations among traits are important, as they allow for several traits to be improved simultaneously. To meet the demands of producers of charcoal from elephant grass, varieties adapted to the different ecosystems, to generate biomass production, are greatly sought. Characteristics such as faster growth, high yield, high energy efficiency, efficient mineral nutrient use, more uniform distribution of the dry matter production throughout the year, and less or more resistance to pests and diseases are used to discriminate between promising genotypes (Menezes et al., 2015; Santos et al., 2014).

Given the earlier-stated facts, this study was conducted to evaluate the effect of different nitrogen and potassium fertilization levels on the main morpho-agronomic traits of three elephant grass genotypes.

## MATERIALS AND METHODS

### Cultivation conditions and genetic materials

The experiment was conducted in the Cattle Unit at the Federal Institute of Science and Technology of Rio de Janeiro State, on Bom Jesus do Itabapoana Campus (UTM 223877 m E and 7660277 m N, 24K zone, 84 m altitude Climate Northwest Fluminense is, according to the classification Köppen, Aw (with hot and rainy summer and dry winters).

The soil was sampled from the 0 to 20 cm layer for particle-size and chemical analyses, and showed the following results: sand, 55.8%; silt,13.6%; clay, 30.6%, pH in $H_2O$, 5.1; P, 3.0 mg $dm^{-3}$; K, 36.0 mg $dm^{-3}$; Na, 0.06 mg $dm^{-3}$; Ca, 84.1 mg $dm^{-3}$; Mg, 31.6 mg $dm^{-3}$; Al, 2.6 mg $dm^{-3}$; H+Al, 47.6 mg $dm^{-3}$; effective CEC, 154.3 mg $dm^{-3}$; CEC at pH 7.0, 199.3 mg $dm^{-3}$; SB, 151.7 mg $dm^{-3}$; base saturation, 68%; and aluminum saturation, 3.0%. The analysis was performed in the Soil Physics Laboratory at the Center for Agricultural Sciences at the Federal Rural University of Rio de Janeiro. The soil was classified a Red-Yellow Ultisol (Embrapa, 2013).

The experiment was implemented as a randomized-block design, in a split-plot arrangement, with three replications, in which the genotype factor ('Cuban Pinda' - G1; 'IAC Campinas' - G2; and 'Cameroon' - G3), which originated from the breeding program at UENF, was randomized in the plot, and the N and K factor, in the sub-plot. Four nitrogen fertilization doses (100, 800, 1500, and 2200 kg N $ha^{-1}$ $year^{-1}$ of urea) and four potassium fertilization doses (50, 400, 750, and 1100 kg $K_2O$ $ha^{-1}$ $year^{-1}$ of potassium chloride) were applied on the subplot, with three replications.

The experimental area was formed by nine 54-m rows spaced 1.50 m apart, and each block was formed by 16 experimental units (plots) with 3.0 m linear extension. The grass was harvested twice, at 365-day intervals. The usable area of 2.25 $m^2$ was obtained

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by removing 1.50 m from each plot. Stems were planted aligned inside the furrows, with the base of a plant touching the apex of another plant, and subsequently cut and covered with 3 cm of soil.

Planting took place on October 02, 2012. A plot-leveling cut was made on February 12, 2013 (130 days after planting). The 1st harvest for evaluation occurred on February 12, 2014 (365 days after the plot-leveling cut) and the second on February 12, 2015 (365 days after the 1st harvest). The mean of both harvests were used to evaluate the morpho-agronomic traits, to have more consistent numbers for the discussion of results.

### Evaluated trais

The dry matter yield (DMY) of the whole plant was estimated as the product between the fresh matter of whole plants (kg), obtained on a digital scale, originating from 2.25 $m^2$, by the percentage of dry matter of the whole plant (%DM), obtained from the sampling of these plants; this variable was estimated from samples of whole plants extracted at random among the plants cut from the usable area, and the obtained value ($kg/m^2$) was converted to t $ha^{-1}$. The percentage of dry matter of the whole plant (%DM) was estimated in whole-plant samples extracted at random among the plants from the usable area which were weighed and pre-dried in a forced-air oven at 65°C for 72 h (air-dried sample, ADS) and weighed again to obtain the percentage of dry matter of the whole plant (%DM), following the method described by Silva and Queiroz (2002). After drying, samples were ground (1 mm) through a Wiley mill and packed in bottles. The dry matter contents were obtained by drying the material in a forced-air oven at 105°C for 24 h (oven-dried sample, ODS), and this parameter served as basis to express the dry matter yield in t $ha^{-1}$ (DMY). The following variables were also determined: average plant height (PH), expressed in meters, measured with a ruler graduated in centimeters from the base of the plant to the apex of erect leaves during the harvest for evaluation, based on the height of five plants from the usable area; number of tillers per linear meter (NT), obtained by counting the number of tillers higher than 70 cm from the usable area of the plot, moments before the harvest for evaluation; average stem diameter at the plant base (SD), expressed in centimeters, taken from five plants from the usable area of the plot, measured 10 cm above the soil level with a digital caliper during the harvest for evaluation; and leaf width (LW), expressed in centimeters, taken from five plants from the usable area of the plot, measured with a millimeter ruler at the middle third of the leaf blade during the harvest for evaluation.

### Statistical analysis

Analyses were performed using the Genes (Cruz, 2013) and SAEG (version 9.0) computer programs developed at the Federal University of Viçosa.

$$Y_{ijkl} = \mu + B_l + G_i + \varepsilon_{(a)} + N_j + G_iN_j + K_k + G_lK_k + N_j K_k + G_jN_jK_k + \varepsilon_{(b)}$$

where $Yi_{jkl}$ is the observed value referring to genotype i, at nitrogen dose j, at potassium dose k, on block l; μ is the overall mean of the experiment; $G_l$ is the effect of genotype i; $B_l$ is the effect of block l;
$\varepsilon_{(a)}$ = effect of error a, associated with genotype i on block l; $N_j$ is the effect of nitrogen dose j; $G_iN_j$ = effect of the interaction between genotype i and nitrogen dose j;
$K_k$ is the effect of potassium dose k; $G_iK_k$ is the effect of the interaction between genotype i and potassium dose k; $N_jK_k$ is the effect of the interaction between nitrogen dose j and potassium dose k; $G_iN_jK_k$ is the effect of the interaction among genotype i, nitrogen dose j, and potassium dose k; and $\varepsilon_{(b)}$ is the effect of error b associated with genotype i with nitrogen dose j and potassium dose k on block l. $\varepsilon_{(a)}$ and $\varepsilon_{(b)}$ ~NID $(0, \sigma^2 \varepsilon_{a,b})$.

## RESULTS AND DISCUSSION

### Variance analysis

The results of the analyses of variance for the morpho-agronomic traits evaluated involving three genotypes and four nitrogen and four potassium levels showed a significant effect ($P<0.05$) for dry matter yield (DMY) from all factors and interactions. For percentage of dry matter (%DM) and average leaf width (LW), however, no significant effect was detected ($P>0.05$) from any factor or interactions, indicating independence among the factors. For the genotype factor, there was no effect on any of the studied traits.

