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Spacing and Genotype on Height and Diameter Growth of Four Eucalyptus Under Short Rotation

Balozi B Kirongo[1]*, Angela S Mbelase[1], Kingiri Senelwa[1], Joseph Hitimana[2], and Lazare Etiegni[1]

[1]Department of Forestry and Wood Science, Moi University, PO Box 1125-30100, Eldoret, Kenya
[2]School of Natural Resource Management, Kabianga University College, PO Box 1-20201, Kabianga, Kenya

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Abstract

In this paper, the dynamic change in tree height, diameter at breast height (dbh), and ground line diameter (gld) at different density was studied. Trial sites were established in Chepkoilel and Nangili areas of western Kenya. Eight tree species (2 hybrid eucalyptus clones; GC 10 and GC 167), 1 eucalyptus local landrace, 2 agroforestry (Grevillea robusta and Markhamia lutea), 1 pure eucalyptus (Eucalyptus grandis), and 2 preferred local species (Maesopsis eminii and Khaya nyasica) were planted on each site. This paper however focuses on the effect of spacing on the height, dbh, and gld growth of the 4 eucalyptus genotypes viz (2 eucalyptus hybrid clones, 1 eucalyptus local landrace, and 1 pure Eucalyptus grandis). These were planted at 10 different spacings (0.6-, 0.8-, 1.0-, 1.2-, 1.4-, 1.6-, 1.8-, 2.0-, 2.2-, and 2.4-by-1.0 m; these being some of the most common spacings used by farmers) in a Nelder radial experimental design in 4 replications. Measurements of height, dbh, and gld were taken at intervals of 6 months over 3 years. The data was subjected to an analysis of variance to determine if there were statistically significant (p = 0.05) differences in tree growth with spacing levels. The results showed that tree growth was significantly influenced by spacing and genotype with the best spacing being 2.4-by-1.0 m, indicated that the relative growth rates of height dbh, gld, and increased with increasing the distance between trees but decreased with age. After 3 years the best spacing for optimal overall tree growth was 2.4-by-1.0 m and GC10 being the outstanding genotype. Of the 2 sites, trees performed better in Nangili. The results from this study further pinpoint the importance of species-site-matching using improved germplasm and planting trees at the correct spacing for optimal growth.

Keywords: tree growth, spacing, eucalyptus hybrid clones, short rotation forestry, species site matching

Correspondence author, email: balozibk@hotmail.com, phone: +254-53-2063105, fax: +254-53-2063257

Introduction

Short rotation forestry (SRF) is defined as the silvicultural practice of cultivating fast growing trees that reach their economically optimum size in a much shorter period. In their publication on short rotation forestry in Kenya, Senelwa and Sims (1997) defined SRF as planted tree crops which reach economic maturity between 5–15 years. However, recent experiences with SRF crops, especially of eucalyptus in western Kenya show that farmers can harvest trees at ages of between 3–5 years as well, in particular where the objective is for small poles, firewood, charcoal or scaffolding material in construction industry (Senelwa *et al*. 2008).

The trees in SRF are planted at spacings that allow for quick growth and easy harvesting. The concept of biomass production from SRF entails planting fast growing trees at higher stocking densities (sometimes greater than 3,000 stems ha^{-1}) than those used in conventional plantation forestry practices. The objective of the high stocking density is to achieve rapid canopy closure and high productivity (Senelwa & Sims 1997). But this should be carefully done to avoid excessive intra-specific competition and loss of volume and value (Kirongo 2000; Kirongo *et al*. 2005). SRF is in fact a modern and a very recent forestry system in Kenya. It however has a lot of potential in reducing deforestation, destruction of natural vegetation, and meeting wood fuel requirements, especially given that it is a clean, renewable resource with numerous additional environmental benefits (e.g. carbon sequestration, soil protection against erosion resulting in positive impacts on soil fertility in farms, and increased agricultural production).

Experiences and observations in western Kenya show that farmers in the region are rapidly embracing commercial and subsistence on-farm tree growing. Short rotation forestry is evident in the region although very little of its technical aspects are known to the farmers. As a result, the farmers are getting into the venture without any clear guidelines such as suitable species to grow, what end products they can get and after how long, the correct spacing and other silvicultural treatments. Consequently, the SRF ventures are not yielding optimum results. There is need, therefore to "put science and professionalism" in to the practice.

This work will focus on establishing suitable SRF planting spacing for use by farmers practicing SRF so as to optimize tree growth and thus financial benefits from SRF ventures.

Methods

Study sites The study was undertaken in Chepkoilel (Eldoret) area and Nangili (Soy) area which are within western Kenya. The selection of these specific sites for detailed analysis was based on the results of a reconnaissance survey carried out earlier by an independent group that highlighted these areas as high potential sites with acute tree products deficit.

