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PRODUCTIVITY POTENTIAL AND SOME MECHANICAL WOOD PROPERTIES FOR 36-YEAR- OLD *Khaya senegalensis* GROWN BY TWO DIFFERENT PLANTATION METHODS IN ASWAN, EGYPT

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ABSTRACT

Aboveground- tree biomass and mechanical wood properties were measured in 36- year- old trees of *Khaya senegalensis* A. Juss. either as an experimental area or as a single- tree row, grown on infertile soil in the Tropical Farm of Kom- Ombo, Aswan Botanical Garden, Hort. Res. Inst., Agric. Res. Center, Egypt. *Khaya senegalensis* grown as a single row had the highest values of total stem volume, diameter at breast height and merchantable height as well as weights of leaves, twigs up to 1 cm diameter and branches up to 5 cm diameter compared to that grown in plantations at 5x5 m spacing. Data revealed that, the productivity potential of 36-year-old *Khaya senegalesnis* grown under Aswan conditions at 5x5 m spacing was about 300.7 m^3/ fed, 61.8 ton/ fed, 61.9 ton/ fed and 34.3 ton/ fed for the total stem volume, branches up to 5 cm diameter, twigs up to 1 cm and fresh leaves, respectively. On the other hand, the mechanical properties of *Khaya senegalensis* planted in this region were comparable of a number of valuable hardwood species grown in different countries. *Khaya senegalensis* as plantations in this study showed a high potential for producing wood with higher values for modulus of rupture (MOR), modulus of elasticity (MOE), compression parallel to grain and maximum shearing of strength than that of trees in a single row.

Keywords: Aboveground biomass, *Khaya senegalensis*, mechanical properties, plantations, single- tree row.

INTRODUCTION

Quantitative estimation of aboveground biomass is important to measure stand production consisting of stem, branch wood and leaves. Height and diameter of a tree are the major parameters that determine the harvestable wood. However, forest biomass and its change over time have long been considered as key characteristics of forest ecosystems (Cannell, 1982). Biomass assessment is important for many purposes. It is aimed at two major objectives: (1) for resource use and (2) for environmental management (Parresol, 1999). It is important to determine how much fuel wood or timber is available for use. Biomass is also an important indicator in carbon sequestration. For this purpose, one needs to know how much biomass is lost or accumulated over time. Consequently, the amount of carbon sequestered can be inferred from the biomass change since 50% of the forest dry biomass is carbon (Losi *et al.,* 2003).

El- Morshedy *et al*. (1996) evaluated the biomass production of *Khaya senegalensis* in the same plantations of our study, but for trees at 28-year-old. They stated that diameter at breast height, total height, total stem volume and branches fresh weight for the plantation area were 34.0 cm, 11.5 m, 1.05

m^3/ tree and 215 kg/ tree, while that grown as a single- tree row produced 67.0 cm, 18.9 m, 3.81 m^3/ tree and 645 kg/ tree for these characters, respectively. Recently, Nasser *et al.* (2010) worked on 9- year- old *Melia azedarach*. They revealed that means of total height, diameter at breast height, stem volume, total fresh biomass and total dry biomass were 6.56 m, 22.98 cm, 0.36 m^3/ tree, 287.5 kg/ tree and 165.4 kg/ tree, respectively.

Wood is one of the oldest engineering materials in the world, which can be used for a variety of purposes, including constructions, furniture, pulp and papers, as well as extractive chemical products. On the other hand, variability, or variation in properties, is common to all materials. Because wood is a natural material and the tree is subject to many constantly changing influences (such as moisture, soil conditions, and growing space), wood properties vary considerably, even in clear material (Kretschmann and Green, 1996). In this respect, mechanical properties are usually the most characteristics of wood products to be used in different purposes as in structural applications.

Mechanical properties most commonly measured and represented as “strength properties” for design include modulus of rupture in bending, maximum stress in compression parallel to grain, compressive stress perpendicular to grain, and shear strength parallel to grain **(**Mallory and Gramer, 1987)**.** In this respect, Josue (2004) studied the mechanical properties of *Xylia xylocarpa* as a hardwood species and a fast growing tree. He reported that the means of modulus of rupture (MOR), modulus of elasticity (MOE), compression parallel to grain and shear parallel to grain were 134.8, 12861, 68.3 and 18.9 N/ mm^2, respectively. On the other hand, Guler *et al*. (2007) studied the mechanical properties of *Pinus nigra* as a softwood species. They found that the mechanical tests resulted in that the static bending and compression strengths were 79.1 and 42.4 N/ mm^2, respectively.

