ABSTRACT – The Cerrado has been the main source of firewood and charcoal in Brazil, but despite being one of the hot spots for conservation of the world’s biodiversity, neither plantations of native species nor sustainable management has been adopted in the region. The aim of this work was to investigate the biomass distribution and the potential for energy production of the cerrado species. The study was conducted in a cerrado sensu stricto site at the Água Limpa Farm (15º 56'14'' S and 47º 46'08'' W) in the Cerrado Biosphere Reserve. An area of 63.54ha was divided in 20 x 50m plots and, a random sample consisting of ten of these plots, representing 1.56% of the study-site, was assessed. All woody individuals from 5 cm diameter at 30 cm above ground level were identified and measured. Each individual was felled, the twigs thinner than 3cm were discarded while the larger branches and the trunks, both with bark, were weighted separately. After that, 2.5cm transverse sections of the trunk with bark were taken at 0, 25, 50, 75 and 100% of the length. A similar sample was also taken at the base of each branch. A total of 47 species in 35 genera and 24 families were found, with an average density of 673 individuals per ha. The diameter distribution showed a reversed-J shape with 67% of the individuals up to 13cm, while the maximum diameter was 32.30cm. Seven species represented 72% of the total biomass. In general, the species with higher production per tree were among those with higher production per ha. This content was distributed by diameter classes, reaching a maximum of 2.5ton/ha between 9 to 13cm and then, decreasing to 0.96 ton/ha between 29 to 33cm diameter. Carbon sequestering was 6.2ton/ha (until the actual stage of cerrado) based on an average 50% carbon content in the dry matter. The heat combustion of the wood varied from 18,903kj/kg to 20,888kj/kg with an average of 19,942kj/kg. The smaller diameter classes fix more carbon due to the large number of small plants per ha. But, for a species that reached larger dimensions and contained individuals in all diameter classes, Vochysia thyrsoidea, one can verify an increase in carbon fixation from 1.41 kg/ha in the first class (5 to 9cm) to 138,3kg/ha in the last (25 to 33cm). That indicates that it is possible to select species that reach larger size with a higher capacity of carbon accumulation per plant. The species that reached larger dimensions, with a production per tree above average and had high calorific power values were Dalbergia miscolobium, Pterodon pubescens and Sclerolobium paniculatum. These species have potential for use in fuelwood plantations and sustainable management.

Keywords: Cerrado, savanna, wood calorific power, biomass and carbon sequestering.

DISTRIBUIÇÃO DE BIOMassa SECA EM Um SÍTIO DE CerrADO sensu stricto no Brasil central

RESUMO – O Cerrado foi a principal fonte de lenha e carvão no Brasil, mas, apesar de ser uma das áreas mais conhecidas para conservação da biodiversidade no mundo, ainda não foram feitas plantações de espécies nativas nem manejo sustentável foi adotado na região. O objetivo deste trabalho foi investigar a distribuição de biomass e o potencial para produção de energia das espécies de cerrado. O estudo foi realizado em...
1. INTRODUCTION

Several renewable sources of energy have been studied as alternatives to fossil fuel, such as solar, wind, tidal and nuclear. Biomass stands out as the most versatile amongst these sources especially due to the well-developed energy conversion technologies and the availability of raw material (GRASSI e PALZ, 1998).

The biomass in Brazil contributed 19% of all primary energy consumed in 1999 and firewood represented 9% of that figure totalling 6.9 x 10^7 tons of wood burned in households (BRASIL, 2000). The native vegetation contributed a total of 70 million tons of the wood consumed for energy of which ca. 21 million were used in households serving about ten million with an average utilization of 22 kg/household/day. Rural people, especially those on low income are the main users of firewood.