Chepkoilel is located in Uasin Gishu District-Eldoret, Kenya at latitude 0º31'N and longitude 35º17' E. It is found 10 km from Eldoret town 3 km off the Eldoret-Iten road. It is at an altitude of 2180 masl. The area receives an annual rainfall of 800–1400 mm while mean annual temperatures range between 14 ºC and 16 ºC. The second site for the study, Nangili, is located in Lugari District–in the Western Province of Kenya at latitude 0º 39' N and longitude 34º 51'E at an average altitude of 2,700 masl. The annual rainfall ranges 500–900 mm with mean temperatures of 22.5 ºC. Most rain falls in the months of March–August, the rest of the months being dry.

Experimental design SRF field trials were established in the 2 sites in a 'Nelder' systematic radial design configuration (Nelder 1962; Krinard 1985) (Figure 1). These field trials were established to evaluate species suitability, silvicultural requirements, growth, and yields of SRF crops at various stocking densities for fuel wood production, poles, and small sized timber. Eight tree species (2 hybrid eucalyptus clones, GC 10 and GC 167, 1 eucalyptus local landrace (of unknown genotype due to possible cross polination over time), 2 agroforestry (*Grevillea robusta* and *Markhamia lutea*),1 pure eucalyptus (improved *Eucalyptus grandis* by the Kenya Forestry Research Institute), and 2 preferred local species (*Maesopsis eminii* and *Khaya nyasica*) were planted on each site. Species performance was monitored over a period of 3 years. Measurements were taken at 6 months, 12 months, 18 months, 26 months, and 36 months. This paper however focuses on the effect of spacing on the height, diameter at breast height, and ground line diameter growth of the 4 eucalyptus genotypes.

The Nelder radial configuration trial as demonstrated by Nelder (1962) and Krinard (1985) was utilized in defining and demonstrating appropriate local tree growing and silvicultural management prescriptions that could be adopted by farmers. The approach was used by Kincheff and Carter (1991) to show that yield in *Eucalyptus nitens* increased with density for each population before starting to decline. This research utilised the same technique to evaluate a range of species and their associated planting spacing in western Kenya. The spacing used for planting corresponds to the growing area and density (Table 1).

The Nelder systematic radial design configuration (Nelder 1962; Krinard 1985) was chosen as it allows for quick evaluation of species and the silvicultural requirements over a limited land area. It therefore enhances quick objective comparisons over a wide range of growing conditions like in this case, spacing. The parameters selected for monitoring are those commonly used in evaluating tree growth in forestry.

Data analysis The SRF experiments were based on a randomised complete block design. Each site was treated as an experimental block with the circles being replications. The density/spacing and genotype were considered as treatments. The genotypes were treated as random samples of fuelwood crops.

Data was analysed using SAS/STATS (2010). Two-way analysis of variances (ANOVA) with genotype and spacing as xed factors was used to select the hybrid clones with the best growth performance and a spacing that gives optimal growth and biomass in Chepkoilel and Nangili. This was deemed necessary so as to give farmers precise information on how to optimize growth of their SRF tree species. Graphical representations were used to show this.

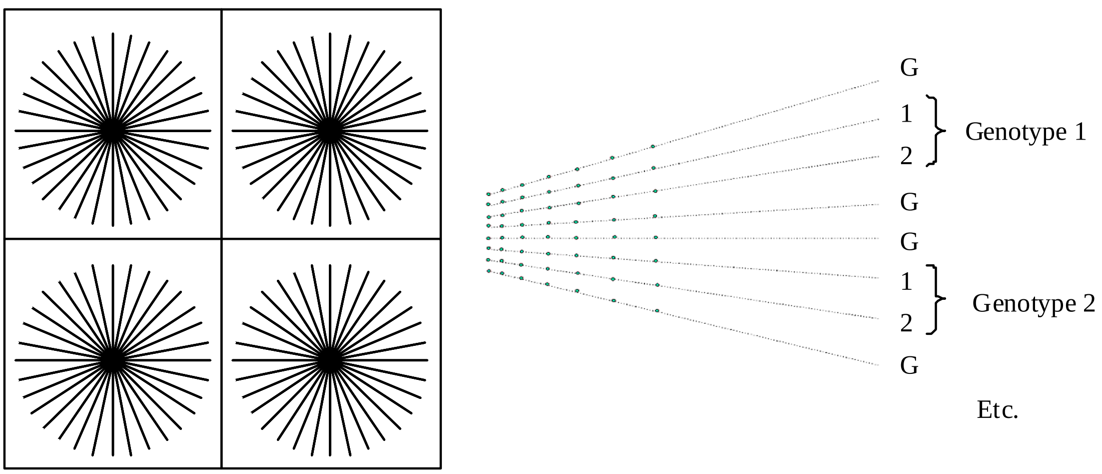

Figure 1 Nelder radial design layout of trial plots (Nelder 1962).

