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Firewood potential production of three sahelian woody species (Grewia *bicolor, Pterocarpus lucens and Combretum glutinosum*) in Ferlo (Northern Senegal)

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Daouda NGOM, Amy BAKHOUM, Valentin KINDOMIHOU, Sékouna DIATTA, Léonard Elie AKPO: Firewood potential production of three sahelian woody species (Grewia *bicolor, Pterocarpus lucens and Combretum glutinosum*) in Ferlo (Northern Senegal)

ABSTRACT

This study aim to find the mostly used forest species for firewood, to establish predictive models for the wood potential and evaluates the needs and the potentialities of production of the ligneous in Velingara-Ferlo Rural Community (Senegal) in western Africa. Three mostly preferred firewood species (*Combretum glutinosum, Pterocarpus lucens* and *Grewia bicolor*.) were identified using socio-economical investigations. The daily wood consumption was estimated from women, to 1.26 kg wood/anybody/day. Allometric relations were also established between the woody biomass and circumference based on dendrometrical and weighed data matrix built from woody individuals, i.e. *C. glutinosum* (n = 23), *P. lucens* (n = 12) and *G. bicolor* (n = 12). This contributes to assess the woody average production of these species which is estimated to 3.5 tons ha^{-1}. *C. glutinosum* shows the largest contribution of this value due to it relatively high density (103 individuals per hectare). The wood quantity currently used a year (7318 tons) meanly account for 2.4% of the forest trees stands (309 474 tons).

Key words: firewood - surveys - production - allometric relations.

Introduction

Firewood is the main domestic source of energy in Ferlo. It offers an essential service to local communities. However, very few studies evaluate the firewood production in sahelian context. Indeed, knowledge on the savannas' productivities [4,7,15,12,21] revealed complexity and diversity of the answers to questions addressing productivity [17], particularly regarding the firewood production. Indeed, most of the methods estimating the wood production in savannas miss the heterogeneity of settlements and production targets (sawlog, service wood and firewood). Thus, methods integrating the various productions (sawlog, service and firewood, forages, fruits), diversity and dynamics of the woody formations [6] are needed. This estimation is essential for establishing a precized assessment between needs and resources, particularly regarding the firewood [5]. The present work lists for Ferlo savanna, the mostly used species, establishes predictive models for the wood potential and evaluates the needs and the potentialities of production of the ligneous.

Material And Method

Study area:

The study was undertaken in the rural community of Velingara-Ferlo in northern Senegal (14°24'-16°11' NL and 13°07'- 14°51' W longitude) (figure 1). It is situated between administrative Matam, Louga and Saint-Louis. Three main ethnic groups i.e. Peuls, Wolofs and Moors prevailed with a more dominance of Peuls. Ferlo is established on dune sandy formations of the continental terminal. The landscape is marked with slopes lower than 3% affecting evolution of the mediums and discriminated three main types of soil: sandy soils, a gradient of clayed-sandy to clayed soils and lateritic soils. The climate is sudano-sahelian characterized by a three-month rainy season high thermal amplitude. The maximum temperature reached 40.4° C in May. The

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annual average temperature is 28.6°C while the minimal monthly average temperatures are 14.1°C in January.

