E. Afr. agric. For. J. (2002) *68*(*1*), 23-30

EFFECTS OF STOCKING DENSITY ON THE GROWTH OF *CRYPTOMERIA JAPONICA* DON. Sugi AT KIMAKIA FOREST, KENYA

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(*Accepted for publication in December 1998*)

The determination of optimum planting density and thinning are very important techniques in silviculture. Several methods including volume, basal area, number of trees per area bole, crown closure and stand density indexes areused to evaluate the stocking of a plantation (Daniel *et al.*, 1982; Breden Kamp and Burkhart, 1990).

The volume method directly measures the desired product. The volume of a stand compared with a norm based on fully stocked stands for the species and site or with some other empirical standard gives a useful expression of stocking. Its disadvantage is involving age of trees as well as site index.

Basal area is widely used to directly measure density. Basal area is often computed from a basal area table. Basal area in fully stocked stands increases rapidly during the youth stand and then levels off, increasing more and sometimes not at all in later years. Basal area increases with site index and age, the better the site, the more the basal area. However, basal area does not necessarily define what stands should carry under management to make best growth.

The number of trees per area method is a simple and logical measure of stocking but its use often offers difficulty in practice, because the total number of trees is unweighted by size which affects density. The total number is consequently influenced by the shorter diameter included and the presence or absence of many little trees which may or may not be of practical significance. Thus, percentage comparisons of actual stands with desirably stocked stands in number of trees only usually give inconsistent results.

The bole area is the actual surface or growing area of the main stem of a tree. It can be used as an expression of growing stock. It enables the expression of growing stock in square metres of bole area per hectare. The measure is definite quantitative and not difficult to compute but it is most applicable in young conifers where bole is mostly in a single and readily measured stem. But for some broad-leafed trees it is rather difficult to define what is the main stem and what are the branches.

Crown closure also can be used to express relative density of particular utility in connection with the use of aerial photographs. It is usually expressed as a percentage of full canopy cover and is often grouped into broad classes such as dense, medium and open. The disadvantage of this method is that ground sampling should be done for accuracy.

Stand density index (SDI) is the other method used in expressing stocking. Using certain mathematical relationships between the number of trees' average diameter, basal area and volume indexes can be constructed which serve as a measure of stand density or stocking. Reineke's SDI is based on the fact that in even aged stands the number of trees in different diameter classes is distributed in a fairly definite frequency pattern often approaching that of the normal curve. The form of frequency curve varies from species to species but is fairly consistent for specific species and characteristic, regardless of age or site. It involves counting the number of trees in an area and measuring their average diameters and by means of a reference curve giving the corresponding values for fully stocked stands the relative density of the stand can be determined. This method is simple because it does not require determination of site index and age for its application (Reineke, 1933; Daniel *et al.*, 1982). The SDI for the maintenance of optimum number of trees per hectare for previously defined objectives of wood production (Daniel *et al.*, 1982; Ortiz 1994).

The SDI provides a reference curve on which average diameter is plotted against number of trees per hectare. By knowing what diameter is needed one can read the optimum number of trees from the curve. It can also be used to determine thinning schedules. Thinning is mainly used to select the most promising trees and to ensure that spacing is geometrical so as to avoid undesirable competition among trees. Early and intensive reductions in the number of stems are carried out according to a prescribed schedule. The timing of the first thinning depends mainly on the role of growth and spacing of trees. The closer the spacing the more number of the seedlings used and the higher the cost of raising, buying and planting the seedlings. Wider spacing results in fewer seedlings and reduces the seedlings cost but increases the maintenance costs due to frequent weeding before the seedlings establish. However, the closer the spacing, the higher the competition between the trees which results in higher percentage of thin and uneconomical trees. This requires early thinning which is costly if the thinnings do not have ready markets. Wide spacing result in few big trees with coarse branches which lower the wood quality if not pruned and might under-utilise the site. Therefore a compromise should be sought for an optimum stocking.

Cryptomeria japonica has recently been introduced to Kenya from India. Its silviculture in tropics is not known. Results from small experiments at high altitudes above 2400 m as shown that the species is fast growing and could be used in plantations to supplement the dwindling *Cupressus lusitanica* for timber production.

The experiment was planted in 1966 by the Forest Department to evaluate the effects of various spacings on the growth of *Cryptomeria japonica* by evaluating the height and diameter distribution with different initial stocking rates and to determine the effect on wood density.