Results and Discussion

From Table 2 and Table 3, it is statistically evident that at $\alpha = 0.05$ the varied spacings used for planting the trees in Chepkoilel and Nangili significantly affected the mean height of the trees at 36 months of age. It should however be noted that this effect of spacing on the mean height growth was evident only at 36 months. Preliminary analysis of data at 6, 12, 18, and 26 months old in both sites indicated that at $\alpha = 0.05$ varied stocking densities did not statistically significantly affect the mean height of the trees. For instance in Nangili at 18 months old (Table 4) spacing is seen to have no statistically significant effect on the mean height at $\alpha = 0.05$.

It suffices to note further that there being no statistically significant effect of spacing on the mean tree height does not mean that the mean tree heights at different spacing levels are the same. There may be a practical difference in the means at different spacings. For example, as shown in Table 5, a farmer in Nangili will gain approximately 0.5 m in height of trees at 18 months planted at a spacing of 1.4-by-1.0 m as compared to those planted at a spacing of 1.2-by-1.0 m.

At 36 moths old, the spacing of 2.4-by-1.0 m gave the highest mean height of 11.5 m and 13.3 m in Chepkoilel and Nangili, respectively. Trees planted at a spacing of 0.6-by-1.0 m reported the lowest mean height of 8.7 m and 10.3 m in Chepkoilel and Nangili respectively.

Table 1 Corresponding growing area and planting density to the various spacing used

Spacing (m)	Growing area per tree (m^2)	Density (Trees ha^{-1})
0.6 × 1	0.6	16,667
0.8 × 1	0.8	12,500
1.0 × 1	1.0	10,000
1.2 × 1	1.2	8,333
1.4 × 1	1.4	7,143
1.6 × 1	1.6	6,250
1.8 × 1	1.8	5,556
2.0 × 1	2.0	5,000
2.2 × 1	2.2	4,545
2.4 × 1	2.4	4,167

Table 5 Mean tree height at various spacings in Nangili at 18 months old

Spacing	*N*	Mean height (m)
1.4 × 1	29	5.7
0.6 × 1	29	5.7
2.0 × 1	26	5.6
0.8 × 1	30	5.5
2.4 × 1	30	5.5
1.0 × 1	31	5.4
2.2 × 1	24	5.4
1.6 × 1	32	5.4
1.8 × 1	31	5.3
1.2 × 1	31	5.2

Table 2 Anova for height in Chepkoilel at 36 months old

Source	DF	Sum of squares	Mean square	F-value	P>F
Genotype	3	56.0469197	18.6823066	4.76	0.003
Spacing	9	176.1292643	19.5699183	4.98	<0.001
Error	275	1079.6061420	3.9258410		
Corrected total	287	1315.3420580			

Table 3 Anova for height in Nangili at 36 months old

Source	DF	Sum of squares	Mean square	F-value	P>F
Genotype	3	282.1752159	94.0584053	12.74	<0.0001
Spacing	9	232.1191176	25.7910131	3.49	0.0004
Error	285	2103.7265070	7.3814970		
Corrected total	297	2619.2886860			

Table 4 Anova for height in Nangili at 18 months old

Source	DF	Sum of Squares	Mean Square	F Value	P>F
Genotype	3	13.13091366	4.37697122	4.68	0.0033
Spacing	9	7.30980905	0.81220101	0.87	0.5533
Error	280	261.66785270	0.93452800		
Corrected total	292	281.78743000			

Table 6 Means separation for genotype on height growth on trees in Chepkoilel at 36 months old

Genotype	Mean height (m)	Tukey grouping	
E. grandis	10.2	A	
Local	9.9	A	
GC 10	9.4	B	A
GC 167	8.9	B	

Means with the same letter are not significantly significant

Table 7 Means separation for the effect of genotype on height growth on trees in Nangili at 36 months old

Genotype	Mean height (m)	Tukey grouping	
GC 10	12.8	A	
GC 167	11.5	B	
E. grandis	10.7	C	B
Local	10.3	C	