The Brazilian cerrado was recently listed as one of the 25 hot spots for conservation of biodiversity, being amongst the most rich and endangered ecosystems of the world (MITTERMEYER et al., 1999). The biome contains a mosaic of savanna vegetation, gallery forests, and seasonal forests on limestone outcrops with over 6,000 vascular plants (MENDONÇA et al., 1998). It covers around two million ha but is being rapidly depleted of its natural vegetation. Around 60% of the cerrado has already been converted to large scale agriculture, cattle ranging, dams and urban sites (MITTERMYER et al., 1999). Until recently, extensive areas were cleared to supply charcoal for steel industries, which were then, used for agriculture. However, with the opening of the national markets to mineral coal from Eastern Europe, wood is now mostly used for domestic purposes, pottery, bricks and other small industries.

Tree planting on degraded land, and forest management supply charcoal by, therefore, avoiding new clearings in the remaining fragments. However, little is known on the biomass production and calorific power of the cerrado species. Calorific power is the quantity of heat liberated by the combustion of a unity of mass of a body. When the combustion happens at a constant volume and the water is produced during the condensation process, it is called superior calorific power (SCP) (DOAT, 1977). Heat combustion at 0% humidity varies from 14,651 kJ/kg to 20,930 kJ/kg (BRITO, 1986).

Palavras-chaves: Cerrado, savana, poder calorífico da madeira, biomassa e seqüestro de carbono.
Basal area is lower in the woody component of the cerrado senso stricto, ranging from 8 to 12 m² ha⁻¹ (FELFILI et al., 1994, 1997), compared to the values found in Amazonian forests (PIRES and PRANCE, 1997) and gallery forests in central Brazil (FELFILI et al., 1994; FELFILI, 1995), of around 20 to 30 m² ha⁻¹. Cerrado biomass is also low at 21.4 ton ha⁻¹ (SILVA, 1990) compared to values found in Amazonian forests, which range from 97.5 ton ha⁻¹ to 254.6 ton ha⁻¹ (KRINGE et al., 1995; RUGANI et al., 1997).

Silva (1990) studied biomass and nutrient partitioning in the aerial parts including trunk, branches, leaves, flowers and fruits of 35 woody species of the Brazilian cerrado. He found an average of 0.62 ton ha⁻¹ per species, varying from Byrrsonima crassa with 0.64 ton ha⁻¹ to Sclerolobium paniculatum with 5.22 ton ha⁻¹ (HARIDASAN 2000). Few species reach more than 10 cm diameter in the cerrado senso stricto (FELFILI and SILVA JÚNIOR, 1988; SILVA JÚNIOR and SILVA, 1988; NASCIMENTO and SADDI, 1992) and one could expect that some would be hardwoods with high calorific power reaching dimensions large enough to be used for charcoal.

The knowledge of the biomass accumulation, the dimensions of the aerial parts and the heart combustion of cerrado woody species can be used, with other characteristics (basic density, moisture, growth rate, etc) to select species for firewood and charcoal plantations and for reclamation of degraded land by small farmers that could earn marginal revenues. It could also help the assessment of carbon emissions from the frequent burning of the cerrado vegetation.

The objective of this work was to determine the dry biomass by diameter classes and the calorific power of the species occurring in a cerrado senso stricto site.

2. MATERIAL AND METHODS

The study-site was a cerrado senso stricto site at the University of Brasilia Research Station in the Água Limpa Farm (15 56' 14'' S and 47 46' 08'' W) in the Federal District, in the nuclear zone of the Cerrado Biosphere Reserve in Brazil. The climate is Aw by Köppen's classification with an average precipitation of 1,600 mm (NIMER, 1989) and average altitude of 1,100 m.

An area of 63.54 ha was divided in 20 x 50 m plots, a random sample consisting of ten of these plots, representing 1.56% of the study-site area, was assessed. All woody individuals from 5 cm diameter at 30 cm above ground (d) were identified and had their height and diameter measured according to the methodology adopted by Felfili and Silva Júnior (1993) for this physiognomy.

Seven diameter classes were found, ranging from 5 to 33 cm. This amplitude and class interval is within the range to that found in other cerrado sites (FELFILI and SILVA JÚNIOR, 1988; SILVA JÚNIOR and SILVA, 1988; NASCIMENTO and SADDI, 1992).