MATERIALS AND METHODS

The experiment was established at Kimakia Forest Station (0°48'S and 36°45' E) at 2438 m. The site has a mean annual temperature of 14.3°C, a mean maximum of 21.1°C and a mean minimum of 7.5°C. The mean annual rainfall is 2385 mm. The soils are well drained but strongly acidic (derived from volcanic ash) (Ochieng 1973a; Ochieng 1973b). The area had previously been under a natural forest which had been cultivated for food crops for 2 years.

The seeds used were obtained from Der jeelung, India, in 1965 and seedlings raised in the nursery in timber boxes for 9 months. The seedlings were planted in the field in April 1966, in a randomised complete block design with four replicates. The seedlings were planted at seven different spacings (treatments) (Table I). Each treatment was contained in a square plot of 36.6 m x 36.6 m. The plots were weeded two times per year for 3 years.

Data were collected on total height, diameters at breast height (DBH), mid diameter and top diameter of merchantable height years using a diameter tape when the trees were young (4-7) and a relascope after 7 years when they became big. Other recorded data were volume, basal area and basic wood density. The final measurement was recorded at the conclusion of the experiment in 1995 at 29 years. Nine trees were sampled in the interior portion of each treatment plot for determination of wood density. A 5-mm diameter increment borer was used for sampling the cores. The cores were placed in water for 72 h and the green volume determined using displacement method. The cores were then dried in an oven at 105°C for 48 h and weighed to determine dry weight. The basic wood density (WD) (kg/m^3) was calculated using the formula [WD = dryweight/green volume] (Table IV).

Total tree volume was estimated using Smalian's formula (Loetsch *et al*, 1973)

$$[V = \frac{gi + gs}{2} L,]$$

where;

v = Volume of the log

gi = Cross-sectional area at the large end of log

gs = Cross-section area at small end of log (merchantable length)

L = Log length

Data were analysed using analysis of variance (ANOVA). The F-test of effects was made using the method described by Freese (1967) and Duncan Multiple Range test was done to compare the means. Regression analysis was done between basic wood density and spacing (Fig. 1).

RESULTS AND DISCUSSION

There were significant ($P<0.05$) differences among treatments for diameter (Table II) and no significant differences in total height at 29 years. Mean values for total height, basal area and diameter for each treatment with respective age of measurement are presented in Table III. There was gradual change in diameter with increase in spacing. The results are similar to those of other spacing studies with pines (Conrad *et al.*, 1992; Malimbwi *et al.*, 1992; Osorio and Uribe, 1994).

TABLE I – PLANTING DENSITIES OF *CRYPTOMERIA JAPONICA* PLANTED AT KIMAKIA FOREST

Treatment No.	Spacing (m)	Trees/ha	Trees per plot	Area occupied by measured trees (m^2)
1	1.8 x 1.8	3087	400	169
2	2.1 x 2.1	2268	324	144
3	2.4 x 2.4	1737	225	100
4	3.1 x 3.1	1112	144	64
5	3.6 x 3.6	772	100	49
6	4.5 x 4.5	473	64	25
7	6.1 x 6.1	269	36	16

TABLE II – THE EFFECT OF VARIOUS SPACING ON THE DIAMETER GROWTH (DBH) OF CRY*PTOMERIA JAPONICA* AT KIMAKIA

Source	SS	df	ms	f	Table f (P=0.05)
Blocks	21.6	3	7.2	0.81	3.1 ns
Spacings	183.8	6	30.6	3.7	2.6*
Residual	150.4	18	8.3	-	-
Total	355.85	27	-	-	-