In the analysis of the sources of variation nitrogen and potassium × nitrogen and potassium × nitrogen × genotype interactions, there was a significant effect ($P<0.05$) on the traits DMY, number of tillers per meter (NT), and plant height (PH). However, there was a highly significant effect ($P<0.01$) of the sources of variation nitrogen, potassium, and potassium × genotype and potassium × nitrogen × genotype interactions on the morpho-agronomic traits DMY, NT, and stem diameter (SD). Hence, it was observed that the effect of nitrogen fertilization did not influence percentage of dry matter (%DM), NT, SD, or average LW; potassium fertilization did not influence %DM, PH, or average LW of the elephant grass; and the variation in these traits may be due to the genetic factor.

### Comparisons between mean of genotypes within the different doses of N and K for each of the evaluated morpho-agronomic traits

The evaluated morpho-agronomic traits DMY, %DM, PH, and LW, described in Table 1, differed statistically according to Tukey's test at the 5% probability level at specific N and K doses. The NT and SD traits, however, did not differ statistically.

For the DMY trait, a significant effect was detected by Tukey's test at the 5% probability level at the N2K1 doses for genotype G1 and also at the N4K2 doses for genotype G2. For the %DM trait, there was an effect for genotype G2 at the N3K4 doses and also for PH and LW at the K4N4 doses, respectively.

The evaluated genotypes (G1, G2, and G3) showed high estimates for DMY at the lowest N and K doses: 48.77, 46.06, and 52.08 t $ha^{-1}$, respectively. These estimates differed from those obtained by Rossi (2010), who found DMY in genotypes 'Cuban Pinda', 'IAC Campinas', and 'Cameroon', of 37.34, 25.67, and 24.71 t $ha^{-1}$, respectively, in a period of 10 months under fertilization with 25 kg $ha^{-1}$ ammonium sulfate and potassium chloride.

With the lower nitrogen fertilization level of 100 kg $ha^{-1}$ and increasing potassium doses, all genotypes expressed elevated production, though no statistical differences

**Table 1.** Mean values for the morpho-agronomic traits (dry mater yield (DMY), percentage of DM (%DM), number of tillers per linear meter (NT), plant height (PH), stem diameter (SD)) evaluated in three elephant grass genotypes (‘Cuban Pinda’ - G1; ‘IAC Campinas’ - G2; and ‘Cameroon’ - G3) under different nitrogen (N1 = 100, N2 = 800, N3 = 1500, and N4 = 2200 kg ha$^{-1}$ N) and potassium (K1 = 50, K2 = 400, K3 = 750, and K4 = 1100 kg ha$^{-1}$ $K_2O$) levels, in a time interval of two years, for energy purposes.

| Doses of K Kg ha$^{-1}$ | GEN | Doses of N Kg ha$^{-1}$ | | | |
|---|---|---|---|---|---|
| | | N1 | N2 | N3 | N4 |
| | | Morpho-agronomic traits (DMY, t ha$^{-1}$) | | | |
| | G1 | $48.77^{a}$ | $54.95^{a}$ | $35.78^{a}$ | $42.25^{a}$ |
| K1 | G2 | $46.06^{a}$ | $44.00^{ab}$ | $42.92^{a}$ | $41.37^{a}$ |
| | G3 | $52.08^{a}$ | $41.71^{b}$ | $44.47^{a}$ | $44.94^{a}$ |
| | G1 | $58.58^{a}$ | $50.16^{a}$ | $44.62^{a}$ | $48.0^{ab}$ |
| K2 | G2 | $47.05^{a}$ | $40.32^{a}$ | $42.87^{a}$ | $58.06^{a}$ |
| | G3 | $57.80^{a}$ | $53.60^{a}$ | $52.79^{a}$ | $41.05^{b}$ |
| | G1 | $58.50^{a}$ | $40.81^{a}$ | $51.57^{a}$ | $51.47^{a}$ |
| K3 | G2 | $50.71^{a}$ | $48.26^{a}$ | $55.17^{a}$ | $54.99^{a}$ |
| | G3 | $48.62^{a}$ | $42.55^{a}$ | $50.65^{a}$ | $43.69^{a}$ |
| | G1 | $72.95^{a}$ | $53.75^{a}$ | $69.46^{a}$ | $60.42^{a}$ |
| K4 | G2 | $70.62^{a}$ | $63.77^{a}$ | $50.60^{a}$ | $52.26^{a}$ |
| | G3 | $57.15^{a}$ | $46.19^{a}$ | $51.28^{a}$ | $48.59^{a}$ |
| | | Morpho-agronomic traits (%DM, %) | | | |
| | G1 | $32.22^{a}$ | $31.05^{a}$ | $33.04^{a}$ | $33.53^{a}$ |
| K1 | G2 | $33.52^{a}$ | $34.42^{a}$ | $33.16^{a}$ | $32.69^{a}$ |
| | G3 | $33.03^{a}$ | $33.47^{a}$ | $32.89^{a}$ | $34.30^{a}$ |
| | G1 | $31.58^{a}$ | $32.10^{a}$ | $32.01^{a}$ | $32.75^{a}$ |
| K2 | G2 | $33.59^{a}$ | $33.42^{a}$ | $32.90^{a}$ | $33.93^{a}$ |
| | G3 | $33.44^{a}$ | $33.24^{a}$ | $33.51^{a}$ | $33.97^{a}$ |
| | G1 | $32.63^{a}$ | $32.38^{a}$ | $31.11^{a}$ | $35.17^{a}$ |
| K3 | G2 | $33.70^{a}$ | $34.09^{a}$ | $32.78^{a}$ | $34.11^{a}$ |
| | G3 | $34.11^{a}$ | $33.14^{a}$ | $33.25^{a}$ | $34.83^{a}$ |
| | G1 | $32.56^{a}$ | $31.74^{a}$ | $33.16^{b}$ | $31.55^{a}$ |
| K4 | G2 | $34.74^{a}$ | $33.76^{a}$ | $37.32^{a}$ | $32.36^{a}$ |
| | G3 | $33.76^{a}$ | $32.27^{a}$ | $31.66^{b}$ | $34.14^{a}$ |
| | | Morpho-agronomic traits (NT/m) | | | |
| | G1 | $23.05^{a}$ | $23.22^{a}$ | $21.16^{a}$ | $20.83^{a}$ |
| K1 | G2 | $23.39^{a}$ | $23.94^{a}$ | $24.03^{a}$ | $21.66^{a}$ |
| | G3 | $25.47^{a}$ | $23.80^{a}$ | $22.58^{a}$ | $22.13^{a}$ |
| | G1 | $22.75^{a}$ | $21.66^{a}$ | $20.52^{a}$ | $22.11^{a}$ |
| K2 | G2 | $22.27^{a}$ | $22.77^{a}$ | $21.19^{a}$ | $27.91^{a}$ |
| | G3 | $22.52^{a}$ | $26.13^{a}$ | $22.94^{a}$ | $24.27^{a}$ |
| | G1 | $28.64^{a}$ | $24.61^{a}$ | $22.39^{a}$ | $24.66^{a}$ |
| K3 | G2 | $24.75^{a}$ | $30.27^{a}$ | $26.86^{a}$ | $28.44^{a}$ |
| | G3 | $25.69^{a}$ | $21.72^{a}$ | $25.42^{a}$ | $22.47^{a}$ |
| | G1 | $30.53^{a}$ | $24.58^{a}$ | $29.28^{a}$ | $26.97^{a}$ |
| K4 | G2 | $33.16^{a}$ | $33.94^{a}$ | $25.41^{a}$ | $23.42^{a}$ |
| | G3 | $23.77^{a}$ | $23.66^{a}$ | $20.69^{a}$ | $26.70^{a}$ |
| | | Morpho-agronomic traits (PH, m) | | | |
| | G1 | $2.95^{a}$ | $2.79^{a}$ | $3.17^{a}$ | $3.19^{a}$ |
| K1 | G2 | $3.08^{a}$ | $2.92^{a}$ | $3.03^{a}$ | $2.99^{a}$ |
| | G3 | $2.95^{a}$ | $3.05^{a}$ | $3.02^{a}$ | $2.95^{a}$ |