Khaya senegalensis A. Juss. belongs to family Meliaceae is a semi-deciduous tree, 20-35 m high, up to 1 m diameter, with a clean bole to 8-10 m. The timber of this species was the first known of the African mahoganies. Young leaves contain fairly large amounts of digestible crude protein. The leaves are used as fodder for cattle and camels, although they are not very palatable. The wood is used in West Africa for pulp. Its timber is one of the hardest African mahoganies and the hardest of the Khaya species (Sahni, 1968). It is widely used on a commercial scale, particularly in West Africa. It is favoured for furniture, high- class joinery, flooring, turnery and veneer. Because of its decorative appearance, the wood of *K. senegalensis* is very popular timber. Therefore, this study aimed to examine the above- ground biomass and some of wood mechanical properties of *K. senegalensis*, which has been planted 36 years ago in Aswan- Egypt.

MATERIALS AND METHODS

Above-ground biomass determination:

This study was done on trees located at Kom-Ombo Tropical Farm, Aswan Botanical Garden, Hort. Res. Inst., Agric. Res. Center, Egypt during 2010 season. The soil at this site was characterized as loamy sand, pH 8.4, organic matter 0.45% and EC 0.31. In 2010 samples were selected from 36-y- old trees of *Khaya sensgalensis* A. Juss., replicated plots planted at 5x5 m spacing with 15 trees per plot. Five sample trees per plot were randomly selected from each of the four replications for a total of 20 sample trees per the site. In addition, thirty- one trees grown as a single- row in the same field at 5 m spacing (spacing between row was 5 m) and five trees were selected to represent the single row.

Sample trees:

Prior to tree cutting, diameter at breast height (DBH) was measured using diameter tape. DBH is the stem diameter at 1.3 m above the ground (FAO, 2004b). For trees with enlargement or buttress, the diameter was measured at 30 cm above the main enlargement (FAO, 2004b). Height of the tree was measured with measuring tape after cutting the tree. The sample tree was segregated into fractions: leaves, twigs (diameter up to 1 cm), small branches (diameter up to 5 cm) and stem (Ketterings *et al.,* 2001). The segregation is important because of the systematic difference in moisture content along the length of the tree. The stem diameter and height were measured to get an estimate of its volume and dry weight as described below. For stem, diameter was measured every two meters length. This measurement was used for stem volume and dry weight estimation. Wood subsamples were then selected from the stem: one each in the lower, middle and upper portion. These wood samples were also collected from each twigs and small branches. Three leaf samples, of 100 g each, were also collected for each tree sample. The wood samples were stored in a sealed plastic bag to retain moisture prior to measurement of fresh weight done on the evening of collection date.

Volume and dry weight estimation:

For volume determination of stem since the stem represents the main portion of the total tree above- ground biomass, stem wood samples were saturated with water, and then the volume was measured by water displacement. The wood and leaf samples were also oven-dried at 105^{0}C until constant weight (Kettering et al., 2001).

The volume of each stem section was calculated using Samilian's formula (de Gier, 2003). The total stem volume was computed as the sum of the calculated stem section volume.

Vol=n/8 (D^2+ d^2) x l. Where, vol= volume of the stem section, l= length of the section, D= diameter of the larger end of the stem section, and d= diameter of the smaller end of the stem section.

The stem volume was converted into dry weight using the formula of Jarayaman (2000).

$DW_f = FV_f \times DW_s / FV_s$. Where, DW_f= dry weight of the stem, FV_f= fresh volume of stem, DW_s= dry weight of the subsample of the stem, and FV_s= fresh volume of the subsample of the stem.

The fresh weight of other fractions were converted into dry weight by using the ratio of subsample dry weight and subsample fresh weight as indicated in the formula of Jarayaman (2000).

$DW_f = FW_f \times DW_s / FW_s$. Where, DW_f= dry weight of the fraction, FW_f= fresh weight of the fraction, DW_s=dry weight of the subsample of the fraction, and FW_s= fresh weight of the subsample of the fraction. Then, the sample tree dry weight is the sum of the dry weight of fractions.

