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Research paper

Growth, yield, fiber content and lodging resistance in eight varieties of *Cenchrus purpureus* (Schumach.) Morrone intended as energy crop

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ABSTRACT

Growth, biomass yield, fiber content and lodging resistance were studied, during a six month growth period, for eight varieties of *Cenchrus purpureus*, intended as energy crop, in Veracruz, Mexico. Then, only yield at day 182 was assessed for two additional years. The varieties were: CT115 (CT), African Cane (AC), Taiwan (TAI), King Grass (KG), Vruckwona (VRU), Roxo (RX), OM22 (OM) and Cameroon (CAM). Local weather is warm and sub-humid, historical data for monthly average temperature and annual rainfall were 25.8 °C and 1142 mm, respectively. Height, diameter and light interception were measured monthly from day 65–185. At day 185, biomass yield and tiller density were measured. Number of lying tillers was counted to estimate lodging resistance. Cellulose and hemicellulose content were estimated in leaf and stem. No differences were found for dry matter yield or stem yield at day 185 in the first year. Regarding the next two years, TAI yielded above CT, OM or ROX. Average dry matter yield was higher in the second year than in the establishment cycle (38.6 vs 21.1 Mg ha^{-1}), but decreased in the third year (32.2 Mg ha^{-1}). In both stem and whole plant, AC and KG showed higher hemicellulose content than RX, OM or CT; while AC and VRU had higher cellulose than RX in stem, or than CT in the whole plant. Furthermore, varieties AC, KG, VRU and TAI were resistant to lodging and had a higher fiber content, so they are recommended as energetic crops.

1. Introduction

Cenchrus purpureus (Schumach.) Morrone, formerly *Pennisetum purpureum* [1] is widely known as Napier Grass, Elephant Grass, or King Grass, but in some cases these names have been used to refer a particular variety. This giant grass has recently attracted interest of researchers due to its high biomass yield. Recent studies focus on topics such as production of second-generation ethanol to replace gasoline [2], use of grass fiber as a wood substitute for the paper-mill industry [3], direct combustion of biomass as charcoal substitute [4] and as a fodder for animal feeding [5].

The varieties available in Mexico have been scarcely studied regarding agronomic or morphologic features. CAM was released in Kenya in 1952 [6], it has been classified as belonging to the Cameroons type among three groups: Cameroon, Dwarf and Napier types [7]. On the other hand, King Grass gave rise to CT by tissue culture and to OM by hybridization with *Cenchrus americanus*, both varieties were released in Cuba [8]. OM is hairless and tall, with wider leaves than those of pure genotypes. In contrast, CT has lower height, less wide leaves and more abundant trichomes than OM. RX is a variety from Togo (Africa) introduced to Estação Presidente Medici in São Paulo, Brazil in 1975 [9], it is easily distinguished from others by a purple color on its leaves, stems and inflorescences.

Abbreviations: CT, CT115; AC, African Cane; TAI, Taiwan; KG, King Grass; VRU, Vruckwona; RX, Roxo; OM, OM22; CAM, Cameroon; NDF, Neutral Detergent Fiber; ADF, Acid Detergent Fiber; ADL, Acid Detergent Lignin; INIFAP, Mexican Institute for Forestry, Agricultural and Livestock Research (for its given acronym in Spanish).

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Genetic distances between some of these varieties are: 0.02, 0.06 and 0.10 for AC vs VRU, CAM or KG; 0.07 and 0.11 for KG vs VRU or CAM and 0.02 between the last two [10].

The high biomass yield of *C. purpureus* stems after its exponential growth stage [11] makes it one of the most promising options both for the paper industry and for ethanol extraction. An ethanol yield of 144 mg g^{-1} in Napier Grass has been reported, 44% of theoretical maximum according to 37 g of hexoses and 26 g of pentoses in 100 g of dry biomass [2].

Biomass yield in *C. purpureus* has been found to decrease after one to three years in the same field. In a study, using Merkeron variety at a single harvest per year [12], authors found that after a fertilization dose of 100-40-90 kg ha^{-1} $year^{-1}$ (N-P-K) either with an inorganic fertilizer or with poultry litter as sources, dry matter yield was systematically reduced from 30 to 10 Mg ha^{-1} in four years for the fertilization treatments and from 29 to 6 Mg ha^{-1} when it was not fertilized. In the mentioned assay, authors found a strong reduction of nitrogen and potassium removal between successive years, which means that availability of such elements was limiting growth. In another long-term study from 1996 to 2001 at three sites equally managed, in Georgia, United States [13], the author reported that biomass yield in Napier Grass decreased after three or four years, from dry matter yields as high as 39 (year 1999, Athens), 41 (1996, Tifton) and 49 Mg ha^{-1} (1998, Midville) until 16, 13 and 18 Mg ha^{-1}, respectively, for the 2001 year. A 4-years experiment with Merkeron variety proved that yield decrease sharply for a low input system [14], achieved yield were 30.4 and 30.1 through the first two years, but 11.2 and 7.1 Mg ha^{-1} during the last two. In the mentioned assay, growth was limited by availability of minerals, since nitrogen and potassium removal had a clear trend to decrease from the first to the fourth year (6.1–1.8 and from 21.3 to 6.5 g kg^{-1}, respectively) and ash content were 60, 54, 45 and 29 g kg^{-1} during the four years included.