**Table 1.** Contd.

| | | | | | |
|---|---|---|---|---|---|
| | G1 | $3.08^{a}$ | $2.99^{a}$ | $3.22^{a}$ | $3.05^{a}$ |
| K2 | G2 | $3.08^{a}$ | $3.04^{a}$ | $3.06^{a}$ | $3.12^{a}$ |
| | G3 | $2.97^{a}$ | $3.01^{a}$ | $3.20^{a}$ | $2.87^{a}$ |
| | G1 | $3.01^{a}$ | $2.82^{a}$ | $3.18^{a}$ | $3.07^{a}$ |
| K3 | G2 | $3.05^{a}$ | $2.96^{a}$ | $3.22^{a}$ | $2.95^{a}$ |
| | G3 | $3.00^{a}$ | $2.98^{a}$ | $3.08^{a}$ | $2.98^{a}$ |
| | G1 | $3.25^{a}$ | $3.18^{a}$ | $2.94^{a}$ | $3.5^{ab}$ |
| K4 | G2 | $3.05^{a}$ | $3.05^{a}$ | $3.15^{a}$ | $3.19^{a}$ |
| | G3 | $3.03^{a}$ | $2.93^{a}$ | $3.03^{a}$ | $2.86^{b}$ |
| | | **Morpho-agronomic traits (SD, cm)** | | | |
| | G1 | $1.37^{a}$ | $1.33^{a}$ | $1.34^{a}$ | $1.38^{a}$ |
| K1 | G2 | $1.41^{a}$ | $1.45^{a}$ | $1.37^{a}$ | $1.45^{a}$ |
| | G3 | $1.50^{a}$ | $1.45^{a}$ | $1.48^{a}$ | $1.47^{a}$ |
| | G1 | $1.48^{a}$ | $1.43^{a}$ | $1.42^{a}$ | $1.43^{a}$ |
| K2 | G2 | $1.51^{a}$ | $1.47^{a}$ | $1.50^{a}$ | $1.48^{a}$ |
| | G3 | $1.47^{a}$ | $1.45^{a}$ | $1.49^{a}$ | $1.42^{a}$ |
| | G1 | $1.44^{a}$ | $1.42^{a}$ | $1.49^{a}$ | $1.46^{a}$ |
| K3 | G2 | $1.40^{a}$ | $1.49^{a}$ | $1.53^{a}$ | $1.38^{a}$ |
| | G3 | $1.52^{a}$ | $1.46^{a}$ | $1.44^{a}$ | $1.45^{a}$ |
| | G1 | $1.42^{a}$ | $1.48^{a}$ | $1.45^{a}$ | $1.43^{a}$ |
| K4 | G2 | $1.50^{a}$ | $1.47^{a}$ | $1.54^{a}$ | $1.62^{a}$ |
| | G3 | $1.48^{a}$ | $1.41^{a}$ | $1.46^{a}$ | $1.44^{a}$ |
| | | **Morpho-agronomic traits (LW, cm)** | | | |
| | G1 | $4.35^{a}$ | $4.28^{a}$ | $4.27^{a}$ | $4.32^{a}$ |
| K1 | G2 | $4.71^{a}$ | $4.12^{a}$ | $4.30^{a}$ | $4.53^{a}$ |
| | G3 | $4.14^{a}$ | $4.17^{a}$ | $3.96^{a}$ | $4.28^{a}$ |
| | G1 | $4.43^{a}$ | $4.28^{a}$ | $4.12^{a}$ | $4.15^{a}$ |
| K2 | G2 | $4.52^{a}$ | $4.32^{a}$ | $4.46^{a}$ | $4.58^{a}$ |
| | G3 | $4.26^{a}$ | $4.40^{a}$ | $4.58^{a}$ | $4.30^{a}$ |
| | G1 | $4.59^{a}$ | $4.25^{a}$ | $4.36^{a}$ | $4.39^{a}$ |
| K3 | G2 | $4.37^{a}$ | $4.24^{a}$ | $4.42^{a}$ | $4.19^{a}$ |
| | G3 | $4.05^{a}$ | $4.22^{a}$ | $4.20^{a}$ | $4.23^{a}$ |
| | G1 | $4.40^{a}$ | $4.25^{a}$ | $4.41^{a}$ | $4.12^{b}$ |
| K4 | G2 | $4.44^{a}$ | $4.42^{a}$ | $4.61^{a}$ | $4.75^{a}$ |
| | G3 | $4.18^{a}$ | $4.11^{a}$ | $4.39^{a}$ | $4.09^{b}$ |

Means followed by the same lowercase letter in the columns do not differ statistically, according to Tukey's test, at the 5% probability level. Whole-plant dry matter yield, in t ha$^{-1}$ = DMY; Percentage of whole dry matter = %DM; Number of tillers per meter = NT; Plant height, in m = PH; Average stem diameter, in cm = SD; Average leaf width, in cm = LW.

were found between doses. A different outcome was noted with the increasing interactions of N and K doses, in which yield did not increase, but a statistical difference was found with the N2K1 and N4K2 interaction. Thus, the increased nitrogen and potassium fertilization did not provide an increase in dry matter yield (Table 1).

The dry matter yield of genotype 'Cuban Pinda' of 42.25 t ha$^{-1}$ year$^{-1}$, at the N dose of 2200 kg ha$^{-1}$, corroborates Santos et al. (2014), who obtained 38.7 t ha$^{-1}$ from cv. 'Cameroon-Piracicaba' in harvest 2 (300 days) at the N dose of 1000 kg ha$^{-1}$, in Alegre - ES, Brazil. It is also in line with Oliveira et al. (2015), who obtained total yields in two harvests of 27.25 t ha$^{-1}$ year$^{-1}$ at the N dose of 1000 kg ha$^{-1}$ in Campos dos Goytacazes - RJ, Brazil.

The study of dry matter yield showed that under low nitrogen supply and with increased potassium doses, DMY increased, but as the nitrogen dose was increased in associated with potassium doses, this yield did not increase but was rather suppressed. Morais et al. (2009)

worked with six elephant grass genotypes and a nitrogen dose of 50 kg ha$^{-1}$ in three crop cycles, each with six months, totaling 18 months, and did not find a significant effect, corroborating the present study, in which no significant statistical difference was observed.

Overall, the genotypes did not differ from each other as to their dry matter production potential in the harvests made with the different nitrogen and potassium doses utilized, demonstrating that they are highly productive.

The average DMY of genotype 'Cameroon', of 48.57 t ha$^{-1}$ was higher than the 38.7 t ha$^{-1}$ obtained by Santos et al. (2014) with a harvest interval of 300 days, using a N dose of 1000 kg ha$^{-1}$. It was also higher than the 24.71 t ha$^{-1}$ found by Rossi (2010) in genotype 'Cameroon' in a period of 10 months and with fertilization with 25 kg ha$^{-1}$ ammonium sulfate and potassium chloride. Morais et al. (2009) obtained, in Ponta Ubú, Anchieta - ES, Brazil, for the same genotype, 8.17 t ha$^{-1}$ in the 3rd cycle in 18 months of growth, using less nitrogen fertilization, which is also a lower value than that obtained in our study.