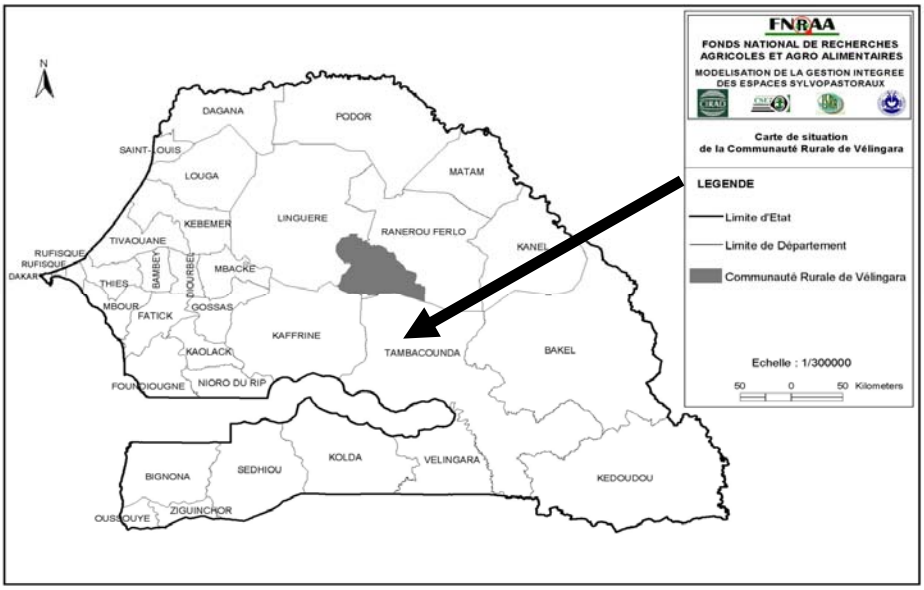

Fig. 1: Map of the rural community of Velingara-Ferlo

Precipitations are concentrated in July, August and September. The Ranerou station'rain averaged 474 mm (from 1951 to 2011). Since 1970, more than 25% of the annual rain is lower than the dry inter-annual mean value as these years belong to the driest ones. Chorologically, the biosphere reserve holds both sahelian formations and sudanian savannas. The woody layer is dominated by shrubs with mainly *Combretum glutinosum, Pterocarpus lucens, Guiera senegalensis, Grewia bicolor, Acacia Senegal, Balanites aegyptiaca,* etc. The herbaceous layer is marked by grass species such as *Cenchrus biflorus, Schoenfeldia gracilis, Eragrostis tremula* and *Dactyloctenium aegyptium.*

Method:

This work uses socio-economic and ecological data. Observations, measurements and investigations from women in 40 smallholders provide knowledge and information on the mostly used firewood species and help in estimating the daily consumption of firewood. The plant material for assessing the wood potential consists in *Combretum glutinosum, Grewia bicolor* and *Pterocarpus lucens*. Each sampled tree is measured for circumference at the basis and height. Various branches were clustered in three groups namely respectively large, averages and small branches. Branches were sampled per group, crossed, defoliated and weighed (figure 2). Each branch was measured for the length and circumference before the weighing. This method of standards branches helps in building the regression linking the dry matter to the basal circumference per branch and/or to the length of the corresponding branches [13]. Thus, a model expressing an allometric relation of the form:

$Y = A. X^b$ with a coefficient of determination (R^2) between the variables Y and X.

Y is the woody production in kg ms (P) and X, the circumference in cm (C).

The power b indicates the range of magnitude in Y when X increases [3]. The force of the link between the two variables is estimated by the coefficient of determination R^2, ranging between 0 and 1. The relationship is strong when R^2 approaches 1 [9].

The dry matter rate (MS) was obtained after the wood discs samples were oven dried at 105°C until a constant weight.

The evaluation of the wood production potential initially consists in establishing the distribution of trees number according to the trunk circumference classes. The regression model is applied to the trees number of each circumference class. The wood production is multiplied by the density of corresponding class. The average minimal and maximal values help to estimate the average value of the wood production expressed in kgMS/ha for the three species.

