JMHT Vol. XVI, (1): 1–9, April 2010 Artikel Ilmiah
ISSN: 2087-0469

Five Year Growth and Survival of Eucalyptus Hybrid Clones in Coastal Kenya

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Abstract

Twelve eucalyptus hybrid clones (6 grandis-camaldulensis i.e. GC and 3 grandis-urophylla i.e. GU hybrids) and 3 local landraces (E. camaldulensis, E. tereticornis, and E. urophylla) were established in Gede, Sokoke, and Msambweni in the Coast Province of Kenya in 2002, to compare growth, survival, and adaptability in the 3 sites. By the end of the 1st year, trees in Sokoke were more than 3 times the mean height of those in Gede and Msambweni. However, these growth advantages during the 1st year in Sokoke were not maintained and by year 2 Gede had caught up, although Msambweni still lagged behind. By age 5 there were significant growth differences between clones. Of the tree sites, Msambweni had the lowest tree growth. GC167, GC14, GC581, and GC584 proved themselves as the better clones, while E. camaldulensis and E. urophylla were the better local land races. Overall, the "local land races" performed poorly in all sites. Survivals were over 80% in all sites for the best performing clones. However, in Sokoke, 1 clone died (GU7) while another (GU8) had a survival of less than 20%, while EC and ET had survivals less than 35%. GC796 died in Msambweni and had 8% survival at Gede. The poor survivals in Sokoke may have been due to a severe drought in the 3rd year. The initial outstanding growth performance in Sokoke may have been due to the fact that Sokoke was a 'virgin' forest site and presumably more fertile than the other two sites. These results show that recommendations on outstanding clones or new germplasm for planting or sale to farmers are best done at the end of the rotation for a particular intended product or use.

Keywords: eucalyptus hybrid clones, growth, site variation, weeding, germplasm selection

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Introduction

Eucalyptus species is one of the tree species that has invoked a lot of debate, especially regarding its suitability for planting in many sites. It is alleged to deplete underground water resources and to show allelopathic effects when grown with other crops; allegations which are contested in some professional cycles (Mbinga 2009). All this notwithstanding, some *Eucalyptus* species have shown very attractive characteristics to tree growers, for example fast growth and bole straightness which means farmers can get firewood, charcoal and poles fairly quickly. Some *Eucalyptus* can grow even in sites considered too dry for many other tree species.

In Kenya, the interest by farmers to grow *Eucalyptus* on short rotation was amplified by the demand for the species, especially in the Western region of the country for curing tobacco. Consequently, tobacco out grower farmers established *Eucalyptus* woodlots for their own use in curing tobacco, building poles and fuelwood (Otuoma and Muchiri 2006). The introduction of *Eucalyptus* hybrid clones by Mondi (a South African company) into the country in early 2000 and the frequent press articles regarding this "wonder fast growing tree from South Africa" increased the demand for the species by small and medium scale farmers many fold. The demand for the clones increased tremendously in the recent past due to perceived market for transmission poles. In the Coast Province alone, it is estimated that over 400,000 seedlings of various clones may have been planted by farmers between 2002 to date. There is little doubt that *Eucalyptus* species is currently one of the species of choice by many farmers in the country.

The main reasons for planting clones in forestry are their perceived fast growth, size uniformity and especially their superior characteristics for the intended use (e.g. fibre strength, pulp quality) as well as cost effectiveness (Libby & Rauter 1984; Ahuja & Libby 1993; Shelbourne *et al*. 1997). While clones have also been regarded as risky venture incase of disease and pest attack, they are generally thought to be less susceptible to diseases arising from inbreeding (Shelbourne *et al*. 1997). Meanwhile they also have a shorter selection time for good performers (Shelbourne *et al*. 1997) compared to classical breeding methods.