The overall mean for the dry matter percentage (%DM) of the genotypes was 33.21% (Table 1) and the lowest value, 31.05%, was obtained in genotype 'Cuban Pinda', under N and K doses of 800 and 50 kg ha$^{-1}$, respectively. The highest result, however, was found in 'IAC Campinas', at the N and K doses of 1500 and 1100 kg ha$^{-1}$, respectively. This percentage of dry matter corroborates Rossi (2010), who used less nitrogen fertilization in a period of 10 months and obtained %DM for genotypes 'Cuban Pinda', 'IAC Campinas' and 'Cameroon' of 35.85, 34.73, and 31.90%, respectively. These values published by Rossi et al. (2014) differ from those obtained by Santos (2013), who reported an overall mean of 24.72%; the lowest value, 23.22%, found in 'Cameroon' at 1500 kg ha$^{-1}$ N; and the highest, 25.77%, in 'Guaçu/IZ.2', at 500 kg ha$^{-1}$ N, with a harvest interval of 180 days. These data also differed from those reported by Souza-Sobrinho et al. (2005), who obtained an average %DM of 24.47% with harvest intervals shorter than 100 days.

Santos (2013) evaluated the chemical composition of elephant grass cv. 'Roxo', 'Guaçu/IZ.2', 'Cameroon', and 'Cana D'África' and found an average %DM of 19.7 and 24.72%, respectively, whereas in this study an average of 33.21% was found for the three genotypes (Table 1). The observed dry matter contents, as compared with the results, confirm that the dry matter increases when the interval between harvests is increased, due to the increased stem diameter, and plant height.

The dry matter content of observed compared with the results confirm that there is an increase of dry matter when the cutting interval increases, due to increased stem diameter, and plant height.

For NT, the genotypes did not differ statistically with the different N and K doses. The overall mean of the trait NT of the genotypes was 24.59 (Table 1) and the lowest obtained value was 20.52, referring to genotype 'Cuban Pinda', with N and K doses of 1500 and 400 kg ha$^{-1}$, respectively, while the highest value, 33.94, was obtained with genotype 'IAC Campinas' at the N dose of 800 and 1100 kg ha$^{-1}$ K. Genotypes had higher tillering with the lowest N and K doses, demonstrating a possible trend for high doses to not increase the number of tillers.

Mean values for NT were similar to those found by Santos et al. (2014), who observed 28.43, 23.00, and 30.58 in genotypes 'Guaçu/IZ.2', 'Cameroon-Piracicaba', and 'Cana D'África', respectively, in the second harvest, with a harvest interval of 10 months, using a lower N dose of 1000 kg ha$^{-1}$. Our values were also close to those obtained by Oliveira et al. (2013), whose cv. 'Guaçu/ IZ.2', 'Cameroon-Piracicaba', 'Cana D'África', and 'Cuban' showed 28, 28, 23, and 24 tillers per meter, respectively, in a six-month interval, also using a lower nitrogen fertilization dose. According to Silva et al. (2010) and Daher et al. (2014), the traits number of basal and aerial tillers per meter have high heritability, indicating little or no influence of the environment on the variability among the studied genotypes. The higher yield coincides with the higher number of tillers per area and plant height.

Concerning PH, only genotype 'IAC Campinas' differed statistically from the others, standing out in relation to 'Cuban Pinda' and 'Cameroon' at the N4K4 dose utilized, with the respective value of 3.19 (Table 1). The height of genotype 'Cameroon' varied negatively with the increasing nitrogen and potassium levels; therefore, fertilization might have suppressed the height of this genotype, though this trait is known to possibly be due to the genetic factor.

Elephant grass varieties can reach great heights depending on climate and management conditions. Kannika et al. (2011) evaluated the height of elephant grass with different harvest intervals and found that at 12 months of age the grass reached 5 m. Oliveira et al. (2013), found an average genotype height of 1.88 m with a cycle of six months. In this study, the average height was 3.02, with a 12-month cycle. According to Xia et al. (2010), this variable is positively correlated with yield.

Analyzing the SD values, the overall mean of the genotypes was 1.45 cm (Table 1); the lowest value of 1.33 was found for genotype 'Cuban Pinda' at the N dose of 800 kg ha$^{-1}$ and K dose of 50 kg ha$^{-1}$; and the highest, 1.62 cm, for genotype 'IAC Campinas', with the N and K doses of 2200 and 1100 kg ha$^{-1}$. Santos (2013) obtained, for genotype 'Cameroon', higher values: 1.80, 1.86, 1.82, 1.92, and 1.79 cm at the N doses of 0, 500, 1000, 1500, and 2000 kg ha$^{-1}$, respectively, while the lowest value, 1.52 cm, was found in genotype 'Cana D'África', at the N level of 500 kg ha$^{-1}$.

For the leaf width (LW) trait, there was a significant effect on genotype 'IAC Campinas', whose mean value was 4.75 cm at the N dose of 2200 and 1100 kg ha$^{-1}$ K and on 'Cuban Pinda' and 'Cameroon', which showed the lowest LW: 4.12 and 4.09 cm, respectively (Table 1).

Genotype ‘IAC Campinas’ responded positively to the K dose of 1100 kg ha$^{-1}$ and the N increase. Santos (2013), adopting a harvest interval of 180 days, found a LW of 6.16 cm at the N dose of 1500 kg ha$^{-1}$, which shows that the harvest interval can influence the width of elephant grass leaves.

## Regression analysis for the evaluated morpho-agronomic traits for the three elephant grass genotypes

The aspects of the most representative biometric models (1st degree, 2nd degree, and lack of regression) are represented in Table 2 and Figures 1 to 3, which show the mean square estimates for the sources of variation due to regression and deviations and the regression graphs, respectively, for the three elephant grass genotypes.

For the DMY involving the three elephant grass genotypes, a significant 1st-degree linear effect was observed as a result of K doses within N1 for genotype ‘Cuban Pinda’ and a 2nd-degree linear effect within N4 and N2 for genotypes ‘IAC Campinas’ and ‘Cameroon’, with the respective coefficients of determination of 36.54, 91.81, and 93.34%, respectively (Table 2).

Santos (2013) found an average yield of 26.74 t ha$^{-1}$ in three elephant grass cultivars (‘Guaçu/IZ.2’, ‘Cameroon-Piracicaba’, and ‘Cana D’África’) and three harvest cycles under two nitrogen fertilization doses (500 and 1000 kg ha$^{-1}$ N). Quesada (2005) obtained, in eight months of growth, DM values of up to 30 t ha$^{-1}$ in ‘Cameroon’ genotypes without application of N fertilizer.

Morais et al. (2009) found, in 18 months of growth, 44.7 t ha$^{-1}$ DM from genotype ‘Cameroon’ with application of 50 kg ha$^{-1}$ N. These results confirm the good selection of elephant grass varieties that has been performed aiming at high biomass production and at its use as an alternative energy source (Quesada, 2005), thereby providing positive results that potentiate the use of elephant grass as an alternative energy source by the direct biomass combustion.