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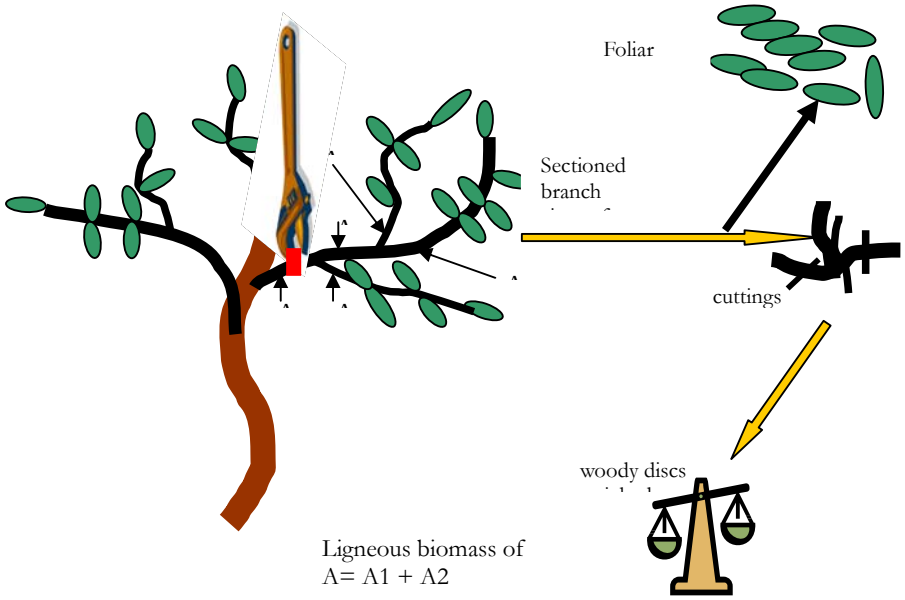

Fig. 2: Principles of the field ligneous biomass measurement

Results:

Species used as firewood:

The firewood is the main domestic source of energy in Velingara-Ferlo. However, the species are not used at the same extend (table 1).

Table 1: Importance of the preferred species for firewood (FR %)

Species	Frequence (%)
Grewia bicolor	95
Combretum glutinosum	80
Pterocarpus lucens	45
Guieria senegalensis	10
Anogeissus leiocarpa	5
Dalbergia melanoxylon	2.5
Balanites aegyptiaca	2.5
Mitragyna inermis	0
Bombax costatum	0
Pterocarpus erinaceus	0
Sclerocarya birrea	0
Lannea acida	0

The ligneous species preferentially used for firewood in the zone are *Grewia bicolor* (95%), *Combretum glutinosum* (80%) and *Pterocarpus lucens* (45%). *Guieria senegalensis* (10%) is also used as wood of the second quality. The wood of *Mitragyna inermis*, *Bombax costatum* and *Anogeissus leiocarpus* are little solicited for fire. In certain villages, burning the wood of *Bombax costatum* and *Anogeissus leiocarpa* would attract the bad spirits.

Populations' structure based on circumference class:

The populations' distribution of the three species in various classes of circumference (figure 3) indicates *Combretum glutinosum* having the best densities except for the class [> 100 cm]. The settlement pattern of *Pterocarpus lucens* shows a prevalence of individuals with large diameter ([51-100 cm] and [> 100 cm]). The weak representation of individuals at small circumferences indicates a low potential of regeneration. The old individuals of *Grewia bicolor* belong mainly to the class [51-100 cm]. The weak representation of intermediate classes ([31-40 cm], [41 - 50 cm]) is related to a recruitment problem because the young individuals ([10-20 cm]) are used as fodder or firewood. This is a multi-purpose species.

