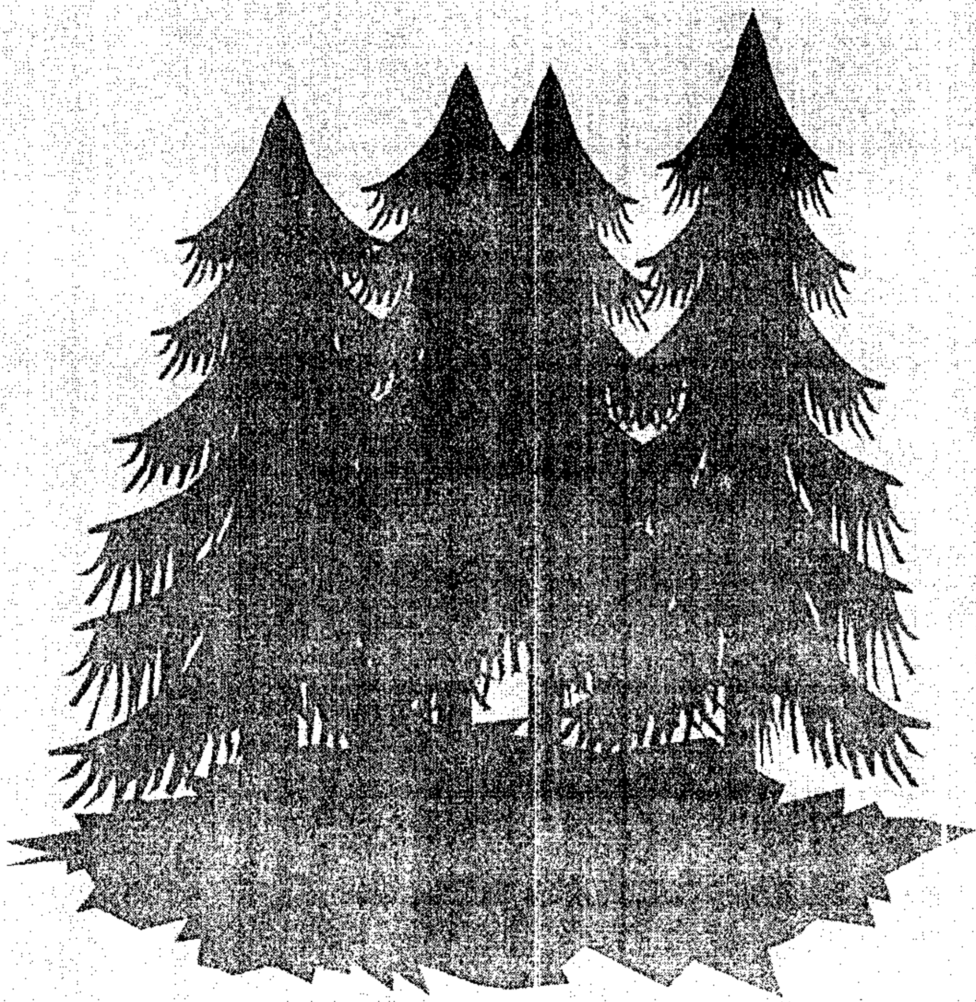
A Review of Current Silvicultural Regimes for Kenya Forest Plantations



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A Review of Current Silvicultural Regimes for Kenya Forest Plantations

A paper prepared by the FD/KEFRI Forest Management and Silvicultural Task Force

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1. INTRODUCTION

1.1. BACKGROUND INFORMATION

For many years, the forest silvicultural practices have depended on technical orders (TO) prepared by the Kenya Forestry Research Institute (KEFRI). The TOs had taken account of the practical plantation management experiences gained over time by the forest operation staff but were not sensitive to the changing economic scenarios.

Some of the TOs issued have become inappropriate to plantation management needs. The deficiencies in the prescriptions and practices have been widely recognised by operational staff as well as by other participants and stakeholders in the forest industry.

The World Bank mid term review team of the Kenya Forestry Development Project (KFDP) which completed its work in February 1996 highlighted areas of silviculture which needed re-examination. The areas highly questioned were pruning and thinning regimes of the current silvicultural practice which have contributed to the existing huge backlogs in the management of *Cupressus lusitanica* and *Pinus patula*. These two species occupy about 75 per cent of industrial plantations in the country.

As stated above the need for change emerges when one realises that there has been no alterations in some of the prescriptions since 1969 though there are new research findings. Also today the Forest Department utilises genetically improved seed for it planting programme and there is new commercial focus for industrial development which has called for the shortening of the rotations.

This paper provide attempts made to developing alternative prescriptions for silvicultural practice as relates to spacing, thinning and pruning specifically for the two species mentioned above. The paper is basically reliant on a simulation model which allow a quick view of the situation under various hypothetical but possible scenarios. The model was used as it had been validated with data from the existing forest plantations. The outcome of these studies should form the basis for preparation of revised technical orders for silvicultural practices or assist in setting up research trials in the field to validate the model.