Three individuals per diameter class per species were randomly selected and, each individual was logged at the ground level. The twigs smaller than 3 cm diameter were discarded while the larger branches and the trunks, both with bark, were weighted separately in a scale of 150 kg maximum capacity. After that, 2.5 cm transverse sections of the trunk with bark were taken at 0, 25, 50, 75 and 100% of the trunk length. A similar sample was also taken at the base of each branch. In multitrunk trees, one was randomly selected for sampling. These transverse sections were tagged, put in plastic bags and sent to a Laboratory.

The moisture contents and the relation between the wood and the bark, was determined in laboratory just after the trees were cut. The fresh mass in the field was calculated by multiplying the fresh mass of wood and bark samples by the percentage of total wood and bark. Based on the moisture contents the total dry mass per tree was estimated per diameter classes.

The total values of energetic biomass were obtained from the trunk and the branches equal or larger than 3 cm diameter, that is, those branches that could be used for firewood.

The superior calorific power of the wood and the bark was obtained according to ABNT NBR 8633 procedure and the operation manual of the calorimeter PARR 1201 (ABNT, 1984).

3. RESULTS AND DISCUSSION

3.1. Community richness and structure

There was a total of 47 species in 35 genera in 24 families (Table 1). The average density was 673 individuals per ha.

Diameter distribution showed a reversed-J shape with 67% of the individuals up to 13 cm while the maximum diameter was 32.3 cm, see Figure 1. The heights varied from 1 m to 13 m with most individuals up to 5 m, see Figure 2.
### Table 1 – Woody species with diameter from 5 cm at 30 cm above the ground level in the cerrado sensu stricto in the Água Limpa Farm, University of Brasília, Brasília - DF