In evaluating the DMY, as shown in Table 2, a significant effect of nitrogen doses (N1, N4, and N2) was observed on genotypes ‘Cuban Pinda’, ‘IAC Campinas’, and ‘Cameroon’, respectively. The highest N and K doses provided the highest estimated DMY for all genotypes. There was also an increase in DMY as the K doses were elevated, regardless of N (Figure 1).

In their study in the experimental area of IFES, Alegre - ES Campus, in the 2012 to 2013 period, Santos (2013) demonstrated a trend towards increased dry matter yield of elephant grass as the nitrogen doses were increased. The ratio of kilograms of N per ton of dry matter produced confirms the behavior of this trend, up to the limit at which N depresses this productivity, since the three cultivars (‘Guaçu/IZ.2’, ‘Cameroon-Piracicaba’, and ‘Cana D’África’) responded positively to the increased nitrogen fertilization levels used.

Carvalho et al. (1995) studied the application of nitrogen (0, 100, 200, and 400 kg ha$^{-1}$ year$^{-1}$ 0, 50, 100, and 200 mg.dm$^{-3}$) and potassium (0, 75, and 150 kg ha$^{-1}$ year$^{-1}$ 0, 31.25, and 62.50 mg.dm$^{-3}$) in Brachiaria grass grown on a Red-Yellow Latosol (Hapludox) and found that under low potassium supply, the response to nitrogen fertilization was limited. However, the effect of nitrogen fertilization on dry matter yield was not significant, and this effect was not deeply influenced by the application of potassium, suggesting that with low potassium and nitrogen supply, the plant response was higher, but with the increase in potassium fertilization there was no marked response to nitrogen fertilization.

Oliveira et al. (2015), found an average dry matter yield in six genotypes of 35.03 t ha$^{-1}$ year$^{-1}$, with a 10-month cycle, showing that the results found in this study are higher, which indicates that fertilization provided an increase in dry matter yield.

The overall mean for percentage of dry matter (%DM) trait of the genotypes as a function of the N and K doses was 32.88% (Table 2). This dry matter percentage corroborates the results obtained by Souza Sobrinho et al. (2005), who found an average of 24.47%, with intervals shorter than 100 days.

The estimates for the 1st- and 2nd-degree linear models applied to the mean values of NT involving the three elephant grass genotypes referring to the two-year crop cycle are shown in Table 2 and Figure 2. In the regression analysis for the trait NT, it was found that the genotype which showed regression was ‘IAC Campinas’ at the N4 dose, whose coefficient of determination was $R^2$ = 83.13% at the 5% significance level by the “F” test. The best-fitting model was the 1st-degree type.

Genotype ‘IAC Campinas’ showed a higher NT, estimated at 23.53, with the highest N dose, differing from genotypes ‘Cuban Pinda’ and ‘Cameroon’, whose NT were 28.82 and 22.75, respectively, under the same dose. Among the N doses, genotype ‘Cameroon’ manifested a reduced number of tillers, 22.75, with the highest N dose, 2200 kg ha$^{-1}$.

The obtained values for NT did not differ from those found by Santos et al. (2014), who observed for the cv. ‘Guaçu/IZ.2’, ‘Cameroon-Piracicaba’, and ‘Cana D’África’, in the 2nd harvest, the respective values of 28.43, 23.00, and 30.58 in a 10-month interval under a lower N dose; they also did not differ from those obtained by Oliveira et al. (2013), whose cultivars ‘Guaçu/ IZ.2’, ‘Cameroon-Piracicaba’, ‘Cana D’África’, and ‘Cuban Pinda’ showed 28, 28, 23, and 24 tillers per meter, respectively, in a six-month interval, also using lower doses of nitrogen fertilization. According to Silva et al. (2010), the traits number of basal and aerial tillers per meter showed high heritability, demonstrating little influence of the environment on the variability among clones. The higher productivity coincides with the higher number of tillers per

**Table 2.** 1st- and 2nd-degree linear regression models for the morpho-agronomic traits (dry mater yield (DMY), percentage of DM (%DM), number of tillers per linear meter (NT), plant height (PH), stem diameter (SD)) of three genotypes ('Cuban Pinda' - G1; 'IAC Campinas' - G2; and 'Cameroon' - G3) under four nitrogen levels (100, 800, 1500, and 2200 kg ha$^{-1}$ N) and four potassium levels (50, 400, 750, and 1100 kg ha$^{-1}$ K$_2$O) and two years of growth.

| GEN | Doses of N | Model | Regression equation | $R^2$ |
|---|---|---|---|---|
| | | | **Morpho-agronomic traits (DMY, t ha$^{-1}$)** | |
| G1 | N1 | 1 | $\hat{y} = 5.79 - 5.5\times10^{-3}K^{*}$ | 36.54 |
| | N2 | Absence | $\hat{y} = 56.34$ | - |
| | N3 | Absence | $\hat{y} = 52.28$ | - |
| | N4 | Absence | $\hat{y} = 67.73$ | - |
| Independent of N | | - | $\hat{y} = 43.42 + 0.0161K^{**}$ | 81.87 |
| G2 | N1 | Absence | $\hat{y} = 46.33$ | - |
| | N2 | Absence | $\hat{y} = 41.23$ | - |
| | N3 | Absence | $\hat{y} = 49.04$ | - |
| | N4 | 2 | $\hat{y} = 73.60 - 0.1973K^{*} + 4.34\times10^{-5}K^{2*}$ | 91.81 |
| Independent of N | | - | $\hat{y} = 42.07 + 0.0148K^{**}$ | 97.54 |
| G3 | N1 | Absence | $\hat{y} = 49.04$ | - |
| | N2 | 2 | $\hat{y} = 56.97 + 1.5\times10^{-3}K^{ns} - 3.8\times10^{-5}K^{2ns}$ | 93.34 |
| | N3 | Absence | $\hat{y} = 47.48$ | - |
| | N4 | Absence | $\hat{y} = 54.18$ | - |
| Independent of N | | - | $\hat{y} = 46.91 + 0.0029K^{ns}$ | 20.32 |
| | | | **Morpho-agronomic traits (%DM, %)** | |
| G1 | N1 | Absence | $\hat{y} = 31.48$ | - |
| | N2 | Absence | $\hat{y} = 31.54$ | - |
| | N3 | Absence | $\hat{y} = 31.78$ | - |
| | N4 | Absence | $\hat{y} = 32.51$ | - |
| Independent of N | | - | $\hat{y} = 32.39 + 3\times10^{-5}K^{ns}$ | 0.14 |
| G2 | N1 | Absence | $\hat{y} = 34.06$ | - |
| | N2 | Absence | $\hat{y} = 33.37$ | - |
| | N3 | Absence | $\hat{y} = 33.68$ | - |
| | N4 | Absence | $\hat{y} = 33.68$ | - |
| Independent of N | | - | $\hat{y} = 33.20 + 0.001K^{ns}$ | 75.97 |
| G3 | N1 | Absence | $\hat{y} = 32.89$ | - |
| | N2 | Absence | $\hat{y} = 33.24$ | - |
| | N3 | Absence | $\hat{y} = 33.46$ | - |
| | N4 | Absence | $\hat{y} = 32.87$ | - |
| Independent of N | | - | $\hat{y} = 33.62 - 0.0003K^{ns}$ | 14.75 |
| | | | **Morpho-agronomic traits (NT/m)** | |
| G1 | N1 | Absence | $\hat{y} = 23.50$ | - |
| | N2 | Absence | $\hat{y} = 22.26$ | - |
| | N3 | Absence | $\hat{y} = 27.40$ | - |
| | N4 | Absence | $\hat{y} = 28.82$ | - |
| Independent of N | | - | $\hat{y} = 20.79 + 0.0059K^{**}$ | 86.81 |
| G2 | N1 | Absence | $\hat{y} = 24.09$ | - |
| | N2 | Absence | $\hat{y} = 21.02$ | - |
| | N3 | Absence | $\hat{y} = 26.32$ | - |
| | N4 | 1 | $\hat{y} = 35.19 - 5.3\times10^{-3}K^{*}$ | 83.13 |