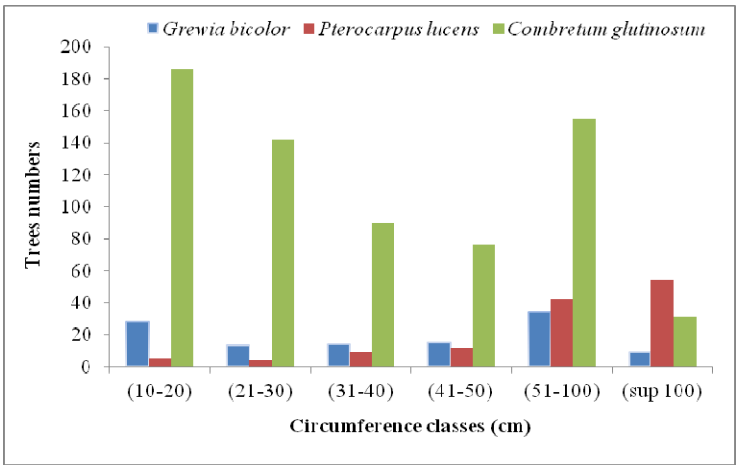

Fig. 3: Distribution of populations of *Pterocarpus lucens*, *Grewia bicolor* and *Combretum glutinosum* following circumference classes

Firewood production modeling:

The dry matter content averages 65.9% for *Grewia bicolor*, 60.8% for *Pterocarpus lucens* and 57.6% for *Combretum glutinosum*. *C. glutinosum* shows the higher value for water content followed by *P. lucens* and *G. bicolor* (Table 2).

Table 2: Wood dry matter and water contents of the different species

Species	Dry matter content (%)	Water content (%)
Grewia bicolor	65.9	34.1
Combretum glutinosum	57.6	42.4
Pterocarpus lucens	60.8	39.2

The dendrometrical characteristics and the branches discs weight help in establishing allometric models for the wood production calculation per species (figures 4, 5, 6). These models were built using the regression equations i.e. $P = a \times C^b$ (table 3).

Table 3: Woody production models for *Grewia bicolor*, *Combretum glutinosum* and *Pterocarpus erinaceus*

Variables	A	b	R^2	Modéles
Grewia bicolor	0.0023	2.812	0.87	$P = 23.10^{-4} \times C^{2.8124}$
Pterocarpus lucens	0.0066	2.171	0.81	$P = 66.10^{-4} \times C^{2.171}$
Combretum glutinosum	0.0025	2.466	0.88	$P = 25.10^{-4} \times C^{2.4658}$