| Species | Family | Common Name |
|---------|--------|-------------|
| Acosmium dasycarpum (Vog.) Yakovl. | Leg. Papilionoideae | Amargozinho |
| Aspidosperma macrocarpon Mart. | Apocynaceae | Bolsinha |
| Aspidosperma tomentosum Mart. | Apocynaceae | Guatambu |
| Byrsonima coccolobaefolia H.B. & K. | Malpighiaceae | Murici-vermelho |
| Byrsonima crassa Nied. | Malpighiaceae | Murici |
| Byrsonima verbascifolia (L.) Rich. ex A. L. Juss. | Malpighiaceae | Murici |
| Byrsonima coccolobaefolia (H. B. & K.) Berg | Malpighiaceae | Murici-vermelho |
| Caryocar brasiliense Camp. | Malpighiaceae | Pequi |
| Connarus suberosus Planch. | Concinaceae | Coração-de-negro |
| Dalbergia miscolobium Benth. | Leg. Papilionoideae | Jacarandá-do-cerrado |
| Davilla elliptica St. Hil. | Mimosiaceae | Lixeirinha |
| Dimorphandra mollis Benth. | Mimosiaceae | Faveira |
| Enterolobium gymniferum (Mart.) Mach. | Mimosiaceae | Orelha-de-negro |
| Eremeanthus glomerulatus Less. | Compositae | |
| Eriotheca gracilipes (K. Schum.) A. Robyns | Bombacaceae | Paineira |
| Eriotheca pubescens (Mart. & Zucc.) Schott. & Endl | Bombacaceae | Paineira-do-cerrado |
| Erythroxylum deciduum St. Hil. | Erythroxylaceae | Fruto-de-passarinho |
| Erythroxylum suberosum St. Hil. | Erythroxylaceae | Muchiba |
| Erythroxylum tortuosum Mart. | Erythroxylaceae | Muchiba-comprida |
| Guapira noxia (Netto) Lund | Nyctaginaceae | |
| Hymenaea stigonocarpa Mart. ex Hayne | Leg. Caesalpinioidae | Jatobá-do-cerrado |
| Kielmeyera coriacea (Spreng.) Mart. var. coriacea | Guttiferae | Pau-santo |
| Kielmeyera speciosa St. Hil. | Guttiferae | Pau-santo |
| Lactorea pacari St. Hil. | Lythraceae | Mangaba-brava |
| Miconia ferruginata DC. | Melastomataceae | Lacre |
| Miconia pohliana Cogn. | Melastomataceae | Lacre |
| Myrsine guianensis (Aubl.) Kuntz | Myrtaceae | |
| Ouratea hexasperma (St. Hil.) Baill. | Ochnaceae | Cabelo-de-negro |
| Palicourea rigidia Kunth | Rubiaceae | Bate-caixa |
| Poatearia ramiflora (Mart.) Radlk. | Sapotaceae | Grão-de-galo |
| Piptocarpha rotundifolia (Less.) Baker | Compositae | Coração-de-negro |
| Psidium warmingianum Kier. | Myrtaceae | Aracá |
| Pterodon pubescens (Benth.) Benth. | Leg. Papilionoideae | Sucupira-branca |
| Qualea grandiflora Mart. | Vochysiaceae | Pau-terra-folha-grande |
| Qualea multiflora Mart. | Vochysiaceae | Pau-terra-liso |
| Qualea parviflora Mart. | Vochysiaceae | Pau-terra-roxo |
| Rourea induta Planch. | Connaraceae | |
| Schefflera (Didymopanax) macrocarpa (Seem.) D.C. Frodin | Araliaceae | Mandioção-do-cerrado |
| Sclerolobium paniculatum Vog. var. subvelutinum Bentham | Leg. Caesalpinioidae | Carvoeiro |
| Strzychnos pseudoquina St. Hil. | Loganiaceae | Quina-do-cerrado |
| Styphnodendron adstringens (Mart.) Cov. | Styracaceae | Barbatimão |
| Styxas ferrugineus Nees & Mart. | Styracaceae | Laranjeira-do-cerrado |
| Symlocos rhamnfolia A. DC. | Symlocaceae | Ipê |
| Tabebuia ochracea (Cham.) Standl. | Bignoniaceae | Ipê |
| Tabebuia serratifolia (Vahl.) Nicholson | Bignoniaceae | Ipê |
| Vochysia elliptica Mart. | Vochysiaceae | Pau-doce |
| Vochysia rufa Mart. | Vochysiaceae | |
| Vochysia thyrsoides Pohl. | Vochysiaceae | Gomeira |
3.2. Dry Biomass production

Total dry biomass was 12.4 ton ha\(^{-1}\) with an average per species of 264 kg ha\(^{-1}\) and 11 species had a total above average production. The highest production per species was 2,886 kg ha\(^{-1}\) for *Sclerolobium paniculatum*. The production (Table 2) increased from the first diameter class (5 to 9 cm) with 1,783 kg ha\(^{-1}\) to the following (9 to 13 cm) with 2,557 kg ha\(^{-1}\) and then, came a smooth decreasing tendency till the last class (29 to 33 cm) with 963 kg ha\(^{-1}\). Total dry biomass (kg per tree) increased with diameter in contrast with number of trees (Figure 3) that decreased sharply. A large number of the species did not reach large diameters, and their trees are small with a low biomass, on average of 18.4 kg tree\(^{-1}\).
The few species that reached large diameters (above 13 cm), with biomass values per tree above average were: Blepharocalix salicifolius, Caryocar brasiliense, Hymenaea stigonocarpa, Pterodon pubescens, Qualea grandiflora, Qualea parviflora, Sclerolobium paniculatum and Vochysia thyrsoidea. Those seven species represented 72% of the total biomass.

In general, the species with higher production per tree were among those with higher production per ha. However, Ouratea hexasperma, with low production per tree, showed a high production per ha due to a high density per ha.

3.3. Heat combustion

The heat combustion of the wood varied from 19,903 kJ kg⁻¹ for Blepharocalix salicifolius to 20,888 kJ kg⁻¹ for Acosmium dasyacarpum. The average for this cerrado was 19,942 kJ kg⁻¹. Species in the same genus had similar values of SCP (Table 2), except for Erythroxylum, with 18,837 kJ kg⁻¹ for E. suberosum, 19,414 kJ kg⁻¹ for E. deciduum and 20,645 kJ kg⁻¹ for E. tortuosum.