**Table 2.** Contd.

| | | | | |
|---|---|---|---|---|
| Independent of N | | - | $\hat{y} = 22.35 + 0.0061K^{**}$ | 90.52 |
| G3 | N1 | Absence | $\hat{y} = 25.33$ | - |
| | N2 | Absence | $\hat{y} = 23.63$ | - |
| | N3 | Absence | $\hat{y} = 24.80$ | - |
| | N4 | Absence | $\hat{y} = 22.75$ | - |
| Independent of N | | - | $\hat{y} = 23.67 + 0.0001K^{ns}$ | 10.10 |
| **Morpho-agronomic traits (PH, m)** | | | | |
| G1 | N1 | 1 | $\hat{y} = 2.84 + 1.5\times10^{-4}K^{*}$ | 56.33 |
| | N2 | Absence | $\hat{y} = 3.06$ | - |
| | N3 | Absence | $\hat{y} = 2.94$ | - |
| | N4 | Absence | $\hat{y} = 3.21$ | - |
| Independent of N | | - | $\hat{y} = 3.03 + 7\times10^{-5}K^{ns}$ | 40.00 |
| G2 | N1 | Absence | $\hat{y} = 3.03$ | - |
| | N2 | Absence | $\hat{y} = 3.05$ | - |
| | N3 | Absence | $\hat{y} = 3.05$ | - |
| | N4 | Absence | $\hat{y} = 3.02$ | - |
| Independent of N | | - | $\hat{y} = 3.01 + 8\times10^{-5}K^{ns}$ | 66.58 |
| G3 | N1 | Absence | $\hat{y} = 2.99$ | - |
| | N2 | Absence | $\hat{y} = 3.03$ | - |
| | N3 | Absence | $\hat{y} = 3.00$ | - |
| | N4 | Absence | $\hat{y} = 3.02$ | - |
| Independent of N | | - | $\hat{y} = 3.02 – 7\times10^{-5}K^{ns}$ | 41.81 |
| **Morpho-agronomic traits (SD, cm)** | | | | |
| G1 | N1 | Absence | $\hat{y} = 1.35$ | - |
| | N2 | Absence | $\hat{y} = 1.46$ | - |
| | N3 | Absence | $\hat{y} = 1.44$ | - |
| | N4 | Absence | $\hat{y} = 1.45$ | - |
| Independent of N | | - | $\hat{y} = 1.37 + 8\times10^{-5}K^{**}$ | 68.77 |
| G2 | N1 | Absence | $\hat{y} = 1.41$ | - |
| | N2 | Absence | $\hat{y} = 1.50$ | - |
| | N3 | 2 | $\hat{y} = 1.37 + 2.6\times10^{-4}K^{ns} - 1\times10^{-7}K^{2ns}$ | 90.0 |
| | N4 | Absence | $\hat{y} = 1.46$ | - |
| Independent of N | | - | $\hat{y} = 1.42 + 9\times10^{-5}K^{**}$ | 69.23 |
| G3 | N1 | Absence | $\hat{y} = 1.48$ | - |
| | N2 | Absence | $\hat{y} = 1.48$ | - |
| | N3 | Absence | $\hat{y} = 1.50$ | - |
| | N4 | Absence | $\hat{y} = 1.45$ | - |
| Independent of N | | - | $\hat{y} = 1.47 - 2\times10^{-5}K^{ns}$ | 64.00 |
| **Morpho-agronomic traits (LW, cm)** | | | | |
| G1 | N1 | Absence | $\hat{y} = 4.32$ | - |
| | N2 | Absence | $\hat{y} = 4.40$ | - |
| | N3 | Absence | $\hat{y} = 4.47$ | |
| | N4 | Absence | $\hat{y} = 4.41$ | - |
| Independent of N | | - | $\hat{y} = 4.29 + 3\times10^{-5}K^{ns}$ | 6.15 |

**Table 2.** Contd.

| | | | | |
|---|---|---|---|---|
| G2 | N1 | Absence | $\hat{y} = 4.47$ | - |
| | N2 | Absence | $\hat{y} = 4.41$ | - |
| | N3 | Absence | $\hat{y} = 4.37$ | - |
| | N4 | Absence | $\hat{y} = 4.37$ | - |
| Independent of N | | - | $\hat{y} = 4.39 + 7\times10^{-5}K^{ns}$ | 10.37 |
| G3 | N1 | Absence | $\hat{y} = 4.11$ | - |
| | N2 | Absence | $\hat{y} = 4.34$ | - |
| | N3 | Absence | $\hat{y} = 4.08$ | - |
| | N4 | Absence | $\hat{y} = 4.18$ | - |
| Independent of N | | - | $\hat{y} = 4.23 - 9\times10^{-6}K^{ns}$ | 0.12 |

$^{**}$, $^{*}$, and $^{ns}$Significant at the 1 and 5% probability levels and not significant according to the F test, respectively. Whole-plant dry matter yield, in t $ha^{-1}$ = DMY; Percentage of whole dry matter = %DM; Number of tillers per meter = NT; Plant height, in m = PH; Average stem diameter, in cm = SD; Average leaf width, in cm = LW.

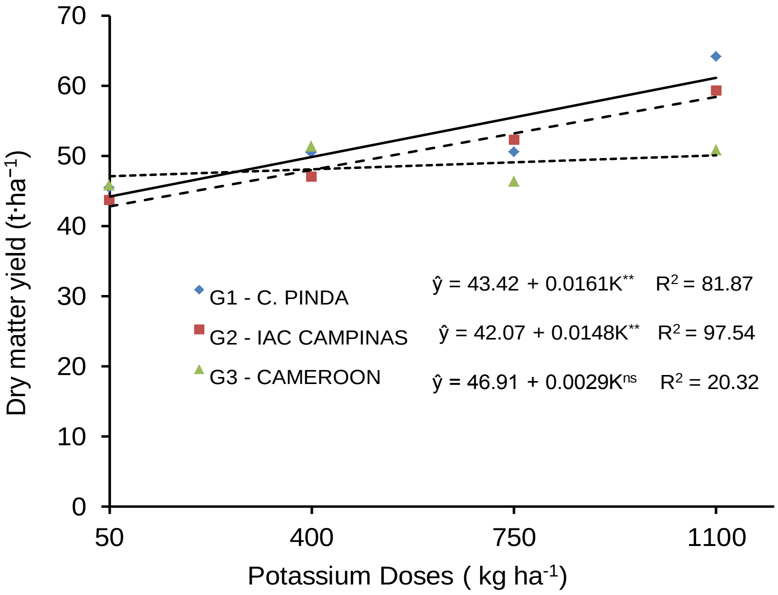

**Figure 1.** Characteristic straight for dry matter yield of genotypes ‘Cuban Pinda’ (G1), ‘IAC Campinas’ (G2), and ‘Cameroon’ (G3) with increasing potassium fertilization doses (50, 400, 750, and 1100 kg $ha^{-1}$ $K_2O$) irrespective of nitrogen fertilization.

area and plant height.