Means with the same letter are not significantly significant

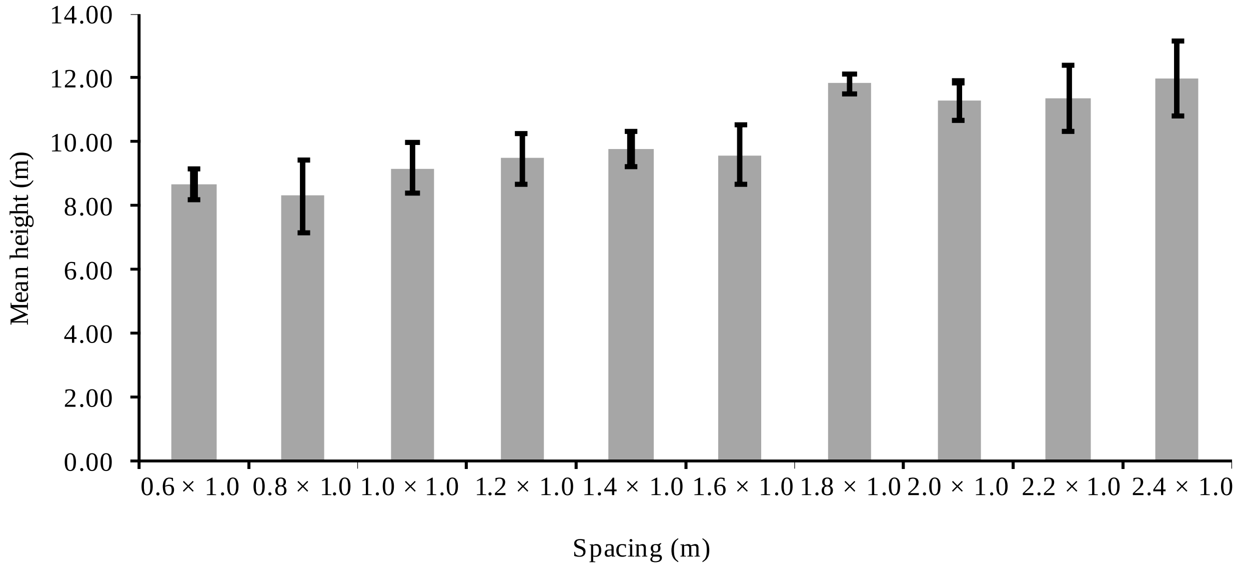

Figure 2 Mean height of *E. grandis* at different spacing in Chepkoilel at 36 months.

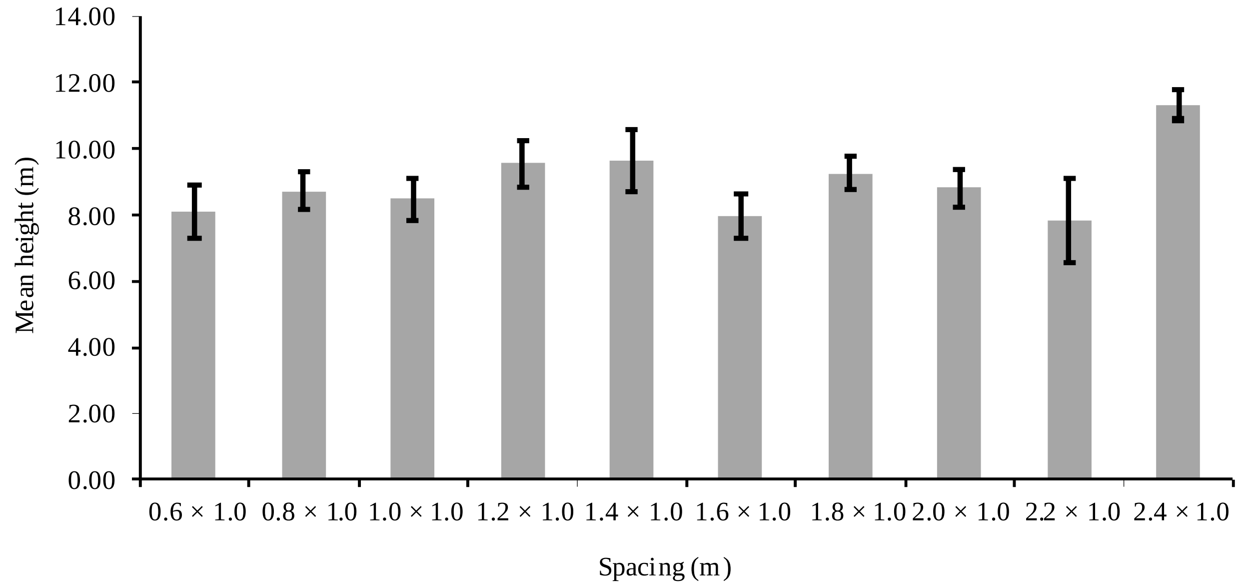

Figure 3 Mean height of GC 167 at different spacing in Chepkoilel at 36 months.

At $\alpha = 0.05$ the genotypes were significantly different in terms of height growth at 36 months old in both Chepkoilel and Nangili (Table 6 and Table 7). *Eucalyptus grandis* performed best in Chepkoilel with a tree mean height of 10.2 m and GC 167 performed the poorest with a mean tree height of 8.9 m. Even in the best and worst performing genotypes, spacing had significantly vivid effects (Figure 3 and Figure 4).