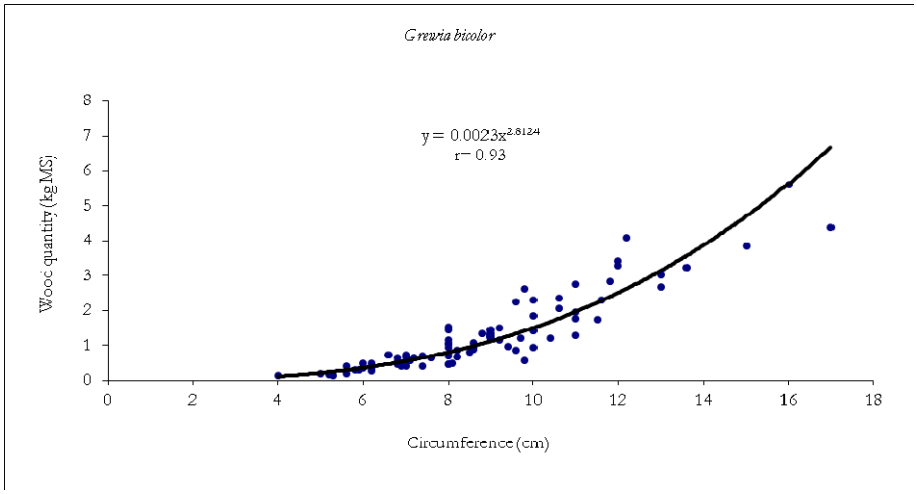

Fig. 4: Relation between wood quantity and circumference with *Grewia bicolor*

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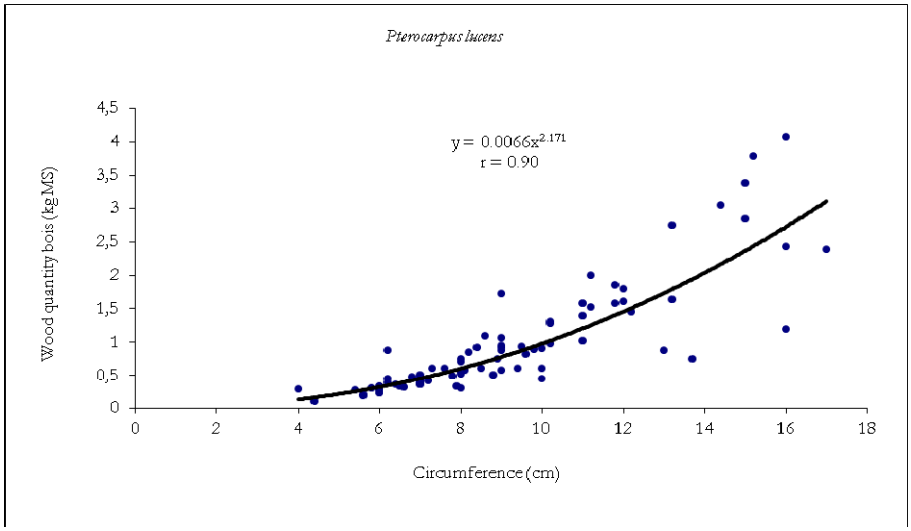

Fig. 5: Relation between wood quantity and circumference of *Pterocarpus lucens*

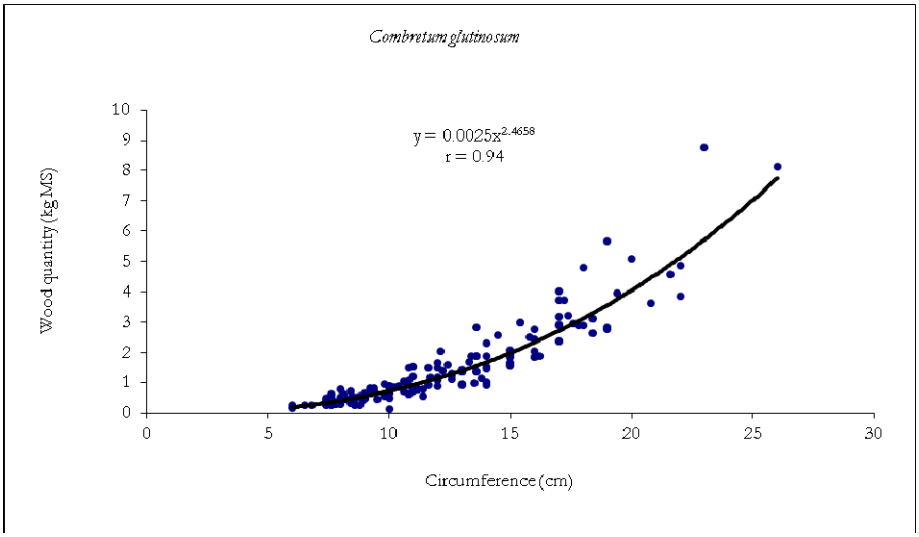

Fig. 6: Relation between wood quantity and circumference of *Combretum glutinosum*

The coefficients of determination are high (R^2>0.75, i.e. *G. bicolor:* 0.93; *P. lucens*: 0.90 and *C. glutinosum*: 0.94). Indeed, these values is regarded as fort when it is higher than 0.75 (Belhedi, 2006). These coefficients measure the degree of relationship between the tree wood production and it circumference. Both traits vary concomitantly with mutual effects. The current values show the strongest correlation between the wood quantity and the circumference. In addition, a model was built by pooling the three species with the following expression (figure 7).

$P = 71.\ 10^{-4} \times C^{2.1471}$ (R^2=0.88) P= Wood production bois C= Circumference

This determination coefficient is lower than those from species specific models R^2 (0.88<0.90<0.93<0.94).

Firewood production potential:

The wood production for the three species that are mostly used as firewood species in Vélingara-Ferlo were calculated using species specific established models.