1.2. CURRENT SILVICULTURAL REGIMES

Tables 1 and 2 show the current regimes for production of sawlog, pulpwood and veneer as per the technical orders in use.

There have been discussions on these regimes focused on the need to increase royalties by:-

- Maximising diameter growth and therefore economic returns on final crop stems
- Reducing establishment costs particularly in the early years of the rotation when heavy losses are usually experienced.

In formulating the proposals for the changes in these regimes, this paper will recognise these two factors in order to relate silviculture to the market needs.

Table 1: Treatment of *Cupressus lusitanica* Plantations

Summary of current practices as described in T.O. 4.4.03 (formerly T.O.no. 42 of 1969)

Objective:	1. Pulpwood		
	2. Saw timber		
Spacing:	Pulpwood	2.75m*2.75m	(1320 stems per hectare).
	Saw timber	2.5m*2.5m	(1600 stems per hectare)

Pruning

Pruning	Age/height	Pruning height	No. of trees to be pruned	
			Pulpwood	Saw timber
p1	2 years	½ht but ≤2 m	All	All
p2	4 years	½ht but ≤4 m	All	All
p3	9.25 m ht	⅔ht (6.2m)	All	533
p4	11.25 m ht	⅔ht (7.5m)	-	533
p5	13.75 m ht	⅔ht (9.2m)	-	533

Prune during long rains (immediately after planting).

Thinning schedule - pulpwood (only if rotation is > 20 years).

Thinning	Thin age/ht	Thin to	Remaining (%)
T1	15 yrs	880	66

Thinning schedule - saw timber

Thinning	Thin age/ht	Thin to	Remaining (%)
T1	11.25m but ≤ 6 yrs	888	55
T2	T1 + 5 yrs	533	33
T3	T1 + 10 yrs	355	22
T4	T1 + 15 yrs	266	16

Clearfell	Pulpwood	15-20 years
	Saw timber	Average diameter of 48 cm.

Table 1: Treatment of *Pinus patula* Plantations

Summary of current practices as described in T.O. 4.4.06 (formerly T.O.no. 53 of 1981)

Objective:	1. Pulpwood		
	2. Saw timber		
	3. Plywood		
Spacing:	Pulpwood	3.0m *3.0m	(1100 stems per hectare).
	Saw timber/Plywood	3.0m*3.0m	(1100 stems per hectare)

Pruning

Pruning	Age/height	Pruning height	No. of trees to be pruned	
			Pulpwood	Saw timber/Plywood
p1	3 years	½ht + one whorl		All
p2	4 years	½ht + one whorl	All	All
p3	8 m	½ht + one whorl	-	600
p4	12 m	½ht + one whorl	-	600
p5	16 m	10 m	-	600

All prunings to take place in the rain season (after planting).

Thinning schedule - Pulpwood (only required if rotation age > 20 yrs).

Thinning	Thin age/ht	Thin to	Remaining (%)
T1	15 yrs	880	80

Thinning schedule - Saw timber and plywood

Thinning	Thin age/ht	Thin to	Remaining (%)
T1	12 m	600	50
T2	T1 + 5 yrs	400	33
T3	T1 + 10 yrs	250	22
T4 (plywood only	T1 + 15 yrs	170	15

Clearfell	Pulpwood:	18 years
	Saw timber:	diameter 37 cm at 356 sph or diameter 48 cm at 250 sph
	Plywood:	diameter 51 cm or 35 years.

2. SPACING

2.1. CURRENT PRACTICE: DESCRIPTION AND ORIGIN IN KENYA

Initial spacings, borrowed from other Commonwealth countries especially India and South Africa, were adapted for Kenyan forest plantations at the beginning of this century. Closer initial spacings were recommended in areas where perennial grasses were likely to occur as well as for other reasons. For example the closer spacing advocated for *Pinus radiata* was due to considerably high number of poor plants observed in young crops, which necessitated planting sufficiently high number to allow for the elimination of poor stems along the rotation through extensive thinning (Technical Note No. 52, 1957). This was done to ensure that the principle object of management of softwoods was achieved ie attaining timber of high quality from a given number of trees per unit area.

At the foresters'' conference of 1951 it was resolved that the forest department carry out planting at 2m x 2m and no pruning or thinning for 10 years. This resolution came after the 1950 foresters'' conference team visited the then Tanganyika and saw the famous Sungwe Cypress plantations near Lushoto. The plantations had developed into remarkably good form and quality despite almost complete neglect of thinning and pruning in their earlier years (Technical Order No. 80, 1961).