In a study with Taiwan, Elephant, Dwarf and King Grass, biomass yield was measured every 14 days from day 70–140. The authors report that dry matter accumulation continues until day 126 in both stem and leaf, as well as in the whole plant [11]. They inform that dry matter yield did not surpass 16.6 Mg ha^{-1} and leaf to stem ratio was 0.54 at day 140. Furthermore, from day 98–140 stem yield increased from 4.9 to 12.2 and leaf yield increased from 3.6 to 4.4 Mg ha^{-1} (average for the mentioned varieties). On this basis, growth periods might range from 70 to 140 days according to biomass requirements. In a different study, it was concluded for *C. purpureus* cv. Maralfalfa, that harvest is feasible from 60 days and onwards, where both fiber content and yield were higher than at younger ages [15]. In this last assay, fertilization and nitrogen availability is reported to be a strong limitation due to the high mineral requirements of *C. purpureus*; nitrogen doses above 240 kg ha^{-1} are recommended to preserve soil fertility.

Previous studies have recorded that longer growth periods promote persistence of *C. purpureus*. By studying the rhizome mass and root concentration of both nonstructural carbohydrates and nitrogen, in response to four defoliation heights and four defoliation frequencies (10, 22, 34 and 46 cm and 3, 6, 9 and 12 weeks), it was concluded that the lowest values, for the three variables were reached for the 10 cm and 3 weeks treatment, whereas the highest values succeed for the 46 cm and 12 weeks treatment [16]. According to the above mentioned, combining high cutting frequency with high cutting intensity depletes reserves and endangers persistence as it has been established before for other tropical species like *Paspalum notatum* [17]. These results, plus the high biomass accumulation in stems at the end of the exponential growth phase [11] and a higher fiber content as the crop ages [15], would help supporting the convenience of harvesting after long growth periods when grass is intended for industrial uses, as proposed in the present experiment.

Lodging has been reported to be a frequent problem in tropical grasses. In *C. purpureus*, some varieties tend to reduce the angle with the ground as a reproductive strategy, allowing axillary buds to reach soil, which in turn gives rise to new tillers. This particular feature has not been studied before for this specie.

Field assessment can help decision making according to the characteristics of each variety. A high lignin and cellulose content is desirable for the paper mill industry and for the fabrication of biomass briquettes as charcoal substitute, but a high lignin content can limit ethanol extraction [18] and is fairly undesirable for animal feeding purposes. On the other hand, industrial crops are kept on vast tracks of land and mechanical harvest cannot be done if they show lodging. The present experiment assesses growth, yield, fiber content and lodging resistance in eight varieties of *C. purpureus* intended as industrial crop in a warm, sub-humid climate in an attempt to help decision making in the field. In addition, a correlation test was run among morphological and yield traits.

2. Materials and methods

2.1. Location

The experiment was conducted at *Campus* Papaloapan of the Mexican Institute for Forestry, Agricultural and Livestock Research (INIFAP) in Veracruz, Mexico, from June 2012 through January 2013, but growth measurements started on August 30 (day 65 after planting) and ended on December 28 (day 185). Yield data for the next two wet seasons come from growth cycles beginning on June 15 of 2013 and June 07 of 2014. The *Campus* Papaloapan is located at 18°06′ N, 95°32′ W and 65 m above sea level. Climate is classified as an Aw, hot sub-humid [19], with 80% of seasonal rain occurring in summer, where historical data (40 years) for annual precipitation and average temperature were 1142 mm and 25.8 °C. Weather data for the term of the present assay is shown in Fig. 1. By means of a soil analysis realized at *Campus* Cotaxtla of INIFAP, for samples collected in the field during sowing, soil was identified as an orthic acrisol with a sandy-loam texture, low organic matter (0.34%), acid pH (3.5), low level of inorganic N, Ca, Mg and Cu (2,174, 48 and 0.2 mg kg^{-1}) but adequate levels of Fe, Zn, Mn and P (57, 1.6, 4.4 and 55 mg kg^{-1}).

2.2. Experimental conditions

Assessed varieties were: CT115 (CT), African Cane (AC), Taiwan (TAI), King Grass (KG), Vruckwona (VRU), Roxo (RX), OM22 (OM) and Cameroon (CAM). Experimental design consisted of four complete randomized blocks and eight treatments (varieties) for a

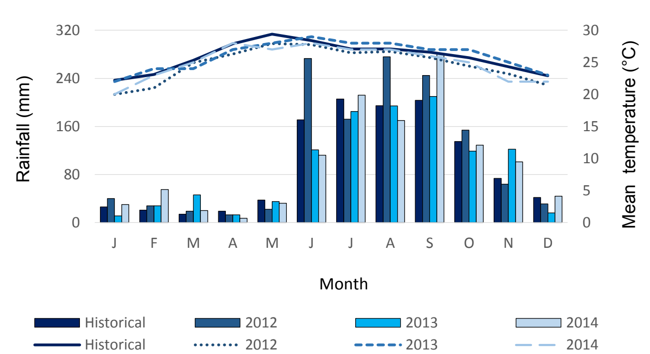

Fig. 1. Rainfall (bars) and mean temperature (lines) during the current assay and historical data for 40 years.