In Kenya many medium to small scale farmers have planted these clones. However, little is known about their growth rates, resistance to diseases and pests and suitability to the diverse sites they have been grown in. In this paper, we report on the 5-year growth and survival of thirteen hybrid clones and 3 “local land races” planted in Gede, Sokoke, and Msambweni in the Coastal region of Kenya. We also make recommendations on the better clones which farmers in the region can grow for firewood, charcoal, and poles on 5-year-rotations.

Method

Twelve hybrid clones and 3 land races (Table 1) were introduced from South Africa by Mondi (a forestry company in South Africa). The clones were raised at the Tree Biotechnology Project (TBP) in Karura Nairobi until they were of plantable size. They were then transported by lorry to the Coast (Gede, Sokoke, and Msambweni) during the start of the long rains of 2002 for planting. The 3 planting sites are found in the Coast Province of Kenya; Gede and Sokoke in the North Coast and Msambweni in the South Coast.

The experiments were established in Gede and Sokoke in the North Coast and Msambweni in the South Coast (more information summarized in Table 2). The Gede site was fallow following a maize crop the previous year. The site had had *Casuarina equisetifolia* which had been harvested about 2 years before planting the clones. Site preparation involved clearing overgrown bushes and grass before pitting and planting. Sokoke site was a ‘virgin’ forest with *Cynometra webberi*, which was cleared and the debris burnt before planting while Msambweni site was under grass before planting. The grass was slashed, heaped, and burnt before pitting.

The experimental design was ‘Randomized Complete Block Design’ (RCBD) in all sites but with varying number of replications; 3 in Gede, 2 in Sokoke, and 4 in Msambweni. Each plot comprised of 16 trees spaced at 2.5 ´ 2.5 m, in a 4 ´ 4 arrangement.

The experiments were established by Tree Biotechnology staff in collaboration with the Forest

Table 1 List of hybrid clones and local land races used in the experiments

	Names	Remarks
Hybrid clones	GCs = 14, 167, 514, 540, 581, 584, 784, 785, 796	GC = *grandis-camaldulensis* hybrid
	GUs = 7, 8, 21	GU = *grandis-urophylla* hybrid
Local land races	EC, ET, EU	Local land races = *E. camaldulensis, E. tereticornis and E. urophylla*

Table 2 Location, rainfall, temperatures, altitude, and soils of the sites

Site	Geo-references	Mean rainfall	Mean temperatures	Altitude	Soils
Gede	3°12'S and 40°02'E	940 mm	32 °C	13 m	Orthic feralsols, sandy to sandy-clay-loams, well drained deep and very friable.
Sokoke	3°194'S and 39°52'E	700 mm	30 °C	325 m	Acrid to Rhodic ferralsols, well drained, deep clay -clay loams, red to dusky red in colour.
Msambweni	4°28'N and 39°29'E	1,200 mm	32 °C	10 m	Lithosols with ferralic combisols, lithic phase. Dark reddish brown sandy clay loams, well drained but shallow in some areas.

ISSN: 2087-0469

Department (now Kenya Forest Service) but were handed over to KEFRI for management and assessment in November 2002 when the trials were 6 old. After site preparation, all the sites were planted between May 28th and 1st June 2002. The plots were fenced following planting to keep off small game and other intruders. Huge signs were posted showing the design and clones used in the trials. Hydrogel was added (2 table spoons) at the base of the planting holes to increase water retention in the root zone. A termitecide was also added to wad off vermin. Weeding was done whenever grass threatened to overtop the planted seedlings.

Tree height size (ht) in metres (m) and survival counts were assessed 6 months after planting and annually thereafter, while diameter at breast height (dbh) in centimeters (cm) was assessed from year 2 onwards. The data were keyed into Microsoft Excel. Analysis of variance (ANOVA) tests were done for each site to identify any significant tree size differences (ht and dbh at $p < 0.05$) among clones and/or blocking effects using PROC GLM in SAS. Where overall model was significant, tests for significance between treatments were carried out using the type III SS (sum of squares). Separation of means using the Waller-Duncan K-ratio *t*-Test procedure in SAS was thereafter carried to identify which clones differed significantly ($p < 0.05$) among which ones. Standard errors of the means were also calculated.