Following the resolution of the above conference the then Forest Divisions were asked to plant out four adjacent one acre (approximately 0.4 hectare) plots at spacings of 2m x 2m, 2.5m x 2.5m, 2.75m x 2.75m and 3m x 3m, with whatever softwood species they were planting. A total of 35 plots were laid down in 1951 and 1952. From preliminary results it was concluded that growing the plants at 2m x 2m without pruning did not result in the intended self pruning. The result then confirmed the choice of 2.5m x 2.5m. (Technical Note No. 80, 1961) coupled with the attendant thinning and pruning regimes.
With strict adherence to pure stands, prescription for these two species were made. It was felt that though pure stands of pines may be planted at 2.5m x 2.5m or 3m x 3m, it was recommended that planting of *Pinus patula* in future at 3m x 3m was appropriate.

The Chief Conservator of Forests authority has seen the move from 2.5m x 2.5m to 2.75m x 2.75m spacing in the Cypresses and to 3m x 3m for Pines in pulp wood areas respectively (Technical Order 4.4.03 on Cypress and 4.4.06 on Pines).

2.2 JUSTIFICATON FOR CHANGE

2.2.1 Spacing and Volumes

From time to time the element of cost appropriateness of the management practices has been questioned. KEFRI in conjunction with Forest Department have instituted measures to try and suit the changing times.

KEFRI established constant spacing trials in Londiani in 1966. Results *for Cupressus lusitanica* and *Pinus patula* have been obtained and analysed as in table 3 and 4.

Muchiri (1996) in his report argues that mere volumes do not meet the principles of forest management. He has compared initial spacing with merchantable volume at different spacings at 30 years of age (Table 3)

Table 3: Effect of Different Spacings of *Cupressus lusitanica* at Age 30 Years on Various Parameters

Spacing	Survival/ Ha (%)	Mean DBH (cm)	Merchantable Volume m^3/Ha	Total Volume m^3/Ha	Merchantable/ total Volume (%)
1.8 x 1.8	36	24	503.4	621	81
2.1 x 2.1	47	25	511.7	623	82
2.4 x 2.4	54	27	544.5	618	88
3.0 x 3.0	54	30	463.2	498	93
3.6 x 3.6	68	34	538.2	564	95
4.6 x 4.6	69	40	445.9	471	95
6.1 x 6.1	79	48	416.7	429	97

2.2.2 Spacing and Wood Quality

A large number of wood quality characteristics exist that might be considered such as wood density, fibre length, fibre diameter, cell wall thickness, fibre angle, cellulose content and extractive content. However, wood quality may best be defined when the end product is known. Wood density can give an indication of many wood properties. In the absence of other actual test data, it can be employed with considerable accuracy to indicate mechanical strength, hardness, shrinkage and other associated properties (Keith, 1961).
Table 4 shows the effect of spacing on specific gravity as a measure of wood quality. These results were obtained from tests carried out on wood samples from the trial plantations at Londiani by KEFRI and Forest Department personnel. The results show that spacing has no significant influence on wood specific gravity.

Table 4: Effect of Different Spacing on Specific Gravity of *Cupressus lusitanica* and *Pinus patula* at the Age of 30 Years.

Spacing (m)	*C. lusitanica*			*P. Patula*		
	Mean S.G.	S.G. at bark	S.G. at Pith	Mean S.G.	S.G. at Bark	S.G. at Pith
1.8 x 1.8	0.4	0.4	0.38	0.45	0.52	0.35
2.1 x 2.1	0.4	0.41	0.41	0.43	0.51	0.37
2.4 x 2.4	0.42	0.42	0.43	0.43	0.48	0.38
3.0 x 3.0	0.4	0.38	0.38	0.43	0.52	0.31
3.6 x 3.6	0.42	0.42	0.42	0.43	0.53	0.35
4.6 x 4.6	0.4	0.40	0.39	0.43	0.54	0.35
6.1 x 6.1	0.42	0.42	0.39	0.43	0.55	0.34

Extracted from "Effect of espacement on wood quality of *Pinus patula* and *Cupressus lusitanica* grown in plantations by Muga M.O. (1997)" Unpublished report.

2.2.3 Other experiments in the tropics

As a matter of comparison, other studies carried elsewhere were considered such as one carried out in Queensland - Australia on the effect of initial spacing on yield of *Pinus caribaea* at the age of 9.3 years. The data is illustrate in Table 5.

Table 5: Effect of Initial Spacing on Yield of *Pinus caribaea* at Age 9.3 Years

Initial spacing(m)	Survival (%)	Dom H (m)	Diameter dg (cm)	Volume		
				V_0	V_1	V_0/V_1 (%)
2.13 x 2.13	88	18.7	16.6	146.14	205.35	71
2.44 x 2.44	86	18.6	17.8	137.12	181.51	76
2.74 x 2.74	89	18.6	18.6	126.85	159.84	79
3.05 x 3.05	90	18.7	20.1	130.33	155.28	84
3.66 x 3.66	92	18.1	20.9	102.60	119.60	86

dom H — Top height; mean height of 100 thickest trees per hectare
dg — Diameter of tree of mean basal area
V_0 — Merchantable volume per ha.
V_1 — Total volume per ha.