In Nangili, the genotypes at 36 months also showed statically significant effects on height growth at $\alpha = 0.05$. GC 10 performed the best with a mean tree height of 12.8 m and the local landrace performed poorest with a mean tree height of 10.3 m (Table 6 and Table 7). Spacing effects were also significant in Nangili just as in Chepkoilel (Figure 4 and Figure 5).

From Table 6 and 7 above, it is statistically evident that at $\alpha = 0.05$ the varied spacings used for planting the trees in Chepkoilel and Nangili significantly affect the mean ground line diameter of the trees at 36 months old (Table 8 and Table 9). This concurs with preliminary analysis of data at 12, 18, and 26 months old which also indicates that at $\alpha = 0.05$ varied stocking densities statistically significantly affect the mean gld of the trees in both sites. This is however different for trees in Nangili at 6 and 18 months and Chepkoilel at 6 months where spacing is seen to have no statistically significant effect on the mean gld at $\alpha = 0.05$.

At 36 months old, the spacing of 2.4-by-1.0 m gave the highest mean gld of 12 mm and 14 mm in Chepkoilel and

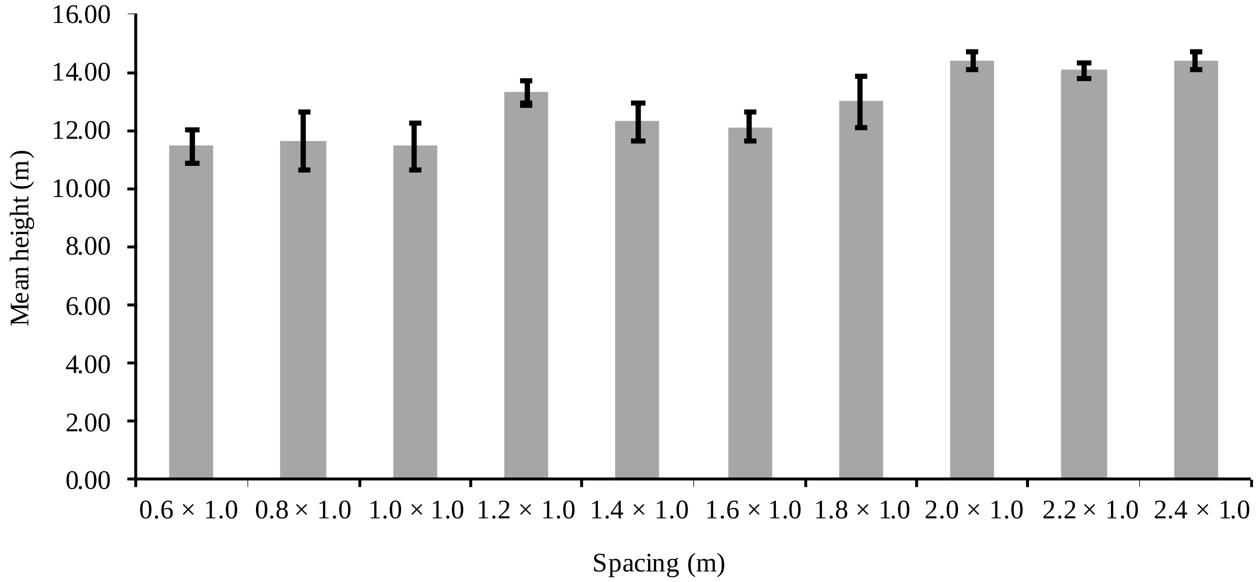

Figure 4 Mean height of GC 10 at different spacing in Nangili at 36 months.

