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Elephant grass ecotypes for bioenergy production *via* direct combustion of biomass

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ABSTRACT

Several perennial grasses have been studied as energetic feedstock due to high lignocellulosic production, making it an alternative bioenergy source. This is the first study to investigate the aptitude of elephant grass (*Pennisetum purpureum* Schum.), aiming to breed it for bioenergy production *via* direct combustion of biomass. The evaluation of the aptitude and the estimates of the genotypic values were carried out using the mixed models methodology. The canonical correlation analyses were carried out among morpho-agronomic and biomass quality traits for the groups Napier and Cameroon. Complementarily, it was used path analysis with calorific value as the principle variable. Elephant grass presented 22.59 Mg ha^{-1} mean biomass production. Cameroon group presents the greatest aptitude to be used as bioenergetic raw material *via* direct combustion of biomass, with 24.13 Mg ha^{-1} total dry biomass, and 18.16 MJ kg^{-1} calorific value. The ash content has high correlation and high direct effect on the calorific value. Genetic breeding for morpho-agronomic traits within the Cameroon group is recommended. The canonical correlation analyses and path analyses indicate that in the initial stages of elephant grass breeding program, there is a possibility of indirect selection *via* morpho-agronomic traits to obtain genetic gain in calorific value. In this sense, tandem selection within the Cameroon group could be a good option, in which the genotypes with the tallest and the thickest stalk diameter should be selected among the genotypes with the greatest dry matter content.

1. Introduction

Plant biomass for energetic feedstock has gained importance in the development of alternative energy for an environmentally renewable and sustainable energy matrix (Nass et al., 2007; Samson et al., 2005), since it can be converted into chemical products, thermal/electrical energy, biofuels, among other essential materials (Fontoura et al., 2015; McKendry, 2002).

The biomass of crops intended to be used for combustion should have low proportion reproductive structures in the biomass, as well as phenology that allows long growing season, associated with high biomass production (Porter et al., 2007). Aside from morpho-agronomic traits, some authors indicate that biomass quality properties (moisture content, calorific value, ash content, and cellulose, lignin, and nitrogen levels) are fundamental for its utilization, since they are able to influence the entire conversion process and thermal utilization (Dorez et al., 2014; Gani and Naruse, 2007; Jaradat, 2010; Karp and Shield, 2008; McKendry, 2002; Obernberger et al., 2006; Prochnow et al., 2009).

Several crops have been quoted as candidates for biomass energy generation (Boehmel et al., 2008; David and Ragauskas, 2010; Ra et al., 2012; Sanderson and Adler, 2008). Some authors

Abbreviations: PHV, Phenotypic vigor; CEL, Cellulose; LIG, Lignin; C/L, Cellulose:lignin ratio; NDF, Neutral detergent fiber; ADF, Acid detergent fiber; HCEL, Hemicellulose; IDBD, *In vitro* digestibility of the dry biomass; N, Nitrogen; ASH, Ash; CAV, Calorific value.

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(Fontoura et al., 2015; Morais et al., 2009; Ra et al., 2012; Strezov et al., 2008) have highlighted elephant grass (*Pennisetum purpureum* Schum.), mainly for gathering appropriate biomass quality traits and high biomass production.

However, the quantification of the biomass quality is costly and time-consuming. Thus, selection based on morpho-agronomic traits in order to obtain indirect gains in biomass quality is a promising strategy at the initial stages of an elephant grass breeding program for bioenergy. In this sense, the canonical correlation analysis is noteworthy, since it maximizes the estimate of the correlation between two sets of variables (Rajasundaram et al., 2014).

Furthermore, the understanding of the association between calorific value released by biomass combustion and its main morpho-agronomic and biomass quality traits contribute for the selection of genotypes with greater calorific value and biomass production. However, according to Silveira et al. (2015), the simple correlation among traits does not represent the cause-effect measurement, and its direct interpretation may result in mistakes in the selection strategy. In this context, the path analysis is noteworthy since it decomposes the simple correlation coefficient into direct effects and indirect effects in relation to a variable of interest (Tyagi and Lal, 2007).

Morphological variability in elephant grass germplasm can be divided into four groups of standard ecotypes: Cameroon – presents erect genotypes with thick stalks, broad leaves, upright clumps and late flowering; Napier – presents genotypes with thick/intermediate stalks, broad leaves, open clumps and intermediate flowering; Mecker – presents reduced height genotypes with thin stalks, thin and more numerous leaves, and early flowering; and Dwarf – presents lower height genotypes (up to 1.5 m high), and high leaf/stalk ratio (Lira et al., 2010). However, there were no reports on the interrelations between biomass quality and morpho-agronomic traits in these groups, which could determine their potential in the production of bioenergy *via* direct combustion.