$P= 23.10^{-4} \times C^{2.8124}$ for *Grewia bicolor*

$P= 66.10^{-4} \times C^{2.171}$ for *Pterocarpus lucens*

P= 25.10-4 X C 2.4658 for *Combretum glutinosum*

Minimum and maximum values of wood production were evaluated per class of circumference (table 3).

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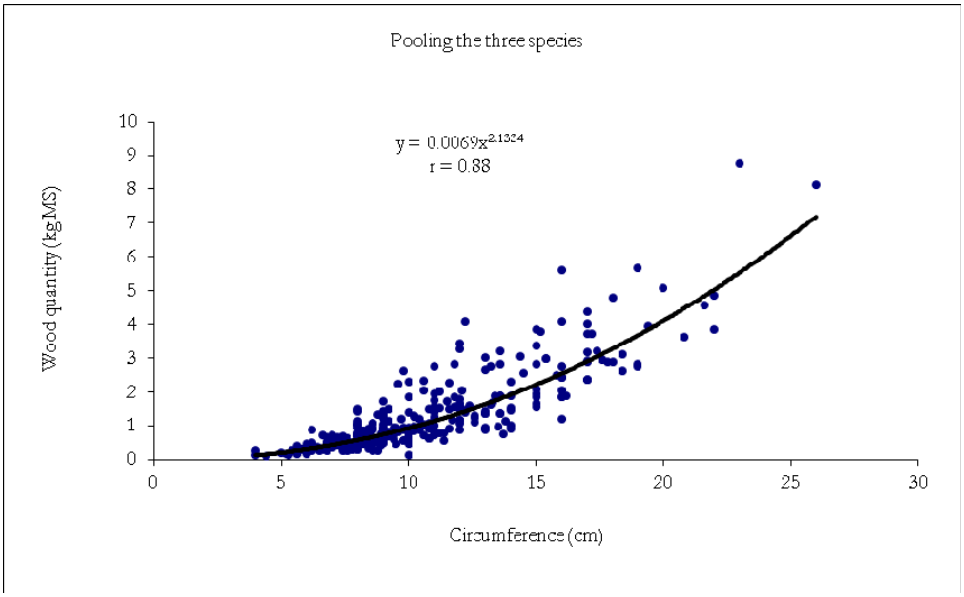

Fig. 7: Relation between wood quantity and circumference for the three forest species

Table 3: Variation of the production according to trees trunk circumference for species

Class of circumference (cm)	[10-20]		[21-30]		[31-40]	[41-50]		[51-100]		[>100]		
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	max
P (kg MS/ha) *G. bicolor*	5.8	40.8	21.8	59.4	69.8	143	241.7	422.3	688.7	4575.8	1385.8	2467.6
P (kg MS/ha) *C. glutinosum*	18.9	104.1	89.8	216.3	148.7	278.7	250.2	408.2	874	4598.2	943.3	8136.3
P (kg MS/ha) *P. lucens*	0.7	3	2.7	5.9	14.3	24.8	35	53.8	196	845.7	1111.7	12865.1

The average values of minima and maxima per class of circumference is used in calculating the average wood production expressed in kgMS hectare^{-1} (±Standard Errors) (table 4) for both species.

Table 4: Estimation of average wood production of the three forest species (kgMS ha^{-1})

Species	Minima	Maxima	Means
Grewia bicolor	402.3 ± 27.2	1284.8 ± 51.9	843.5 ± 47.7
Combretum glutinosum	387.5 ± 20.9	2290.3 ± 70	1338.9 ± 67.9
Pterocarpus lucens	226.7 ± 29.2	2299.7 ± 108	1263.2 ± 103.3