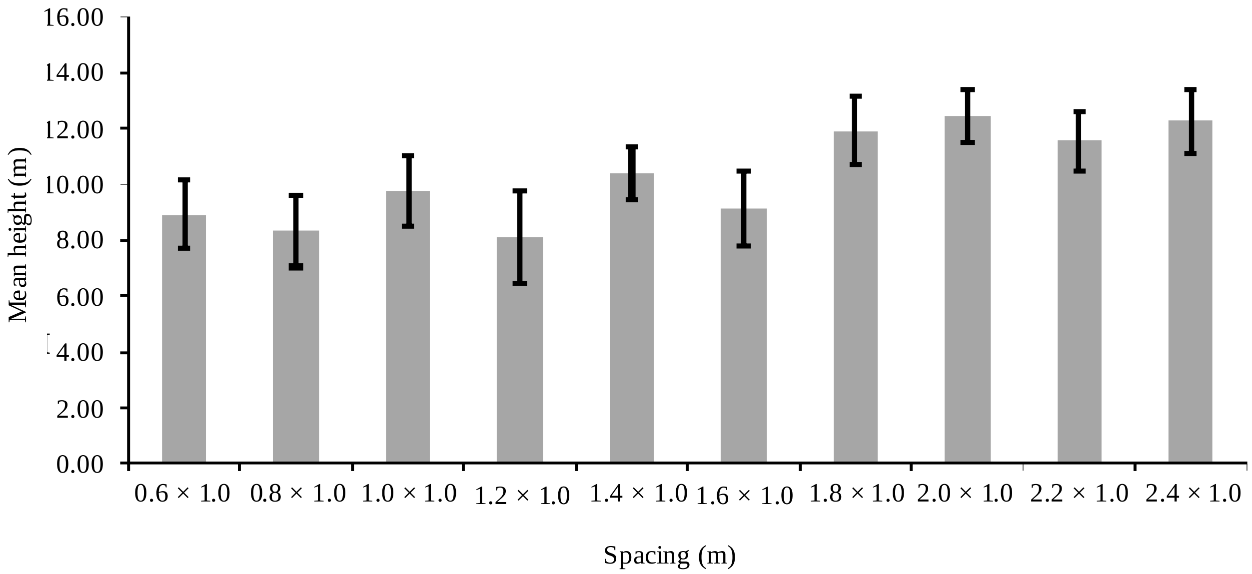

Figure 5 Mean height of the local land race at different spacing in Chepkoilel at 36 months.

Table 8 Anova for gld in Chepkoilel at 36 months old

Source	DF	Sum of squares	Mean square	F-value	P>F
Genotype	3	40.9584428	13.6528143	2.16	0.0034
Spacing	9	580.1719921	64.4635547	10.18	<0.0001
Error	275	1740.8846840	6.3304900		
Corrected total	287	2377.7421880			

Table 9 Anova for gld in Nangili at 36 months old

Source	DF	Sum of squares	Mean square	F-value	P>F
Genotype	3	216.8539193	72.2846398	7.84	<0.0001
Spacing	9	909.6941064	101.0771229	10.96	<0.0001
Error	285	2628.7681840	9.2237480		
Corrected total	297	3775.2488930			

Nangili respectively. Trees planted at a spacing of 0.1-by-1.0 m in Chepkoilel reported the lowest mean gld of 7 mm and a spacing of 0.8-by-1.0 m was gave the least gld mean in Nangili of 7 mm.

The genotypes also had significantly different mean ground line diameters ($\alpha = 0.05$) at 36 months old in both Chepkoilel and Nangili. GC 10 had the best mean ground line diameter of 9.5 mm and 10.5 mm in Chepkoilel and Nangili, respectively. The local landrace gave the least mean gld of 8 mm in Chepkoilel while in Nangili, *Eucalyptus grandis* had the least gld mean of 8 mm as well. Spacing effects on genotypes were also significant in both sites for gld (Figures 6 and Figure7).

Table 10 and Table 11 show that at $\alpha = 0.05$ the varied spacings used for planting the trees in Chepkoilel and Nangili significantly affected the mean dbh of the trees at 3 years old. This concurs with preliminary analysis of data at 6, 12, 18, and 26 months old which also indicates that at 95% confidence level, varied stocking densities statistically significantly affects the mean dbh of the trees in both sites. This however, is with an exception of trees in Chepkoilel at 12 months old and in Nangili at 18 months old where spacing is seen to have no statistically significant effect on the mean dbh at $\alpha = 0.05$.

At a planting spacing of 2.4-by-1.0 m in Chepkoilel, the trees attained the highest mean dbh of 8.9 cm.This spacing also gave the best mean dbh in Nangili of 10.5 cm. The lowest mean dbh in Chepkoilel was 5.3 cm at a spacing of 0.6-by-1.0 m. Nangili had its least mean dbh of 5.6 cm at a spacing of 0.8-by-1.0 m.

The results from the study showed further that the genotypes in Chepkoilel did not statistically differ significantly from one another at 36 months old (Table 12). However, *E. grandis* had the highest mean dbh of 6.8 cm and GC 167 was had the least mean dbh of 6.0 cm. In Nangili, the genotypes showed significant differences in mean dbh at 36 months old (Table 13) with GC 10 having the highest mean dbh of 7.9 cm