Mechanical wood properties:

Bolts of approximately 50 cm length were taken at three height levels of the tree: bottom, middle and top. These bolts were used as samples for the evaluation of mechanical properties of *Khaya senegalensis* as plantations in 5x5 m or as single row at 5 m spacing. Four boards with nominal thickness of 3cm were sawn from each bolt obtained from the trees. The boards were cut parallel to the anatomical planes of wood. Then sticks of 2cm x2cm were prepared and labeled according to tree number. All wood sticks were then stacked to air dry in the testing room at 20 ±2^{0}C and 65± 3% relative humidity until the specimens were reached to the equilibrium moisture content of 12% MC. Testing of mechanical properties namely, static bending (modulus of rupture and modulus of elasticity), compression parallel to grain and shear parallel to grain were conducted in accordance with ISO- 3133 (Anonymous, 1975c), ISO- 3787 (Anonymous, 1976a) and ISO- 3347 (Anonymous, 1976b) standard, respectively. The studied tests of air-dried 20x20 mm (cross section) and 30 mm long specimens were performed by using a general testing machine (LR 50 K) attached to a computer, in testing room with standard condition of 20 ±2^{0}C and 65±3% relative humidity.

Data of above-ground biomass and mechanical wood properties were pooled to compute the overall minimum, maximum, mean and standard deviation of these characters.

RESULTS AND DISCUSSION

Biomass determination:

Total stem volume, diameter at breast height, merchantable height and total height of *Khaya senegalensis* grown either at 5x5m spacing or as single row are given in Table 1. The results of the Table pointed out that, these measurements were increased for *K. senegalensis* grown as a single- tree row compared to that grown as plantations at 5x5m spacing. Total stem volume for trees grown at 5x5m spacing ranged from 0.55 to 3.40 m^3/ tree with an average of 1.79 ± 0.65 m^3/ tree, while it ranged from 3.40 to 4.50 m^3/ tree for trees grown as a single row with an average of 3.9 ± 0.73 m^3/ tree . However, the mean of diameter at breast height, merchantable height and total height was 40.45 cm, 18.55 m and 22.39 m for trees grown at 5x5 m spacing, while it was 60.38 cm, 23.07 m and 25.20 m for trees in a single row, respectively.

Table (1): Total stem volume m^3/tree, diameter at breast height (cm), merchantable height (m) and total height (m) for *Khaya senegalensis* grown at 5x5m or as single row at 5m spacing.

Properties	*K. senegalensis* at 5x5m spacing				*K. senegalensis* as single row			
	Min	Max	Mean	SD	Min	Max	Mean	SD
Total stem volume	0.55	3.40	1.79	0.65	3.40	4.35	3.90	0.73
Diameter at breast height	39.17	41.68	40.45	9.80	56.14	63.03	60.38	10.90
Merchantable height	17.25	19.20	18.55	3.80	21.46	24.35	23.07	4.10
Total height	21.43	23.64	22.39	4.90	23.45	26.65	25.20	5.30

Min= Minimum Max= Maximum SD= Standard deviation

The fresh weight of total biomass, leaves, twigs up to 1 cm, and small branches up to 5 cm as well as main stem of 36- year- old *K. senegalensis* planted at 5x5 m or as a single row at 5 m spacing are presented in Table 2. The fresh weight of total biomass ranged from 2355.6 to 2420.7 kg/tree and the average was 2380.1 ± 380 kg/ tree for trees at 5x5 m spacing, while it ranged from 5496.2 to 5554.2 kg/ tree with an average of 5521.8 ± 465 kg/ tree for that grown as a single- tree row. For *K. senegalensis* at 5x5 m spacing, the mean fresh weight of leaves, twigs, small branches and main stem were 204.6, 368.9, 367.8 and 1438.9 kg/ tree, respectively, while they were 317.2, 548.9, 1261.4 and 3394.3 kg/ tree for those grown as a single row, respectively. In general, the characters of biomass fresh weight of 36-year- old *K. senegalensis* planted in single- row at 5 m spacing were higher than the biomass ranges of the same species at 5x5 m spacing.

Table (2): Fresh weights (kg) of total biomass, leaves, twigs up to 1 cm diameter, branches up to 5 cm diameter and main stem up to merchantable diameter for *Khaya senegalensis* grown at 5x5m or as single row at 5m spacing.