Thus, the objective of this study was to evaluate the aptitude of the groups Cameroon and Napier, aiming at the breeding of elephant grass for the bioenergy production *via* direct combustion.

2. Material and methods

2.1. Genetic material and experimental conduction

A total of 100 accessions of the Active Elephant Grass Germplasm Bank of Embrapa (BAGCE) were used, of which 18 were classified in the Cameroon group, 44 in the Napier group, four in the Mercker group, and the other accessions were classified as intermediate to the aforementioned groups. However, only the data of the groups Cameroon and Napier were used to compare the aptitude, due to the small number of genotypes in the Mercker group, and to the non-existence of genotypes of the dwarf group in this study. Besides, the groups Mercker and Dwarf have low energy biomass production potential.

The experiment was carried out in the Embrapa Dairy Cattle Research Center experimental field, located in the city of Coronel Pacheco, MG, Brazil (21°33′18″s, 43°15′51″W, at 417 m asl). The experiment was implemented in December 2011, in 0.20 m deep furrows. Fertilization was performed with 80 kg ha^{-1} P_2O_5. After the establishment, 30 days after the implantation of the experiment, plots were cut to 0.30 m of the soil surface (standardized harvest), and it was applied 300 kg ha^{-1} NPK formulation (20:05:20). Thereafter, data collection was carried out. The maintenance fertilization was performed with 300 kg ha^{-1} NPK formulation (20:05:20) after each evaluation cutting. Fertilization was carried out according to the soil analysis. The rest of the culture treatments were those recommended for elephant grass crop.

After the standardized harvest, two evaluation cuttings were carried out (the 1st cutting at 250 days – September 2012, and the 2nd cutting at the same interval in days – June 2013).

2.2. Experimental design

Plots consisted of one 4 m row, spaced 1.5 m apart. The experiment was a simple lattice (10 × 10) design with two replications.

2.3. Evaluation of measured traits

The traits evaluated were classified in two categories: morpho-agronomic and biomass quality.

(i) Morpho-agronomic traits. Flowering – determined by the number of days from the standardized harvest until the flowering of 50% of the experimental plot. Mean height – obtained from the mean height of three plants. Phenotypic vigor (PHV), obtained using a grading scale that ranged from 1 to 5, in which 5 was assigned to high vigor, and 1 was assigned to low vigor. Stalk diameter – obtained from the mean of five plants, measured at 10 cm above soil surface. Green biomass – quantified by weighing the green biomass collected in each plot. Total dry biomass – quantified by multiplying the green biomass by the dry matter content (%).
(ii) Biomass quality traits of elephant grass. Before each experimental cutting, random samples were taken from complete plants in the field, dried and sent to the biomass analysis laboratory for the chemical analyses described below:

Acid detergent fiber (ADF), neutral detergent fiber (NDF), levels of cellulose (CEL), lignin (LIG), and hemicellulose (HCEL) – were determined following the methods proposed by Goering and Van Soest (1967). *In vitro* dry biomass digestibility (IDBD) – was determined following the method proposed by Tilley and Terry (1963). Nitrogen (N) – was determined following the method proposed by the Association of Official Analytical Chemical (AOAC, 1975). Cellulose/lignin ratio (C/L) – was given by the cellulose/lignin ratio. Ash (ASH) – was determined following the method proposed by Silva and Queiroz (2002). Calorific value (CAV) – was determined using an IKA C-5000 calorimeter. Dry matter content – was determined by the dry weight/green weight ratio (this variable was used as a common denominator to estimate cellulose, lignin, acid detergent fiber, neutral detergent fiber, *in vitro* dry biomass digestibility, nitrogen, ash, and calorific value).

2.4. Statistical analysis

For the statistical analyses, it was adopted the mixed models methodology − REML/BLUP (restricted residual maximum likelihood/Best Linear Unbiased Prediction), according to Patterson and Thompson (1971) and Henderson (1975). The genotypic values (BLUP means) were estimated in each cutting for the 17 traits, using the statistical model given by: $y = Xm + Zg + Wb + Op + Ti + \varepsilon$, in which y is the data vector; m is the measurement-replication combination effect vector (assumed as fixed), added to the general mean; g is the genotypic effect vector (assumed as random); b is the block effect vector (assumed as random); p is the permanent environmental effect vector (assumed to be random); i is the genotypes x cuttings interaction effect vector; and ε is the residue vector (assumed as random). X, Z, W, Q, and T are the incidence matrices for the effects. The matrices of the genotypic correlation between the traits were also obtained from the BLUP means of the accessions of each group.