Twenty one species had heat combustion values above average: Acosmium dasyacarpum, Aspidosperma macrocarpon, Aspidosperma tomentosum, Byrsonima coccolobaefolia, Byrsonima crassa, Byrsonima verbascifolia, Caryocar brasiliense, Connarus suberosus, Dalbergia miscolobium, Dimorphandra mollis, Erythroxylum tortuosum, Hymenaea stigonocarpa, Kielmeyera speciosa, Lafoensia pacari, Miconia ferruginata, Ouratea hexasperma, Pouteria ramiflora, Pterodon pubescens, Sclerolobium paniculatum, Stryphnodendron adstringens, Tabebuia serratifolia.

3.4. Discussion.

Species richness and density at this site was within the range found for several other cerrado sites (FELFILI and SILVA JUNIOR, 1993; FELFILI et al., 1997). This cerrado contained 12 of the 28 most common species for the biome listed by Ratter et al. (1996) being therefore, very representative of that vegetation.

The heat combustion with values between 18,903 kJ kg⁻¹ and 20,888 kJ kg⁻¹ were similar or higher than those found for other tropical species such as Eriotheca globosa (16,647 kJ kg⁻¹), Ceiba samauma (19,695 kJ kg⁻¹) according to Meifa and Castilho (1992) and Acacia mangium (19,335 kJ kg⁻¹) according to Vale et al. (1999). The 47 species studied here therefore presented a good potential for firewood and charcoal production. The species Dalbergia miscolobium, Pterodon pubescens and Sclerolobium paniculatum have potential for fuelwood management in natural conditions and they could
Table 2 – Dry biomass (kg/ha) distribution by diameter class in the cerrado *sensu stricto* in the Água Limpa Farm, University of Brasília, Brasília-DF

| Species | Diameter class (cm) | Dry biomass (kg/ha/species) | Heat Combustion (kJ/kg) |
|---------|---------------------|-----------------------------|-------------------------|
|         | 5 - 9               | 9 - 13                      | 13 - 17                 | 17 - 21 | 21 - 25 | 25 - 29 | 29 - 33 |
| Acanthospermum hispidum | 15.16 (1) | 9.64 (1) | 25.8 (1) | 15.16 (1) | 20.88 |
| Aspidosperma macrocarpon | 4.35 (3) | 24.57 (5) | 20.21 |
| Aspidosperma pterostigma | 44.80 (10) | 25.10 (5) | 20.35 |
| B. r. alata | 3.00 (1) | 4.99 (1) | 7.99 (2) | 20.28 |
| B. r. heimii | 23.43 (11) | 23.43 (11) | 20.01 |
| B. r. jasminoides | 8.68 (4) | 8.68 (4) | 19.97 |
| B. r. rubra | 33.39 (9) | 51.43 (1) | 226.38 (1) | 19.15 |
| Caryocar brasiliense | 13.20 (5) | 20.88 |
| Dimorphandra mollis | 9.04 (1) | 20.83 |
| Enterolobium gummiferum | 5.68 (1) | 5.68 (1) | 19.83 |
| Eremaphysalis glomerulata | 8.16 (1) | 8.16 (1) | 19.83 |
| Eriotheca gracilipes | 7.24 (2) | 7.24 (2) | 19.11 |
| Erythroxylum deciduum | 8.68 (4) | 8.68 (4) | 20.64 |
| Guapira noxia | 27.20 (8) | 35.13 (1) | 20.15 |
| Hymenaea stigonocarpa | 28.14 (21) | 28.14 (21) | 19.34 |
| Kielmeirusonaceae | 33.00 (11) | 4.88 (1) | 37.88 (12) | 19.44 |
| Pilicium tomentosum | 13.20 (5) | 13.20 (5) | 19.83 |
| Qualea grandiflora | 37.88 (12) | 37.88 (12) | 19.34 |
| Qualea multiflora | 14.25 (1) | 14.25 (1) | 20.04 |
| Qualea parviflora | 37.88 (12) | 37.88 (12) | 19.34 |
| Rourea induta | 1.88 (1) | 1.88 (1) | 19.54 |
| Schistostegia macrocarpa | 47.6 (14) | 47.6 (14) | 19.84 |
| Strychnos pseudoquina | 27.66 (1) | 27.66 (1) | 19.91 |
| Symplocos rhamnifolia | 0.43 (1) | 0.43 (1) | 19.92 |
| Tabebuia ochracea | 4.19 (1) | 4.19 (1) | 19.92 |
| Tabebuia serratifolia | 4.19 (1) | 4.19 (1) | 19.92 |
| Vochysia elliptica | 4.19 (1) | 4.19 (1) | 19.92 |
| Vochysia urophylla | 4.19 (1) | 4.19 (1) | 19.92 |
| Vochysia thyrsoidea | 11.28 (4) | 11.28 (4) | 19.72 |
| Total absolute dry biomass (kg/ha) | 1783.56 | 2562.92 | 1857.89 |
| Total Relative dry biomass (%) | 15.11 | 20.67 | 17.27 |
| Number of individuals/ha | 393 | 176 | 58 |