2.2.4 Spacing and Costs

Generally, widely spaced plantations are cheaper to grow. This is because there are fewer pits to dig, fewer plant seedlings needed and fewer seedlings to actually plant. In their study on production of seedlings in a few sample forest stations in Kenya, Seppanen and Miano (1989) found out that it required Ksh.1/62 to raise a single seedling for industrial plantation. Assuming proportionality of spacing to the number of seedlings required, a 2.5 by 2.5m spacing would require an average of 2000 seedlings per hectare whereas it would require 1500 seedlings per hectare for the 3.0 by 3.0 m spacing. The cost of raising seedlings in 2.5 by 2.5 m spacing would therefore be Ksh.3240 per hectare whereas it would take Ksh.2430 per hectare for the 3.0 by 3.0m spacing. This implies that there would be a net saving of Ksh.810 per hectare if one uses a 3.0 x 3.0 m spacing instead of the 2.5 m by 2.5m currently widely used. The Forest Department (FD) proposes to plant an average of 6000 hectares per year. This would lead to a saving of Ksh.4.86 million, which is quite substantial.

If the same argument is applied to subsequent operations until the time of beating up in cases where shamba system is applied, 15 mandays will be required to cut stakes and beat up. With a cost of Ksh.92/60 per manday, the discounted costs will be Ksh.1450 per hectare for the 2.5 x 2.5 m spacing whereas it will require Ksh.996 per hectare for the 3.0 x 3.0 m spacing.

Thus there will be a saving of Ksh.464 per hectare. If 6000 hectares are to be planted, then Ksh.2.784 millions will be saved each year. Therefore, with an increased spacing, the department will be able to save approximately Ksh.7.644 millions to be used in other forest operations.

2.3 SUMMARY OF RESULTS AND DISCUSSIONS

It is evident from the results of experiment carried out by KEFRI and those from elsewhere that if spacing is reasonably selected it could determine the profitability of plantation forestry. Also from these results it is possible to draw the following conclusions:

(a) Closer spacing result in higher mortality rate than wider spacing.

(b) Spacing has no influence on the development of the dominant height.

(c) Greater diameter growth results from wider spacing.

(d) Wider spacing leads to some loss of total volume production per hectare.

(e) Widely spaced stands have proportionally more large trees and the yield of merchantable timber is greater up to a certain extent.

(f) A wider spacing should be more profitable than closer spacing when it relates to the volume of merchantable timber again up to certain limit.

(g) Wider spacing results in reduced establishment costs.

There will be guaranteed good tree growth as long as good quality genetic material are used. Therefore wide spacing and tree improvement programmes should be developed together.

Theoretically with wide spacing there arises an opportunity for mechanisation and fewer trees to tend though usually for a longer time due to the longer time taken for the canopy to close. This too may have negative effect such as thicker branches, hence the necessity to carry out pruning, delay in canopy closure which may lengthen period of fire hazard and a delay in thinnings with less damage to remaining stems in wider spacing than in closer spacing.

2.4. RECOMMENDED NEW SPACINGS

From the foregoing, it is evident therefore, there is need to increase spacing in order to meet the principles of forest management, i.e. those of raising plantations sustainably. It will be observed that a reasonable change in spacing to the one quoted above i.e. 3 x 3m, should lead to the utilisation of material which hitherto have been lacking market due to felling of very young trees through early thinnings. This will theoritically be possible because the first thinning could be delayed such that the trees are marketable at the time of cutting.
Furthermore, the 3 x 3 m spacing had better economic returns than 3.5 x 3.5 m as far as the trial at Londiani was concerned. At the same time it would make reasonable utilisation of the site over the duration of the rotation if not as good as the closer spacing of 2.5 m by 2.5 m.

3.0 THINNING AND PRUNING

3.1 CURRENT PRACTICE: DESCRIPTION AND ORIGIN

Plantation establishment in Kenya has entailed planting so many trees in a hectare of land to achieve specific purposes. These include suppression of the ground vegetation, encouragement of straight growth and after allowing for casual losses, to leave the forester a larger choice from which to select his final crop which depends on the ultimate objective.

The thinning process is inevitable as a silvicultural operation for various purposes but the main ones are:-

(a) to remove dead, diseased, dying, forked and malformed trees.

(b) to remove trees that are unfavourably competing for light, moisture and nutrients with those trees that are selected for high pruning and for future harvesting.

(c) to improve the value of the remaining crop and obtain revenue early in the rotation.