* - Significant (P=0.05); ns - Not significant

TABLE III – GROWTH CHARACTERISTICS AND AREA ESTIMATE OF *CRYPTOMERIA JAPONICA* AT DIFFERENT DENSITIES

Age (years)	Spacing or Treatment	Height (m)	DBH (cm)	Basal area /ha (m^2)	Bole Volume (m^3)	Volume/ha (m^3)
4	1	4.0	5.5	7.3	0.004	12.34
	2	4.0	6.0	6.4	0.005	11.34
	3	4.0	6.0	4.6	0.005	8.68
	4	4.5	7.0	3.7	0.007	7.28
	5	4.0	7.0	2.6	0.006	4.38
	6	4.5	7.0	1.7	0.007	3.45
	7	4.5	7.0	1.0	0.007	1.87
7	1	6.8	7.5	13.6	0.002	61.72
	2	6.5	8.0	11.4	0.025	56.67
	3	7.0	8.5	9.8	0.032	55.58
	4	7.5	9.0	6.6	0.037	38.48
	5	8.4	10.0	5.7	0.053	38.69
	6	8.5	11.5	5.1	0.074	36.48
	7	8.5	12.0	3.0	0.076	20.36
9	1	13.0	12.0	34.9	0.055	169.73
	2	13.0	12.0	25.6	0.055	124.68
	3	13.5	13.0	23.0	0.063	109.36
	4	13.0	15.0	19.6	0.081	84.24
	5	14.0	16.0	15.5	0.097	70.81
	6	14.5	18.0	12.0	0.128	63.10
	7	14.5	19.0	7.6	0.147	39.39
11	1	17.5	16.0	62.0	0.123	370.32
	2	18.5	16.0	45.6	0.130	294.71
	3	17.5	17.0	39.4	0.139	241.30
	4	16.5	21.0	38.5	0.200	208.00
	5	18.5	24.0	34.9	0.292	213.16
	6	19.0	25.0	23.2	0.362	178.46
	7	21.0	26.0	14.3	0.389	104.25
19	1	22.0	24.0	139.5	0.323	996.77
	2	22.5	27.0	129.7	0.386	875.06
	3	22.5	28.0	106.8	0.415	720.44
	4	22.0	29.0	68.7	0.471	489.84
	5	21.5	29.0	48.2	0.461	336.53
	6	22.0	35.0	47.4	0.653	321.92
	7	21.5	38.0	30.4	0.731	195.90
29	1	22.5	27.5	183.2	0.368	1126.39
	2	22.5	30.2	162.3	0.523	1185.64
	3	23.0	32.0	139.5	0.601	1043.33
	4	22.4	36.0	105.8	0.740	769.60
	5	22.7	36.2	75.1	0.758	553.34
	6	22.6	44.9	78.0	1.162	572.87
	7	22.5	46.3	45.1	1.230	329.64

The means in bole volume are not significantly ($P<0.05$) different using DMRT

TABLE IV - BASIC WOOD DENSITY FOR *JAPONICA* AT DIFFERENT DENSITIES AT DIFFERENT DENSITIES AT 29 YEARS

Treatment No.	Initial number of trees/ha	Basic wood density(kg/m^3)	Dry weight (ton/ha)
1	3086	108.3	334.2
2	2267	109.4	248.0
3	1736	108.3	188.0
4	1040	107.7	112.0
5	730	105.2	76.8
6	493	104.5	51.5
7	268	104.2	28.0

There were no significant differences among the treatments in basic wood density

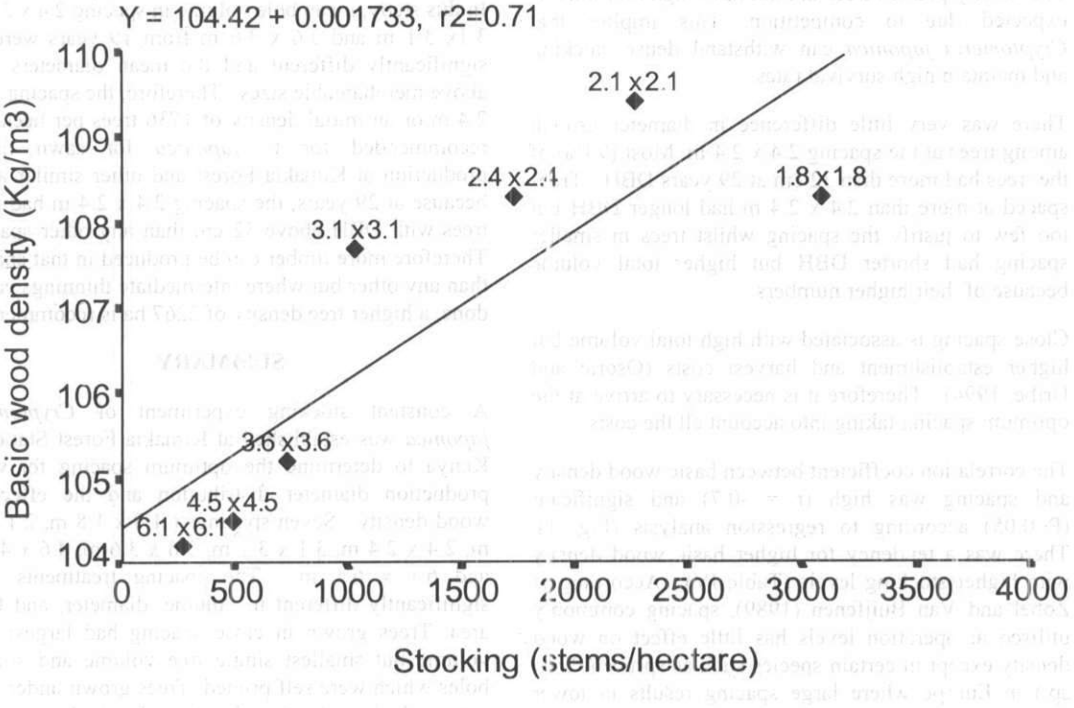

Fig. 1 - The best fit relationship between Basic Wood Density and Stocking of *Cyptomeria japonica* at Kimakia