Results and Discussion

The results from the ANOVA at age 5 years showed that tree size (ht and dbh) in all sites was significantly influenced by the genotype (hybrid clone) (Table 3 for Gede, same findings observed for Sokoke and Msambweni; results not shown).

As the overall model was significant ($p < 0.05$), tests for significant differences between treatments (clones and blocking effects) were done (results not shown) followed by means separation using the Waller-Duncan K-ratio *t*-Test (Table 4 and Table 5).

Generally, trees in Sokoke were more than twice the size of those in Gede and Msambweni in the 1st year irrespective of genotype (Figure 1).

The clones outshone the local landraces in both height and dbh growth (Table 4 and Table 5). The best land race in Gede had a mean height of 14.83 m compared to 18.88 m for GC167. In Sokoke, EC had 15.71 m to GC167's 18.1

Table 3 ANOVA results for height at age 5 years for Gede

Source	DF	Sum of squares	Mean square	*F* value	$p > F$
Model	14	3641.549793	260.11070	34.90	0.0001
Error	580	4323.155669	7.45372		
Corrected Total	594	7964.705462			

Table 4 Means separation for height for Gede, Sokoke, and Msambweni

Gede (minimum significant difference = 1.34, critical *t* = 1.7507)		Sokoke (minimum significant difference = 1.5775, critical *t* = 1.82606)		Msambweni (minimum significant difference = 0.6064, critical *t* = 1.74058)	
Clone	Means	Clone	Means	Clone	Means
GC167	18.88 *a*	GU8*	18.50 *a*	GC14	13.99 *a*
GC581	18.76 *ab*	GC167	18.09 *ab*	GC167	12.60 *b*
GC14	17.51 *bc*	GC584	17.10 *abc*	GC581	12.49 *b*
GC584	17.01 *cd*	GC514	17.10 *abc*	GC514	12.11 *b*
GC514	16.85 *cd*	GC540	16.76 *bc*	GU21	12.00 *bc*
GC540	16.24 *cde*	GC14	16.48 *cd*	GC784	11.44 *cd*
GC784	16.01 *def*	GU21	16.26 *dce*	GC540	11.34 *d*
GC796*	15.69 *def*	EC	15.71 *cdef*	GC584	11.12 *de*
GU21	15.28 *fe*	GC785	15.69 *cdef*	GC785	10.73 *e*
EC	14.83 *f*	GC581	15.00 *def*	EU	9.49 *f*
GC785	14.82 *f*	GC784	14.76 *ef*	ET	9.27 *f*
ET	12.93 *g*	GC796	14.42 *fg*	EC	9.11 *f*
GU8	12.2 *g*	EU*	13.03 *g*	GU7	7.73 *g*
EU	12.05 *g*	ET*	10.68 *h*	GU8	7.65*g*
GU7	10.34 *h*	GU7	*DIED*	GC796	*DIED*

Note: Means with the same letter are not significantly different. Clones with '*' have survival below 40%; GU7 died in Sokoke while GC796 died in Msambweni.