The estimates for the 1st- and 2nd-degree linear models applied to the mean values for PH involving three elephant grass genotypes referring to the two-year crop cycle are described in Table 2 and Figure 3. For this variable, there was no model fit for genotypes ‘IAC Campinas’ and ‘Cameroon’, which showed no regression, while ‘Cuban Pinda’ showed a 1st-degree regression, with $R^2$ = 56.33%. As reported by Oliveira et al. (2015), in regression analysis of PH, ‘Guaçu/IZ.2’ did not obtain regression and for ‘Cameroon-Piracicaba’, the best-fitting regression model was the 2nd-degree type, with a coefficient of determination of $R^2$ = 41.93% at the 1% significance level by the “F” test.

In the analysis of the average height (PH) trait, genotypes ‘IAC Campinas’ and ‘Cameroon’ did not differ statistically across the nitrogen doses. The growth of genotype ‘Cameroon’ with increasing potassium and nitrogen doses did not influence PH, demonstrating that neither element provided a highly significant increase in

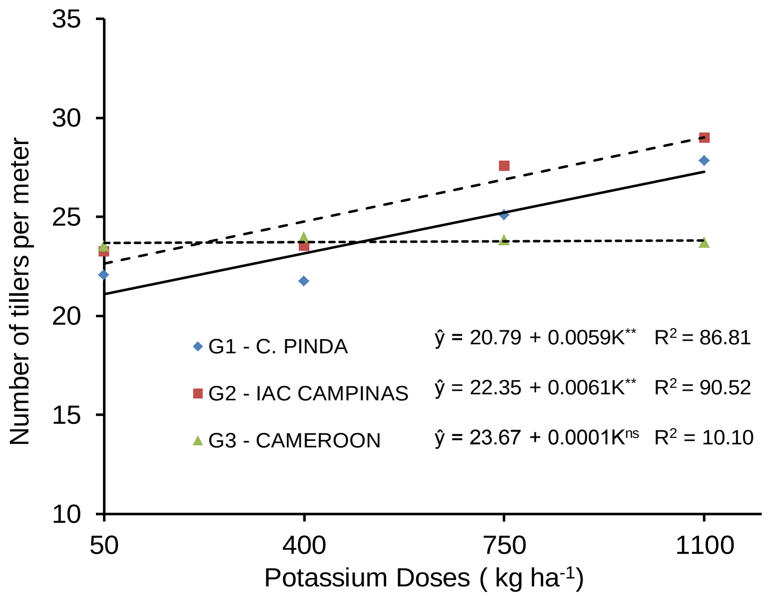

**Figure 2.** Characteristic straight for number of tillers per meter of genotypes 'Cuban Pinda' (G1), 'IAC Campinas' (G2), and 'Cameroon' (G3) with increasing potassium fertilization doses (50, 400, 750, and 1100 kg ha$^{-1}$ $K_2O$) irrespective of nitrogen fertilization.

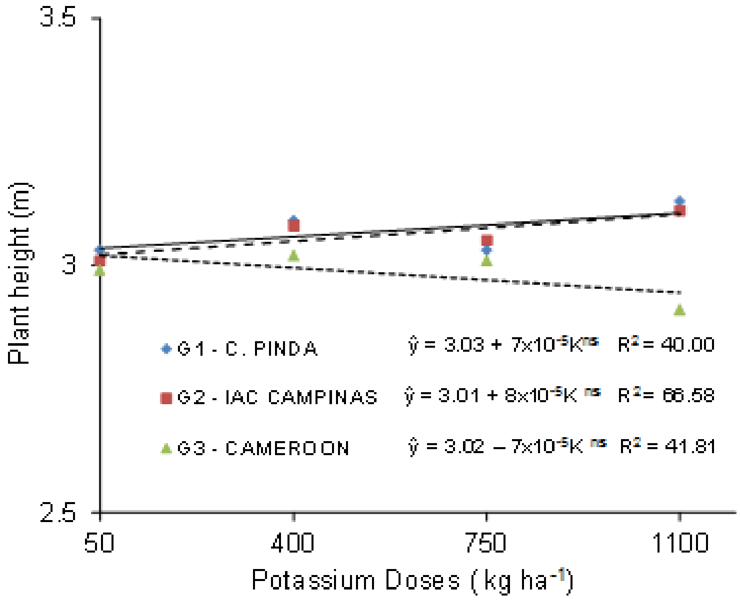

**Figure 3.** Characteristic straight for plant height of genotypes 'Cuban Pinda' (G1), 'IAC Campinas' (G2), and 'Cameroon' (G3) with increasing potassium fertilization doses (50, 400, 750, and 1100 kg ha$^{-1}$ $K_2O$) irrespective of nitrogen fertilization.

the height of genotypes 'Cuban Pinda' and 'IAC Campinas' and led to a decrease in the PH of genotype 'Cameroon' (Figure 3).

Elephant grass genotypes may reach great heights depending on climatic and management conditions. Kannika et al. (2011) evaluated the height of elephant grass with different harvest intervals and found that at 12 months of age the grass had reached 5 m. Oliveira et al. (2013) found that the average of the studied genotypes was 1.88 m, at 24 weeks. In our study, the average height was 3.02 cm, with a 12-month cycle. According to Xia et al. (2010) and Menezes et al. (2015), this variable is positively correlated with dry matter yield.

The estimates for the 1st- and 2nd-degree linear models applied to the mean values for SD involving three elephant grass genotypes referring to the two-year crop cycle are shown in Table 2. Analyzing the average SD, genotypes ‘Cuban Pinda’ and ‘Cameroon’ showed no regression for the N and K doses. For the N3 dose, genotype ‘IAC Campinas’ displayed a 2nd-degree regression, with $R^2$ = 90.0%, at the 5% significance level by the “F” test.

Genotype ‘IAC Campinas’ differed from genotypes ‘Cuban Pinda’ and ‘Cameroon’ at the N3 dose. With the lower N and K doses, the genotypes already showed an increase in stem diameter. According to Oliveira et al. (2015), for the genotype ‘Cuban Pinda’, the model that best fit was the 2nd-degree model, with a coefficient of determination of $R^2$ = 18.62%, at the 5% significance level by the “F” test. For genotype ‘Cameroon-Piracicaba’, the 1st-degree model had the best fit, with 24.03% at the 5% significance level by the “F” test.

Studying the stem diameter and number of basal tillers per meter, Silva et al. (2010) observed the existence of high heritability. However, heritability estimates are part of the set of genotypes evaluated and of a certain environmental condition. In a small-sized Pennisetum clone, researchers (Silva and Rocha, 2010; Silva et al., 2010) observed 98% heritability for stem diameter and 83% for number of tillers, because the lower genetic variation found for these clones indicates that a large part of phenotypic variability has genetic causes.

Estimates for the 1st- and 2nd-degree linear models applied to leaf width involving the three elephant grass genotypes are shown in Table 2. There was no model fit for the genotypes that showed no regression.

## Conclusions

The three genotypes higher number of tillers, height, and stem diameter with the lowest N and K doses, showing a possible trend of elevated doses not providing a highly significant increase in these traits.