The basal area increased with decreasing spacing (number of trees per hectare) (Fig. 2). The differences in basal area were significant at all ages. The total basal area kept on increasing except for treatment 7 where the rate was reduced after the 19th year. This indicated that the trees in the closely spaced plots were still growing and needed more time before they are clear cut. The mean annual increment in volume slowed down at 12 years for spacings 1.8 x 1.8 m, 2.1 x 2.1 m and 2.4 x 2.4 m and decreased at 19 years whilst in the wide spaced treatments 3.1 x 3.1 m, 3.6 x 3.6 m, 4.5 x 4.5 m and 6.1 x 6.1 m, the mean annual increment (M.A.I.) slowed at a later age (Fig. 3).

The mean annual continued to increase although there was a tendency towards maximum values at higher planting densities.

The survival rate was high in all the treatments and had significantly stabilised after age 11 years, but the sparsely distributed trees had formed double and multiple leaders and had the butts forming buttresses. The closely planted trees did not have high mortality as expected due to competition. This implies that *Cryptomeria japonica* can withstand dense stocking and maintain high survival rates.

There was very little difference in diameter growth among trees at the spacing 2.4 x 2.4 m. Most (90%) of the trees had more than 32 cm at 29 years DBH. Trees spaced at more than 2.4 x 2.4 m had longer DBH but too few to justify the spacing whilst trees in smaller spacing had shorter DBH but higher total volume because of their higher numbers.

Close spacing is associated with high total volume but higher establishment and harvest costs (Osoric and Uribe, 1994). Therefore it is necessary to arrive at the optimum spacing taking into account all the costs.

The correlation coefficient between basic wood density and spacing was high ($r = -0.7$) and significant ($P<0.05$) according to regression analysis (Fig. 1). There was a tendency for higher basic wood density with higher stocking levels (Table IV). According to Zobel and Van Buijfenen (1989), spacing commonly utilised at operation levels has little effect on wood density except in certain species such as spruce (*Picea* sp.) in Europe where large spacing results in lower wood density. This study shows that *C. japonica*, being a temperate species has similar growth characteristics to *Picea* sp.

The main objective of plantation forests in Kenya is to produce wood for sawn timber and pulp and paper industries. The minimum merchantable DBH in Kenya is 22.0 cm.

Therefore, merchantable bole volume (which determines amount of timber produced) is more important than the total volume. In this study, merchantable bole volume was higher (0.42-1.23 m^3) at lower stocking. However, higher initial stocking levels produce wood for products such as pulp, posts and poles other than sawn timber. on rotations of less than 15 years. For sawn timber however, large diameter trees are desired hence the rotation is higher than 15 years.

The selection of initial spacing should be based on financial benefits. An economic evaluation of initial spacing for different products should be done to justify stocking density.

In this study, mean bole volume in spacing 2.4 x 2.4 m, 3.1x 3.1 m and 3.6 x 3.6 m from 19 years were not significantly different and the mean diameters were above merchantable sizes. Therefore, the spacing 2.4 x 2.4 m or an initial density of 1736 trees per hectare is recommended for *C. japonica* for sawn timber production at Kimakia Forest and other similar areas, because at 29 years, the spacing 2.4 x 2.4 m had more trees with DBH above 32 cm than any other spacing. Therefore more timber can be produced in that spacing than any other but where intermediate thinnings can be done, a higher tree density of 2267 ha is recommended.

SUMMARY

A constant stocking experiment of *Cryptomeria japonica* was established at Kimakia Forest Station in Kenya to determine the optimum spacing for wood production diameter distribution and the effect on wood density. Seven spacings (1.8 x 1.8 m, 2.1 x 2.1 m, 2.4 x 2.4 m, 3.1 x 3.1 m, 3.6 x 3.6 m, 4.6 x 4.6 m and 6.1 x 6.1 m. The spacing treatments were significantly different in volume, diameter, and basal area. Trees grown in close spacing had largest total volume but smallest single tree volume and straight boles which were self pruned. Trees grown under wide spacing had smallest total volume but high single tree volume and low basic wood density. The tree density of 1736/ha or spacing of 2.4 x 2.4 m is recommended.