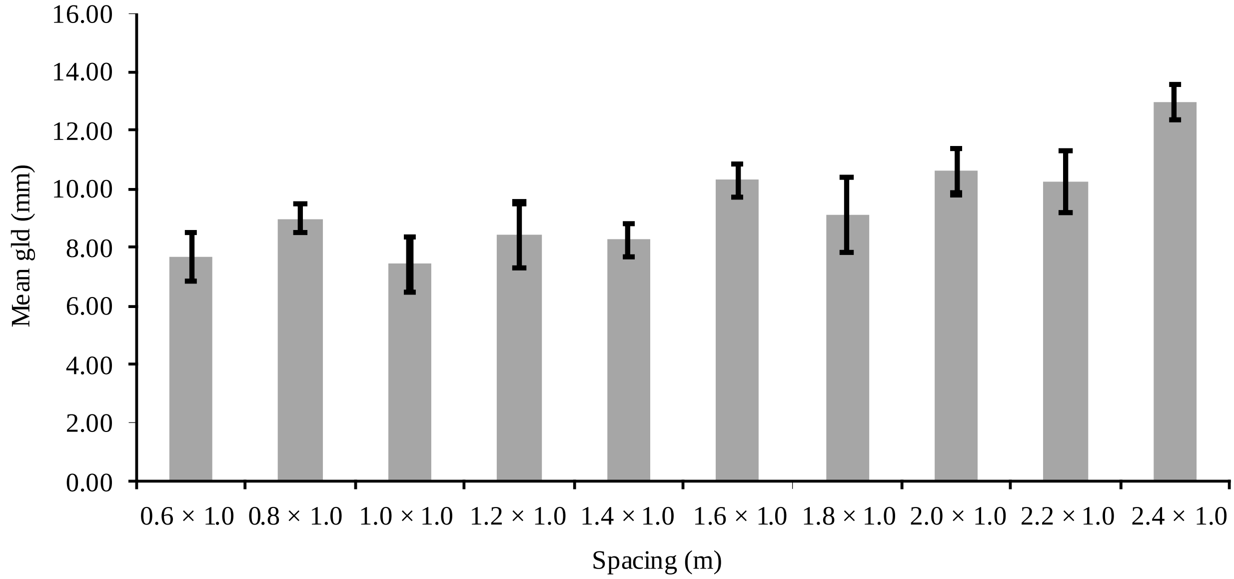

Figure 6 Mean gld of GC 10 at different spacing in Chepkoilel at 36 months.

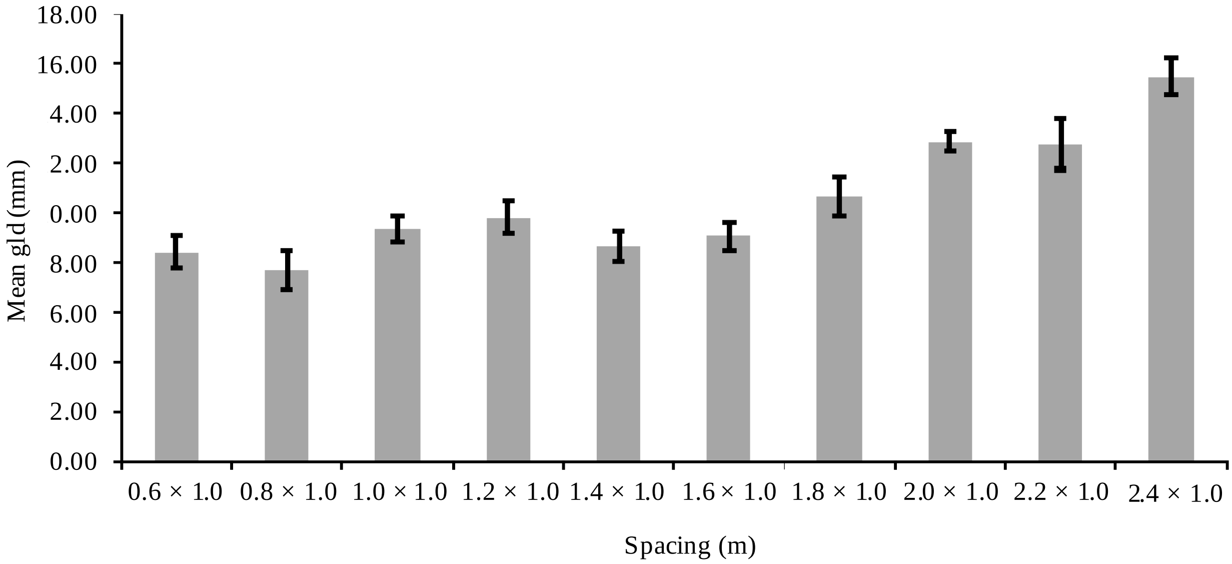

Figure 7 Mean gld of GC 10 at different spacing in Nangili at 36 months.