It should be noted that though some thinnings may yield very little profit immediately, their effects on the final profitability of the crop may be quite considerable.

Pruning has to be done if knot-free timber is desired. This has to be done since our plantations grown for sawlog and veneer require to produce high grade, clear timber. Therefore pruning will be viewed by the forester as an investment to improve wood quality which should command a higher market value, sufficient to cover compounded pruning costs, compared with knotty timber from unpruned trees.

In the 1930s and 1940s much work was done in South Africa by Craib (1947) on pines. Since the 1950s many African countries notably Kenya, Madagascar, Nigeria and Tanzania have used or adapted South African and Indian thinning practices to develop local regimes (Evans 1982). The Kenyan case was more allied to South Africa as shown by Pudden in Technical Note No. 15, 1945. However, the widely used method of thinning in Kenya has been the Queensland method and for most of the thinning regimes the total volume of timber removed during a rotation amounts to about 40 to 60 per cent of total production if reasonably done. Though the thinning has been going on over the years, thinning backlogs have developed. These delayed thinnings (backlogs) are a result of lack of market for the early produce and this has posed a common problem in tropics (Evans 1982). Secondly the labour supply in the Forest Department has greatly been reduced due to the early retirement programme which has resulted in most workers leaving. This has reulted in shortage of manpower to carry out these labour intensive activities in almost all forest stations. Fortunately enough work on pruning has been done and data on pruning are more reliable than on thinning as they have been done repeatedly over the period (Technical Note Nos. 50 and 51). However, more research work is still being carried out in the area of pruning especially due to the short rotation the plantations are being subjected to as the forest plantation becomes smaller on a daily basis.

3.2 JUSTIFICATION FOR CHANGE

Thinning and pruning as prescribed in the current regimes are very expensive operations to undertake in the field. This has resulted in the accumulation of huge backlogs of the two operations in the field. Furthermore, with the proposed change in the initial spacing, there is need to change the prescription. Some of the regimes as practiced today are unnecessary and unjustified, e.g. the three prunings in pulpwood crop of *Cupressus lusitanica.*

3.3 PROPOSED THINNING AND PRUNING REGIME FOR THE NEW SPACING

The adoption of a spacing as recommended above require adjustments in the thinning and pruning regimes. The adjustment will entirely depend on the end use of the final crop. The management objective for the two species mentioned will presently be two-fold namely:-

- Production of pulpwood. This should include chipboard production.

- Sawlog and veneer production.

3.3.1 Production of Pulpwood and Chipboard

3.0 x 3.0 m espacement.

There will be two early prunings in these stands, one at 2 and 4 years.

There will be one thinning at age 15 years for those plantations to be harvested after 20 years to 880 stems per hectare.

3.3.2. Production of sawlog and Veneer

The objectives of the treatment for this option are designed to:-

(a) Produce a final crop with minimum knotty core in 30 years of 300 trees with a minimum diameter at breast height (DBH) of 45 cm and a merchantable yield of 500 m^3/ha. or more of which 50% will be suitable for high grade veneer. This figure should be attained considering that the unthinned research stands in Londiani by KEFRI had yield of 604 m^3/ha.

(b) To produce a series of fewer but intermediate thinnings suitable for economic exploitation.

Tables 6 to 8 shows the thinning regime for *Pinus patula* and *Cupressus* lusitanica in a 3.0 x 3.0 m spacing.

Table 6: Thinning regime for the production of sawlogs and veneer in a 3.0 x 3.0 spacing

Age (Years)	Operation	Trees/Ha.
0	Plant	1110
0 - 1	Beat Up	1110
8	Thin to	800
15	Thin to	500
22	Thin to	300
30 +	Clearfell	---

NOTE: Delay in first thinning. This deliberate delay in thinning is supported by Evans (1976) who found out that "using slowing of growth as an indicator, between tree competition occurred in *Pinus patula* stands planted at 2.74 x 2.74 m spacing at about 5 - 6 years of age when the trees were about 7 m tall. The competition appeared to have an effect from about the time of canopy closure. It is expected that competition will start late in a wider spacing.

Table 7: Pruning regime for the production of sawlogs and veneer in a 3.0 x 3.0 m spacing.

Approximate Age/Years	Operation	Dominant Height (m)	Maximum Pruning Height (m)
2	P_1 - Prune all stems 1/2 ht but not more than 2m.		2.0
4	P_2 - Prune all stems 1/2 ht but not more than 4m.		4.0
8	P_3 - Prune 500 stems to 2/3 ht	9.25	6.2
11	P_4 - Prune 500 stems to 2/3 ht	11.25	7.5

Table 8: Pruning regime for the production of pulpwood in a 3.0 x 3.0 spacing.