Properties	*K. senegalensis* at 5x5m spacing				*K. senegalensis* as single row			
	Min	Max	Mean	SD	Min	Max	Mean	SD
Total biomass	2355.6	2420.7	2380.1	380	5496.2	5554.2	5521.8	465
Leaves	192.4	224.7	204.6	67.9	303.0	325.9	317.2	81.7
Twigs up to 1cm diameter	331.4	395.2	368.9	87.6	501.7	586.4	548.9	96.3
Branches up to 5 cm diameter	340.3	404.4	367.8	88.9	1215.1	1305.3	1261.4	117
Main stem	1396.3	1470.5	1438.9	290	3349.1	3433.6	3394.3	328

Min= Minimum Max= Maximum SD= Standard deviation

The minimum, maximum, mean and standard deviation values of dry weight of leaves, branches up to 5 cm diameter and main stem for 36-y- old *K. senegalensis* planted at 5x5 m or as a single- tree row at 5 m spacing are summarized in Table 3. Generally, the dry weight of biomass characters of the trees that planted in single row at 5 m spacing was higher than that of trees grown in plantations at 5x5 m spacing. The average values for leaves, small branches and main stem were 98.9 ± 14.6, 186.3 ± 78.7 and 738.7± 197 kg/ tree, respectively for plantations at 5x5 m spacing. These values are lower than those of trees planted as a single row which recorded 153.2 ± 19.8, 637.7 ± 93.5 and 1738.9 ± 218 kg/ trees for the same characters, respectively.

From these results about biomass yield, *K. senegalensis* planted as a single row resulted in higher values than that of trees at 5x5 m spacing assuming that nutrient and water is limited and maximum sunlight is desirable for growth, widely spaced trees will grow faster than crowded ones. When this relationship is combined with the knowledge that growth rate in tree species is related to the tree spacing, it is easy to see the differences between biomass characters of the studied trees. Our results are in a good agreement with the previous study of El- Morshedy *et al*. (1996) on the same plantations at 28-year- old. They also reported that for planted area, the predicted yield per feddan is 181.4 m^3 for total stem volume and 36.1 ± 5.9 ton/ fed for branches fresh weight, while for the single- tree row the predicted yield is 510.7 m^3/ fed for total stem volume and 108.4 ± 24.4 ton/ fed for branches fresh weight.

Table (3): Dry weight (kg) of leaves, branches up to 5cm diameter and main stem up to merchantable diameter for *Khaya senegalensis* grown at 5x5m or as single row at 5m spacing.

Properties	*K. senegalensis* at 5x5m spacing				*K. senegalensis* as single row			
	Min	Max	Mean	SD	Min	Max	Mean	SD
Leaves	93.0	108.0	98.9	14.6	145.7	156.7	153.2	19.8
Branches up to 5cm diameter	172.7	204.2	186.3	78.7	613.7	662.6	637.7	93.5
Main stem	712.4	754.1	738.7	197	1708.7	1760.8	1738.9	218

Min= Minimum Max= Maximum SD= Standard deviation

Mechanical properties:

The ranges, means and standard deviations of the mechanical properties of 36-y- old *K. senegalensis* planted at 5x5 m spacing or as a single- tree row at 5 m spacing are tabulated in Table 4. Generally, the strength properties of *K. senegalensis* grown in plantations at 5x5 m spacing resulted in higher values than those grown as a single- tree row. The average values for modulus of rupture (MOR), modulus of elasticity (MOE), compression parallel to grain and maximum shearing strength of trees at 5x5 m spacing were 124.6, 12596, 63.1 and 15.8 N/ mm^2, while it were 110.1, 10681, 57.9 and 13.0 N/ mm^2 for that grown as a single row, respectively. The strength properties of mature *K. senegalensis* grown in southern Egypt are almost comparable to other mature valuable hardwood species grown in different countries as reported by Keating and Bolza (1982) and Josue (2004). From this comparison, the values for modulus of rupture, compression parallel to grain and maximum shearing strength of *K. senegalensis* plantations are lower than that of *Eusideroxylon zwageri, Shorea laevis* and *Xylia xylocarpa*, but are higher than *Intsia palembanica* and *Vatica cuspidate*. Meanwhile, the mean modulus of elasticity (MOE) of 36-year- old *K. senegalensis* is low in comparison to the other species.

However, the differences between wood strength properties of trees in plantations or in a single row my be related to the differences in their density. Haygreen and Bowyer (1996) pointed out that, within any species there is a considerable variation in clear wood strength properties, which corresponds to the variation in density and to the density- strength relationship for that property.

Table (4): Mechanical properties of *Khaya senegalensis* grown at 5x5m or as single row at 5m spacing.