The *G. bicolor* wood production ranges from 402.3 to 1284.8 kgMS ha^{-1}. The relationship between the maximum and minimal values of the wood production of this species (3) is higher than that of the two other species. *Pterocarpus lucens* shows the lowest minimal value (226.7 kgMS ha^{-1}) and the highest maximum value. This is due to availability of higher proportion of individuals from class [> 100]. By contrast, this presents the highest standard uncertainty. *P. lucens'* wood production averages 1263.2 kg MS ha^{-1}) while *C. glutinosum* shows 1338.9 kg MS ha^{-1}). These species with bigger individuals are more wood producers than *G. bicolor* which is a shrub. Globally, both three species accounting about 91% of the firewood used in velingara Ferlo rural community produce together 3.5 tons wood per hectare. The total area of the rural community is of 261170 ha. The inhabited surface accounts for 7.6% and the classified surface, 58%. Natural formations (not inhabited and non classified) represents 65.4%, i.e. 88421 ha. Available forest trees of the three species is estimated to 309.474 tons per year (i.e. 3.5 T * 88421).

Wood consumption:

The wood consumption in Vélingara-Ferlo rural community averages 1.26 kgMS per a person per day (table 5). The households' size ranges from 5 to 40 persons with an average value of 16 persons. The daily wood consumption coefficient of variation is 21.2%. Daily firewood consumption is 1.26 kgMS per person per day. The Vélingara-Ferlo rural community accounts 15913 inhabitants in 2005. The annual wood consumption is 7318.4 tons per year (i.e. 1.26 kg * 15913 * 365).

Table 5: Firewood consumption in kg person^{-1} day^{-1}

Households	Consumption kg day^{-1}	Number of persons	Consumption in kg per person per day
1	20	20	1.00
2	25	20	1.25
3	16	9	1.78
4	16.7	17	0.98
5	16	18	0.89
6	14	10	1.40
7	12	8	1.50
8	14	8	1.75
9	8	7	1.14
10	16.7	14	1.19
11	30	25	1.20
12	12	8	1.50
13	12	10	1.20
14	33.3	40	0.83
15	33.3	32	1.04
16	20	18	1.11
17	20	14	1.43
18	6	5	1.20
19	15	9	1.67
20	33.3	30	1.11
average value	18.67	16.1	1.26 kg per person per day
Coefficient of variation			21.20 %

Potential consumption assessment:

The study area' natural woody formations cover 95% of the energy needs. The relationship between the annual wood consumption and the available trees average 2.4% (table 6). The consumed quantities of wood account for 2.4% of the in situ available stands volumes. This parameter helps in testing the natural formations capacities to satisfy the rural population firewood needs and requirements. The increased rate of the natural population (2.8%) and the annual decrease of sahelian natural formations (0.67%) [8] were integrated for modelling over 25 years (table 6). In 2030 the annual wood consumption will double while the production potential will have dropped by 15.4%.

Table 6: Firewood offer and demand characteristics in the CR of Velingara-Ferlo

Measured traits	2010	2035
Population	15913 inhabitants	31738 inhabitants
Forest Wood Capital	309 474 tons of dried wood an^{-1}	261892 tons of dried wood an^{-1}
Woody dairy consumption	1.26 kg per person per ha	1.26 kg per person per ha
Annual woody consumption	7318.4 tons of dried wood an^{-1}	14596 tons of dried wood an^{-1}
Consumption balance per production	2.4 %	5.6%

Discussion And Conclusion:

The goal of this work was to identify the three species mostly used for firewood in Ferlo, to estimate firewood consumption and to evaluate the potential wood production using allometric models for production. *Grewia bicolor* (95%), *Combretum glutinosum* (80%) and *Pterocarpus lucens* (45%) are preferred for firewood in the zone because of their wood physical characteristics (hardness, density, and calorific value), the convenience (little smoke and more flame), availability of the three species. Also its offer qualified charcoal. The various dry matter rates in wood of these species are related on physical characteristics (hardness and density) different but also to nature from the edaphic substrate and the water availability in the ground. According to Renaud (2006), the ecological factors determining the creation of woody matter are numerous such as the tree age, soil conditions (ground, climate), the water availability or wood density together with individual genetic factors. The comparison of the various models developed reveals a certain difference. Indeed we compared the models of the three species studied between them and with the model from pooled species to know whether a single model is employable for the three sahelian firewood species as previously did by Auclair and Métayer [2] on three firewood species such as *Carpinus betulis* L,. *Betula pubescens* Ehrh. and *Quercus robur* L.). The comparison of the three models showed an impossibility of using a tariff for the three firewood species. However, it should be noted that the tariffs of *Grewia bicolor* and *Combretum glutinosum* are a little similar, but different from the model for the pooled firewood species. Indeed, the tariffs obtained depend on the firewood species [16,2], the tree morphology and the morpho-pedological conditions. The results obtained are interesting for practices in a context of increase in rural request for forest products (firewood, wood of service). Today, the challenge of the sylvo-pastoral ecosystems sustainable management in Ferlo is to reconcile the production with the populations needs. Therefore,

knowing the potential of production of these ecosystems are required as well as the wood quantities consumed. Moreover, the three species studied are overexploited because of their attractive utility. Indeed Grewia bicolor and *Pterocarpus lucens* that are preferred for firewood are also higly grazed by cattles, but also most pruned by the shepherds; they are multi-purpose species. Each day of the trucks charged with this wood of good quality leaves the zone to supply the great urban centres.

Globally, the firewood is still available and women are charged on the collection. There is no regulation and the women seem to be worried more the collected wood transportation than that of its availability. Average firewood consumption is of 1.26 kg per person per day in the rural community of Velingara-Ferlo. These results are comparable with those found in Chad (1.14 kg per person per day) [20], but they are higher than those from Niger native rural environment, i.e. 0.8 kg per person per day [10] and 0.6 kg per person per day [1]. In spite of the gap between our results and those from Niger, it seems that they fit all in the usual standards of general average of wood consumption in Africa in the southern Sahara as defined by Taga [22] i.e. 0.6 to 1.5 kg per person per day. The use of the allometric models made help to evaluate the production and productivity of the three characteristic species which account for 91% of the firewood consumed in the rural community of Velingara-Ferlo. The aggregate output of the three firewood species is of 3.5 tons ha^{-1}. These results corroborate those from Ada and Mahamane [1] in the formations of Combretaceae in Niger (3.3 tons ha^{-1}) and by the Project ED I.S. Ltd [18] in the dry Sudanese wooded area of Chad (3.5 tons ha^{-1}). The trend in the potential of wood production of the ecosystems is an indicator of the human pressures on natural resources. The quantities of wood actually exploited in one year (7318 tons) account for average 2.4% of the capital tree (309474 tons). In Chad, estimation varies according to authors, although the magnitude around 5% of the capital tree [22]. Indeed, exploitable wood volumes must represent more 5% of volumes in forest stand not to put in danger the inheritance of the woody resources. By comparing our results with those obtained in these ecosystems. It can be said that the woody resources are still overall sufficient to satisfy the population needs. This situation is explained by the extent of the rural community (5 times the area of Dakar) and by a very low density (6 inhabitants km^{-2}) compared to the national average i.e. 48 inhabitants km^{-2}. However, in 25 years, the ratio of wood consumption to total tree quantity would be over than 5.6%, i.e. the demand will be higher than the offer and that the woody resources inheritance would be threatened. The ratio of wood consumption to the total tree quantity appeared as indicator of the uptake rate of the wood resource. It is a good indicator to study the ecosystems sustainability but also the balance between the needs of wood for the rural populations and production capacity for the sylvopastoral ecosystems [14]. However, the transfer of the models suggested to other areas must be made prudently. Many parameters are to be considered in building the models of production like the tree state and the soil type [11]. Also, a great exactitude is not attainable generally with allometric models.

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