Approximate Age/years	Operation	Dominant ht (m)	No. of trees to be pruned
2	P1 - Prune to 1/2 ht but not more than 2 m.		All
4	P2 - Prune to 1/2 ht but not more than 4 m.		All
15 (if clearfelling at ≥ 20 years)	Thin to 880 stems per hectare		
20+	Clearfell		

4. COST/BENEFIT ANALYSIS OF THE ALTERNATIVE SILVICULTURAL REGIMES

The World Bank Mid-Term Review of KFDP Projects defines the silvicultural situation in Kenya as a major drawback to realisation of the goals of profitable forest management. Of great concern are the prevalent backlogs in planting, thinning and pruning (Forester 1996). This has been suggested to be due to initial high stocking, poor timing of the operations especially thinnings and prunings which have proved inappropriate and uncoordinated. The problems have been compounded by the lack of semi-skilled labour due to the retrenchment of permanent staff the Kenya Government has carried out in the 1994-1997 period. These issues have necessitated the need to cut on further cost by reducing the activities of the operations yet meet the forestry management objectives in plantation areas.

Several possible regimes were proposed by the team for consideration for trial in the field after subjecting them to some projection using simulation models. These include the regimes shown in table 9 with all earmarked to be harvested at 30 years.

Table 9: Alternative thinning regimes and their value*

Case No.	Spacing	Age and stocking density after thinning 1st	2nd	3rd	4th	*Net Present Value (Ksh/ha
1	3.0 x 3.0	8-800	15-500	22-300		105618
2	3.0 x 3.0	8-800	13-500	21-300		107127
3	3.0 x 3.0	8-650	15-450	21-270		105856
4	3.0 x 3.0	7-600	12-400	17-250		110278
5	**2.5 x 2.5**	**7-888**	**12-533**	**17-355**	22-266	**119017**
6	3.0 x 3.0	8-650	15-450	21-300		104469
7	3.0 x 3.0	8-800	13-500	22-300		104095
8	3.0 x 3.0	10-800	15-500	23-300		102921
9	3.0 x 3.0	9-800	15-500	21-350		103857
10	3.0 x 3.0	10-800	15-500	20-300		104432

* assumes that the establishment costs are the same and that the only cost to be considered is incurred when undertaking the first thinning. Prunings are assumed to be standard in all cases and are therefore not included in the calculations.

Case number 5, is the current prescribed thinning regime for saw timber plantations. These cases were subjected to a simulation model which projected growth based on the age of the stand, the stocking density before and after thinning and the duration between any two subsequent operations.

Results of these simulations are given in table 10 and indicate clearly that even with increased spacing, delayed first thinning and reduced number of thinnings, the current regime is the most appropriate in terms of generating revenue.

Table 10: Results of simulating the various alternative thinning regimes

Case 1	3.0x3.0m										
	Thinning	Basal	Diam.	Density	Vol.	Royalty/DE	Royalty/ha	DiscRev	T.Cost	Dis.Cost	NPV
	Age	Area									
before	8	17.9	15.4	963	101						
after	8	19.3	16.0	800	108						
remove		0	0.0	163	0				67	45.34824	
before	15	41.2	26.1	768	322						
after	15	32.6	23.3	500	259						
remove		8.6	20.2	268	63	265	16695	8030.58			
before	22	46.9	35.3	480	450						
after	22	35.2	30.6	300	343						
remove		11.7	28.8	160	107	403	43121	14740.9			
C/F	30	46.8	45.7	286	523	685	358255	82892.1			
Totals								105664		45.3482	105618
@@@@	@@@@	@@@	@@@	@@@@	@@@	@@@@	@@@@@	@@@@	@@@	@@@@@	@@@
Case 2	3.0x3.0M										
	Thinning	basal	diam	density	vol.						
	Age	Area									
before	8	17.9	15.4	963	101						
after	8	19.3	16.0	800	108						
remove		0	0.0	163	0				67	45.34824	
before	13	35.9	24.2	777	260						
after	13	28.7	21.7	500	211						
remove		7.2	18.2	277	49	230	11270	5976.72			
before	21	46.4	35.2	477	435						
after	21	35.1	30.6	300	334						
remove		11.3	28.5	177	101	403	40703	14610.0			
C/F	30	48.4	46.6	285	540	693	374220	86586.0			
Totals								107173		45.348	107127