Table 2 – Distribuição da biomassa seca (kg/ha) por classe de diâmetro em cerrado sensu stricto na Fazenda Água Limpa, Universidade de Brasília, Brasília-DF
Eighteen of the 21 species with SCP above average are widely distributed in the cerrado biome (RATTER et al. 1996), so fuelwood plantations with these species could help the conservation of these populations and management strategies developed for their management could be broadly used. These species were: Acosmium dasycarpum, Aspidosperma macrocarpon, Aspidosperma tomentosum, Byrsonima coccolobaefolia, Byrsonima crassa, Byrsonima verbascifolia, Caryocar brasiliense, Connarus suberosus, Dalbergia microlobium, Dimorphandra mollis, Erythroxylum tortuosum, Hymenaea stigonocarpa, Lafoensia pacari, Ouratea hexasperma, Pouteria ramiflora, Pterodon pubescens, Sclerolobium paniculatum and Stryphnodendron adstringens.

Carbon sequestering in the cerrado sensu strictu at the Água Limpa Farm was 6.2 ton/ha based on an average 50% carbon content in the dry matter. This content was distributed by diameter classes, reaching a maximum of 1.3 ton/ha between 13 to 17 cm and then, decreasing to 0.96 ton/ha between 29 to 33 cm diameter. The smaller diameter classes stock more carbon due to the large number of small plants per ha. But, for a species that reaches larger dimensions, Vochysia thyrsoides and contained individuals in all diameter classes, one can verify an increase in carbon storage from 1.41 kg ha$^{-1}$ in the first class (5 to 9 cm) to 482 kg ha$^{-1}$ in the last (25 to 33 cm). That indicates a possibility to select species that reaches larger sizes with a higher capacity of carbon accumulation per plant.

The rapid sprouting of cerrado plants after fire and clear cutting are also positive features regarding carbon accumulation. These plants grow quicker than new seedlings since they usually have deep root systems. The larger quantity of carbon accumulation in the subterranean organs, roots and xylopodia (PAULILLO and FELIPE, 1998) could also be an advantage of cerrado species under management for carbon accumulation. Stands could be cut, the aerial parts could be continuously growing after each cutting and at the same time most of the carbon accumulated would be kept underground.

4. CONCLUSIONS

The cerrado species studied here that presented high production per tree, high production per area and high hest combustion were Dalbergia microlobium, Hymenaea stigonocarpa, Pterodon pubescens and Sclerolobium paniculatum. These species, that reach larger sizes with a high capacity of carbon accumulation per plant, should be used in fuelwood plantations and be targeted for firewood management.

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