Properties	*K. senegalensis* at 5x5m spacing				*K. senegalensis* as single row			
	Min	Max	Mean	SD	Min	Max	Mean	SD
MOR (N/mm^2)	118.6	131.4	124.6	20.4	91.2	114.6	110.1	16.8
MOE (N/ mm^2)	10530	13290	12596	1780	9589	11802	10681	1611
Compression (N/mm^2)	43.5	73.8	63.1	6.8	39.4	68.3	57.9	5.9
Shear (N/mm^2)	11.7	23.9	15.8	3.8	10.4	20.5	13.0	3.1

Min= Minimum Max= Maximum SD= Standard deviation
MOR= Modulus of rapture MOE= Modulus of elasticity
Compression= Compression parallel to grain (maximum crushing strength)
Shear= Shear parallel to grain (maximum shearing strength)

Conclusion

Our results revealed that, the productivity potential of 36-year- old *K. senegalesnis* grown under Aswan conditions at 5x5 m spacing was about 300.7 m^3/ fed, 61.8 ton/ fed, 61.9 ton/ fed and 34.3 ton/ fed for total stem volume, branches up to 5 cm diameter, twigs up to 1 cm and fresh leaves, respectively. Also, *K. senegalensis* trees when planted along roadsides, on the banks of the river Nile and canals and around fields to strengthen the economy of Egypt, this tree should produce about 780 m^3/ Km and 252.3 ton/ Km for total stem volume and branches up to 5 cm diameter, respectively at 36-year- old.

Generally, the mechanical properties of *K. senegalensis* planted in Aswan were comparable of a number of valuable hardwood species such as *Eusideroxylon zwageri, Instia palembanica, Shorea laevis, Vatica cuspidate* and *Xylia xylocarpa,* indicating its suitability for heavy construction and different uses. This study further reinforces the fact that number of woody species in Egypt as general and *K. senegalensis* in particular could be potential source of commercial timber. Results of the present study may be useful in the choice of species for establishing forest plantations and afforestation programs.

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امكانية الانتاجية وبعض خصائص الخشب الميكانيكية للكايا السنغالى عمر ٣٦ سنة النامية تحت ظروف طريقتين مختلفتين بأسوان، مصر

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أجريت هذه الدراسة على أشجار الكايا السنغالى عند عمر ٣٦ سنة، والمنزرعة فى تربة فقيرة بالمزرعة الاستوائية بكوم أمبو- الحديقة النباتية بأسوان والتابعة لمعهد بحوث البساتين- مركز البحوث الزراعية- مصر. وقد تمت الدراسة لتقييم صفات الكتلة الحيوية والخصائص الميكانيكية للخشب لأشجار منزرعة فى مساحة تجريبية على مسافة ٥ x ٥ م فى أربع مكررات وبكل مكررة ١٥ شجرة بعدد كلى للأشجار ٦٠ شجرة ،و مقارنة ذلك بنظيرتها المنزرعة فى صف طولى وحيد به أشجار منزرعة على مسافة ٥ م بعدد كلى للأشجار ٣١ شجرة. وقد تم اختيار عدد ٢٠ شجرة عشوائيا من المساحة التجريبية، وعدد ٥ أشجار من الصف المفرد لتقييمها من حيث صفات الكتلة الحيوية وخصائص الخشب الميكانيكية.

وكانت أهم النتائج كمايلى:

- تفوقت الأشجار المنزرعة فى صف طولى مقارنة بمثيلتها المنزرعة كمساحة تجريبية فى صفات حجم الساق الكلى, القطر عند مستوى الصدر، الطول القابل للتسويق،و أيضا من حيث وزن الأوراق، وزن الأغصان حتى قطر ١ سم،ووزن الأفرع الصغيرة حتى قطر ٥ سم.
- أوضحت الدراسة أن هذه الأشجار المنزرعة فى المساحة التجريبية تعطى حوالى ٣٠٠,٧ م٣ / فدان من حجم كلى للساق،٦١,٨طن/ فدان من الأفرع الصغيرة حتى قطر ٥ سم، و ٦١,٩ طن/ فدان من الأغصان حتى قطر ١ سم.
- وجد أن الأشجار المنزرعة فى المساحة التجريبية على مسافة ٥ x ٥ م متفوقة فى خصائص الخشب الميكانيكية مثل معامل الكسر ، معامل المرونة، الانضغاط الموازى للألياف (قوة التهشم العظمى) ، والقص الموازى للألياف (قوة القص القصوى) عن تلك الخاصة بالأشجار المنزرعة فى صف طولى وحيد على مسافة ٥ م.

قام بتحكيم البحث

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