Case 3	3.0 x 3.0m										
	Thinning Age	Basal Area	Diam.	Density	Vol.	Royalty DE	Royalty/ha	DiscREV	T.Cos	Dis Cost	NPV
before	8	17.9	15.4	963	101						
after	8	16.5	14.8	650	94						
remove		1.4	7.5	313	7	3	939		130	87.98912	
before	15	37.6	27.7	624	296						
after	15	32.7	25.8	450	259						
remove		4.9	18.9	174	37	249	9213	4431.61			
before	21	45.2	36.4	434	424						
after	21	34	31.6	270	324						
remove		11.2	29.5	164	100	415	41500	14896.1			
C/F	30	47.3	48.5	256	528	709	374352	66616.6			
Totals								**105944**		87.989	105856
@@@@	@@@@@	@@@	@@@	@@@@	@@@	@@@@@	@@@@@	@@@@	@@@	@@@@@	@@@@
Case 4	3.0 x 3.0										
	Thinning Age	Basal area	diam.	stocking	volume	Royalty/ DE	Royalty/ha				
before	7	14.2	13.7	968	76						
after	7	12.7	12.9	600	69						
remove				368					155	110.1556	
before	12	29.1	25.2	583	203						
after	12	25.2	23.5	400	178						
remove		3.9	16.5	183	25	211	5275	2937.31			
before	17	37.7	35.2	388	318						
after	17	30	31.3	250	256						
remove		7.7	26.7	138	62	377	23374	10195			
C/F	30	51	53.0	232	568	740	420320	97252.5			
Total								110388		110.16	110278

Case 5	2.5x2.5m										
	Thinning Age	Basal Area	Diam.	Density	Vol.	Royalty/DE	Royalty/ha	DiscRev	T.Cost	Dis.Cost	NPV
before	7	18.8	13.7	1273	105						
after	7	17.7	13.3	888	100						
Remove		0	0.0	385	[illegible]				160		
before	12	35.8	23.0	862	266						
after	12	27.8	20.3	533	210						
Remove		8	17.6	329	56	230	12880	7?72.06			
before	17	40.5	31.6	516	364						
after	17	33.5	28.7	355	304						
Remove		7	23.4	163	60	316	18960	8272.18			
before	22	43	39.9	345	441						
after	22	38.6	37.7	266	397						
Remove		4.4	26.6	79	44	377	16588	5670.60			
C/F	30	50.2	50.2	254	590	718	423620	93016.1			
Total								119131		113.71	119017
@@@@	@@@@@	@@@	@@@	@@@@	@@@	@@@@@	@@@@@	@@@@	@@@	@@@@@	@@@@
Case 6	3.0x3.0 M										
before	8	17.9	13.7	963	101						
after	8	18.5	14.8	650	94						
Remove		1.4	7.5	313	[illegible]	3	939		130		
before	15	37.6	27.7	624	296						
after	15	32.7	25.8	450	259						
Remove		4.9	18.9	174	37	249	9213	4431.61			
before	21	45.2	36.4	434	424						
after	21	36.9	32.9	300	350						
Remove		8.3	28.1	134	74	389	28786	10332.5			
C/F	30	50.3	47.4	285	560	693	388080	89792.9			
Total								104557		87.989	104469

Case 7	3.0x3.0m										
	Thinning Age	Basal Area	Diam.	Density	Vol.	Royalty/DE	Royalty/ha	DiscRev	T.Cost	Dis.Cost	NPV
before	8	17.9	15.4	963	99						
after	8	19.3	16	800	106						
Remove				163		3	489		70	47.37876	
before	13	35.9	24.2	777	255						
after	13	28.7	21.7	500	207						
Remove		7.2	18.2	277	48	230	11040	5854.74			
before	22	48.1	36	474	454						
after	22	36.4	31.3	300	348						
Remove		11.7	29.3	174	106	403	42718	14603.1			
C/F	30	48	46.2	286	528	685	361680	83684.6			
Totals								**104142**		47.379	104095
@@@@	@@@@@	@@@	@@@	@@@@	@@@	@@@@@	@@@@@	@@@@	@@@	@@@@@	@@@@
Case 8	3.0x3.0M										
before	10	24.9	18.3	951	157						
after	10	25.7	16.6	800	162						
Remove				151		3	453		65	39.90436	
before	15	40.4	25.7	777	316						
after	15	31.8	22.8	500	252						
remove		8.6	19.9	277	64	265	16960	8158.05			
before	23	47.7	35.7	477	468						
after	23	35.9	31	300	357						
Remove		11.8	29.1	177	111	403	44733	14563.8			
C/F	30	45.9	45	288	513	676	346788	80238.9			
Totals								102961		39.904	102921

Case 9	3.0x3.0m										
	Thinning	Basal	Diam.	Density	Vol.	Royalty/DE	Royalty/ha	DiscRev	T.Cost	Dis.Cost	NPV
	Age	Area									
before	9	21.5	16.9	957	128						
after	9	22.6	17.3	800	1[illegible]5						
remove		0	0.0	157	0				65	41.89958	
before	15	40.8	25.9	772	3[illegible]9						
after	15	32.2	23	500	2[illegible]5						
remove		8.6	20.1	272	6[illegible]	265	16960	8158.05			
before	21	44.7	34.3	483	4[illegible]0						
after	21	38	31.7	350	3[illegible]9						
remove		67	25.3	133	6	348	21228	7619.63			
C/F	30	51.3	44.4	332	5[illegible]1	667	380857	88121.7			
Totals								103899		41.9	103857
@@@@	@@@@@	@@@	@@@	@@@@	@@@	@@@@@	@@@@@	@@@@	@@@	@@@@@	@@@@