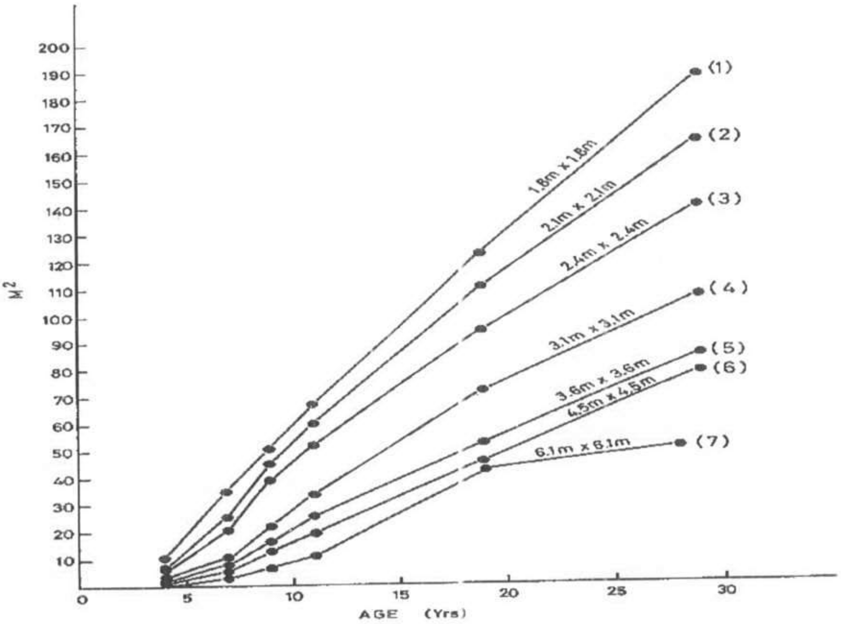

Fig.2: Total basal area of different spacings of *Cryptomeria japonica* at various ages at Kimakia Forest Station, Kenya.

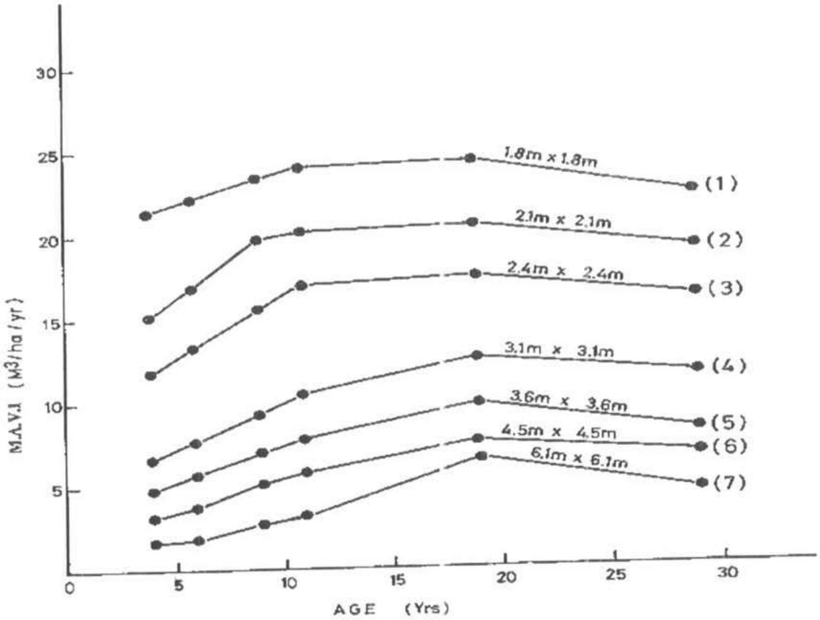

Fig.3: Mean annual volume increment M.A.V.I of *Cryptomeria japonica* at different spacings suggested in Kimakia Forest Station, Kenya.

ACKNOWLEDGEMENT

The author thanks the former Forester of Kimakia Forest, Mr. Kimani Kiema and Foresters J. Kioko and Mr. Peter Wanjawa of Kenya Forestry Research Institute (KEFRI) for assisting in data collection. Special thanks go to Mr. Muchiri of KEFRI who assisted in data analysis. This paper was published with the permission of the Director KEFRI.

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