The study of dry matter yield showed that under low nitrogen doses and with increased potassium doses, dry matter yield increased; however, as the nitrogen level was increased in associated with potassium doses; this production did not increase but was rather suppressed.

The three elephant grass genotypes, ‘Cuban Pinda’, ‘IAC Campinas’, and ‘Cameroon’, obtained average yields of 52.66, 50.60, and 48.57 t.ha$^{-1}$, respectively. These results are quite promising and prove the possibility of using elephant grass as an alternative source for biomass production.

## Conflict of Interests

The authors have not declared any conflict of interests.

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## Abbreviations

**GEN,** Genotype; **G1,** Cuban Pinda; **G2,** IAC Campinas; **G3,** Cameroon; **DMY,** dry matter yield; **%DM,** percentage of whole dry matter; **NT,** number of tillers per meter; **PH,** plant height in m; **SD,** average stem diameter in cm, **LW,** average leaf width in cm.

## REFERENCES

Carvalho LP de, Cruz CD, Morais CF de (1995). Genetic divergence in brazilian cotton, *Gossypium hirsutum* var. *latifolium* Hutch. Rev. Bras. Genet. 18(3):439-443.

Cruz CD (2013). GENES - a software package for analysis in experimental statistics and quantitative genetics. Acta Sci. Agron. 35(3):271-276.

Daher RF, Souza LB, Gravina G de A, Machado JC, Ramos HCC, Silva VQR, Menezes BRS, Schneider LSA, Oliveira MLF, Gottardo RD (2014). Use of elephant grass for energy production in Campos dos Goytacazes - RJ, Brazil. Genet. Mol. Res. 13:10898-10908.

Embrapa - Empresa Brasileira de Pesquisa Agropecuária (2013). Sistema Brasileiro de Classificação de Solo. 3ª edição. Centro Nacional de Pesquisa de Solos, Rio de Janeiro, Brasil. 353p.

Flores RA, Urquiaga SS, Alves BJR, Collier LS, Zanetti JB, Prado RM (2013). Nitrogênio e idade de corte na qualidade da biomassa de capim- elefante para fins agroenergéticos cultivado em Latossolo. Semin: Ciênc. Agrár. 34(1):127-136.

Kannika R, Yasuyuki I, Kunn K, Pichit P, Prapa S, Vittaya P, Pilanee V, Ganda N, Sayan T (2011). Effects of inter-cutting interval on biomass yield, growth components and chemical composition of napiergrass (*Pennisetum purpureum* Schum.) cultivars as bioenergy crops in Thailand. Grassl. Sci. 57:135-141.

Marschner H (1995). Mineral nutrition of higher plants. London, Academic Press, 889p.

Menezes BRS, Daher RF, Gravina G de A, Pereira AV, Sousa LB, Rodrigues RV, Silva VB, Gottardo RD, Schneider LSA, Novo AAC (2015). Estimates of heterosis parameters in elephant grass (*Pennisetum purpureum* Schumach.) for bioenergy production. Chil. J. Agric. Res. 75(4):395-401.

Meurer EJ (2006). Potássio. In. FERNANDES, M. S. (editor). Nutrição mineral de plantas. Viçosa: SBCS/UFV, pp. 281-298.

Morais RF, Zanetti JB, Pacheco BM, Jantália CP, Boddey RC, Alves BJR, Urquiaga S (2009). Produção e qualidade da biomassa de diferentes genótipos de capim-elefante cultivados para uso energético. Rev. Bras. Agroecol. 4:1.

Oliveira AV de, Daher RF, Menezes BR da S, Gravina G de A, Sousa LB de, Gonçalves AC de, Oliveira ML F (2013). Avaliação do Desenvolvimento de 73 Genótipos de Capim-Elefante em Campos dos Goytacazes – RJ. B. Indústr. Anim.70(2):11-131.

Oliveira E da S, Daher RF, Ponciano NJ, Gravina G de A, Sant'ana JA de A, Gottardo RD, Menezes BR da S, Souza PM de, Souza CLM de, Silva VB da, Rocha A dos S, Novo AAC (2015). Variation of Morpho-gronomic and Biomass Quality Traits in Elephant Grassfor Energy Purposes According to Nitrogen Levels. Am. J. Plant Sci. 6(11):1685.

Quesada DM (2005) Parâmetros quantitativos e qualitativos da biomassa de genótipos de capim-elefante (*Pennisetum purpureum* schum.) com potencial para uso energético, na forma de carvão vegetal. Tese (Doutorado)- Seropédica-RJ, Universidade Federal Rural do Rio de Janeiro, 65 p.

Rocha A de S, Daher RF, Gravina G de A, Pereira AV, Rodrigues EV, Viana AP, Silva VQR da, Amaral Junior AT do, Novo AAC, Oliveira MLF, Oliveira E da S (2015). Comparison of stability methods in elephant-grass genotypes for energy purposes. Afr. J. Agric. Res. 10(47):4283-4294.

Rossi DA (2010). Avaliação morfoagronômica e da qualidade de biomassa de acessos de capim-elefante (*Pennisetum purpureum*, Schum.) para fins energéticos no Norte Fluminense. Mestrado - Produção Vegetal, Campos dos Goytacazes, 57f.

Rossi DA, Menezes BR da S, Daher RF, Gravina G de A, Lima RSN de, Ledo F da S, Gottardo RD, Campostrini E (2014). Canonical correlations in elephant grass for energy purposes. Afr. J. Biotechnol. 13(36):3666-3671.

Santos MM, Daher RF, Ponciano NJ, Gravina G de A, Pereira AV, Santos CL (2014). Respostas do capim-elefante sob doses de adubação azotada de cobertura para fins energéticos. Rev. de Ciências Agrárias 37:1.

Santos MMP (2013). Otimização da adubação nitrogenada em três cultivares de capim-elefante para fins energéticos no sul do Espírito Santo. Tese de doutorado. Universidade Estadual do Norte Fluminense – UENF, 147p.

Silva ALC, Santos MVF, Dubeux Júnior JCB, Lira M A, Ferreira RLC, Freitas EV, Cunha MV, Silva MC (2010). Variabilidade e herdabilidade de caracteres morfológicos em clones de capim-elefante na Zona da Mata de Pernambuco. R. Bras. Zootec. 39:2132-2140.

Silva DJ, Queiroz AC de (2002). Análise de alimentos: métodos químicos e biológicos. 3. ed. Viçosa. 235 p.

Silva E, Rocha CR (2010). Eucalipto e capim elefante: características e potencial produtivo de biomassa. Rev. Agrogeoambiental 2:143-152.

Souza Sobrinho F de, Pereira AV, Ledo FJ da S, Botrel MA, Oliveira JS, Xavier DF (2005). Avaliação agronômica de híbridos interespecíficos entre capim-elefante e milheto. Pesq. Agropec. Bras. 40(9):873-880.

Woodard KR, Sollenberger LE (2015). Production of biofuel crops in Florida: Elephant grass. SS-AGR-297, Agronomy Department, University of Florida UF)/Institute of Food and Agricultural Sciences (IFAS) Extension, Gainesville, Florida, USA. Available at https://edis.ifas.ufl.edu/ag302#FOOTNOTE_1 (accessed July 2015).

Xia Z, Hongru G, Chenglong D, Xiaoxian Z, Jianli Z, Nengxiang X (2010). Path coefficient and cluster analyses of yield and morphological traits in *Pennisetum purpureum*. Trop. Grassl. 44:95-102.