Case10	3.0X3.0M										
before	10	24.9	18.3	951	157						
after	10	25.7	18.6	800	162						
remove		0	0.0	151	0				65	39.90436	
before	15	40.4	25.7	777	316						
after	15	31.6	22.8	500	252						
remove		8.6	19.9	277	64	265	16960	8158.05			
before	20	42.4	33.4	466	[illegible]89						
after	20	32.1	29	300	299						
remove		10.3	26.6	186	[illegible]0	377	33930	1[illegible]787.9			
C/F	30	47.2	46.1	283	[illegible]27	685	360995	83526.1			
Totals								104472		39.904	104432

Further on one of these proposed cases, similar pruning regimes to the one currently used was theoretically applied as well as on the 2.5 m by 2.5 m spacing regime and their net present values compared (table 11). In this case, the number of mandays required to perform a specific task were reduced proportionally based on the stocking density of the stand. As in the previously findings, the current spacing regime had the highest net present value which form the main guiding factor.

Other considerations that may influence spacing but were not examined are (i) the possibility of mechanising forest operations which may require wide spacing and (ii) the need to facilitate the cultivators to work in the plantations for a longer period through delayed canopy closure by employing wide spacing. However the latter while sounding appropriate from a socio-economic point of view, may lead to excessive pressure on the forest land to the point of causing some form of excision as seen in the recent past in the country. Thus further studies are required. Otherwise unless information to the contrary is available, the status quo should be maintained in as far as spacing thinning and pruning are concerned.

Table 11a: Plantation Costs and Revenues
Cupressus lusitanica at 2.5 m * 2.5 m spacing - applying current silvicultural regime

		COSTS				REVENUES			
yr.	operation	stocking	m/days	Ksh.	NPV	Vol m^3	Royalty	Total Ksh.	NPV
0	seedlings	0	22	2,037	2,037			0	0
0	plant	1,600	11	1,019	1,019			0	0
1	beat up		5	463	441			0	0
2	P1		10	926	840			0	0
3				0	0			0	0
4	P2		15	1,389	1,143			0	0
5				0	0			0	0
6	T1	888	10	926	691			0	0
7				0	0			0	0
8	P3	888	15	1,389	940			0	0
9				278	0			0	0
10				0	0			0	0
11	P4	888	15	1,389	812			0	0
12	T2	533	3	0	155	56	230	12,880	7,172
13				0	0			0	0
14	P5		15	278	702			0	0
15				0	0			0	0
16				0	0			0	0
17	T3	355	3	0	121	60	316	18,960	8,272
18				0	0				0
19				278	0				0
20				0	0				0
21				0	0				0
22	T4	266	3	0	95	44	377	16,588	5,671
23				0	0			0	0
24				0	0			0	0
25				0	0			0	0
26				0	0			0	0
27				0	0			0	0
28				0	0			0	0
29				0	0			0	0
30	C/F			0	0	590	718	423,620	98,016
					8,996	750			119,131
				Net Present Value			110,135		

Direct costs only included
Note revenues indicated are not currently being collected

Table 11b Plantation Costs and Revenues
Cupressus lusitanica at 3 m * 3 m spacing - applying current silvicultural regime

		COSTS				REVENUES			
yr.	operation	stocking	m/days	Ksh.	NPV	Vol m^3	Royalty	Total Ksh.	NPV
0	seedlings	0	15	1,389	1,389			0	0
0	plant	1,100	8	741	741			0	0
1	beat up		3	278	265			0	0
2	P1		7	648	588			0	0
3				0	0			0	0
4	P2		10	926	762			0	0
5				0	0			0	0
6				0	0			0	0
7				0	0			0	0
8	P3, T1	800	18	1,667	1,128			0	0
9				0	0			0	0
10				0	0			0	0
11	P4	800	14	1,296	758			0	0
12				0	0			0	0
13				0	0			0	0
14	P5		14	1,296	655			0	0
15	T2	500	3	278	134	63	265	16,695	8,03[illegible]
16				0	0			0	0
17				0	0			0	0
18				0	0			0	0
19				0	0			0	0
20				0	0			0	0
21				0	0			0	0
22	T3	300	3	278	95	107	403	43,121	14,741
23				0	0			0	0
24				0	0			0	0
25				0	0			0	0
26				0	0			0	0
27				0	0			0	0
28				0	0			0	0
29				0	0			0	0
30	C/F			0	0	523	685	358,255	82,892
					6,515	693			105,664
					Net Present value =		99,149		

Direct costs only included
Note revenues indicated are not currently being collected