Table 10 Anova for dbh in Chepkoilel at 36 months

Source	DF	Sum of squares	Mean square	F-value	P>F
Genotype	3	21.9553014	7.3184338	2.12	0.0978
Spacing	9	297.5392312	33.0599146	9.58	<0.0001
Error	275	948.9884470	3.4508670		
Corrected total	287	1276.8298610			

Table 11 Anova for dbh in Nangili at 36 months

Source	DF	Sum of squares	Mean square	F-value	P>F
Genotype	3	84.8346401	28.2782134	5.37	0.0013
Spacing	9	535.6272649	59.5141405	11.30	<0.0001
Error	284	1496.0363140	5.2677340		
Corrected total	296	2128.4372390			

Table 12 Anova table for dbh in Chepkoilel at 36 months old

Source	DF	Sum of squares	Mean square	F-value	P>F
Genotype	3	21.9553014	7.3184338	2.12	0.0978
Spacing	9	297.5392312	33.0599146	9.58	<0.0001
Error	275	948.988447	3.4508670		
Corrected total	287	1276.829861			

being statistically different from the other 4 species. *E. grandis* had the least mean dbh of 6.4 cm. However, there were statistically significant effects of spacing on dbh (Table 12 and Table 13).

Result above indicated that relative growth rates of dbh, gld, and height increased with increasing the distance between trees but decreased with age. Increasing stem diameter and height of the eucalyptus trees with increasing the distance between trees is simply a result of exploiting same available below-ground resources (water and nutrient) by less number of trees (Palik & Pregitzer 1995).

As could be expected, the trees at wider spacing had greater diameters than those of the same age at close spacing. This can be attributed to reduced competition for water and nutrients for widely spaced stems. Once site resources, particularly light and moisture, become limiting, any increase in competition will lead to a direct reduction in the size or efficiency of the individual tree canopy. As a result, the amount

Table 13 Anova table for dbh in Nangili at 36 months old

Source	DF	Sum of squares	Mean square	F-value	P >F
Genotype	3	84.8346401	28.2782134	5.37	0.0013
Spacing	9	535.6272649	59.5141405	11.30	<0.0001
Error	284	1496.0363140	5.2677340		
Corrected total	296	2128.4372390			

of sugars produced by the leaves and fed down the branches and trunk for cambium growth will be reduced. This results in reduced diameter growth. A study by Rowan *et al*. (2000) showed that increasing the spacing between trees in a young eucalypt plantation can cause a dramatic increase in the diameter increment. For instance in Nangili at 3 years, as spacing between trees increased from 2.2-by-1.0 m (4,545 stems ha^{-1}) to a spacing of 2.4-by-1.0 m (4,167 stems ha^{-1}) the mean dbh increased by as much as 2.3 cm between populations that differed by 378 stems ha^{-1}.

Therefore, to maximize diameter growth, farmers should be advised on planting spacings that will promote healthy and optimal growth. Then, when the trees grow, thinning must be done to reduce competition. Repeated thinning to avoid excessive competition while maintaining mutual shelter will allow the trees to maximise height and diameter growth. Diameter growth is important, as tree volume is a function of the square of diameter.

Overall, height increments get smaller at all spacing as age increases and probably taper off in wider spacing as trees reach a maximum height of 13–15 m. Spacing had little/ delayed effect on height growth as compared to its effect on the diameter. This concurs with a study by Chaudhry and Ghauri (1995) that indicated a similar response to spacing variations in *Eucalyptus camaldulensis*. Where statistical comparison of means showed no significant effect of spacing on mean tree height growth ($\alpha = 0.05$). For instance in this study, the mean height of trees in Chepkoilel after 26 months for the 2.4-by-1.0 m spacing was 5.51 m vs. 5.73 m and 5.23 m for the 1.4-by-1.0 m and 1.2-by-1.0 m spacing. Similar patterns were reported for all other spacing levels in Chepkoilel at 6 and 12 months. This trend is similar in Nangili with an exception of trees at 3 years old. At 3 years old, the mean tree height of trees in both sites showed a statistically significant response to spacing levels ($\alpha = 0.05$).

This delayed effect of tree planting density on the tree heights has been attributed to competition for water and nutrients by the trees. Other studies have also shown that competition affects diameter growth more than it does height growth (Balozi 2000). For a farmer, planting trees at very close spacing levels, will certainly reduce the result yield due to high competition. In addition to this, trees planted at high densities will take longer to mature for harvesting thus subjecting the farmer to a higher risk on investment due to the price factor. The high competition can also make the trees more susceptible to diseases and pests.

Conclusions

Considering all the 3 years of growth, *Eucalyptus grandis-camaldulensis* (GC 10) was the best overall performer in Chepkoilel and Nangili closely followed by GC 167. The local landrace gave the overall worst performance in both sites. The spacing of 2.4-by-1.0 m gave the best results in terms of overall tree growth. Further, 1.2-by-1.0 m spacing gave promising growth and farmers wishing to have more stems per ha but of reduced girth can adopt this spacing. The spacing of 0.6-by-1.0 m gave the worst overall tree growth.

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