Table 5 Means separation for dbh for Gede, Sokoke, and Msambweni

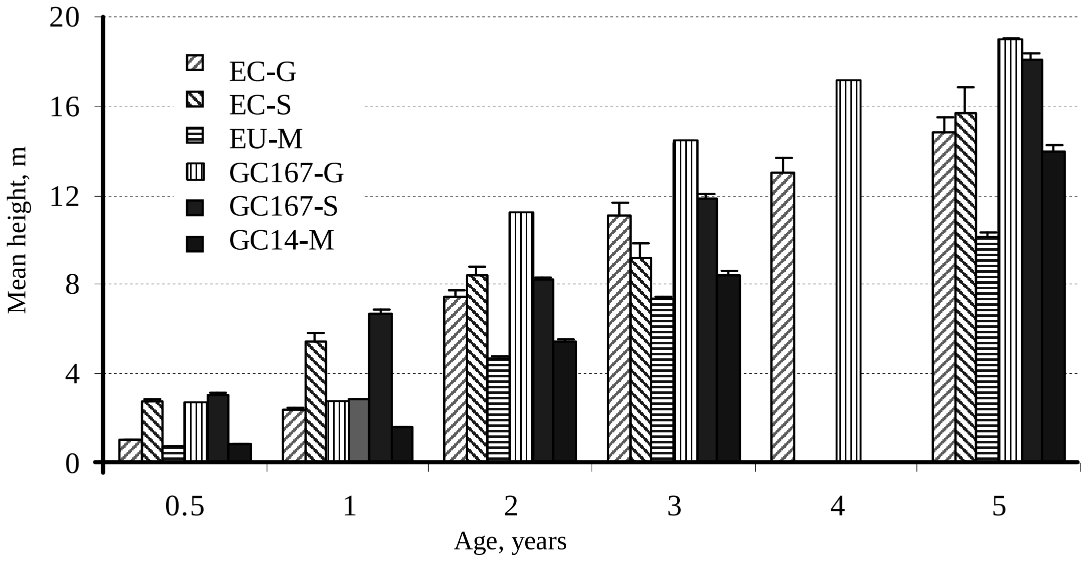
Gede		Sokoke		Msambweni	
Clone	Means	Clone	Means	Clone	Means
GC167	14.78	GU8*	14.58	GC14	11.35
GC581	13.84	GC167	12.84	GC167	10.69
GC14	12.27	GC584	13.00	GC581	12.44
GC584	13.76	GC514	11.65	GC514	10.18
GC514	11.77	GC540	12.40	GU21	12.37
GC540	11.71	GC14	11.63	GC784	10.99
GC784	12.37	GU21	12.97	GC540	9.89
GC796*	15.53	EC	11.99	GC584	10.35
GU21	12.86	GC785		GC785	
EC	11.10	GC581	13.00	EU	8.73
GC785		GC784	12.05	ET	8.15
ET	10.31	GC796	9.98	EC	7.56
GU8	9.53	EU*	11.17	GU7	5.97
EU	10.46	ET*	9.55	GU8	6.47
GU7	7.43	GU7	*DEAD*	GC796	*DIED*

Note: means with the same letter are not significantly different (other comments as in Table 4).

m, while in Msambweni EU had 9.5 m compared to GC14's 14 m (Table 4). The poor performance trend was the same for dbh (Figure 1 and Figure 2 for Gede; similar observations in other sites, results not shown).

Comparisons of the best 4 hybrid clones and the best 2 local landraces were made for all 3 sites. It was evident that trees in Msambweni performed the poorest irrespective of genotype (hybrid clones and local landraces), (Figure 3 and Figure 4). Hybrid clones in Gede performed better than their counterparts in Sokoke. However the trend was reversed for the landraces i.e. those in Sokoke did better than Gede (Figure 3 and Figure 4).

The survival of the hybrid clones and local landraces were mixed in all the 3 sites. In Gede, all treatments survived but GC796 had less than 10% survival by age 5. In Sokoke, GU8, EU, and ET had survivals of less than 40%, while GU7 perished altogether. Meanwhile in Msambweni, apart from GC796 which died, all the others had survivals of more than 50% (results not shown). However, the best performing clones in all three sites had survivals of more than 80%



(Key to Figure 1: *EC-G=EC in Gede, GC167-G =GC167 in Gede, EU-M = EU in Msambweni, GC14-M = GC14 in Msambweni, EC-S = EC in Sokoke and GC167-S = GC167 in Sokoke*).

Figure 1 Best performing hybrid clones and land races in all three sites.

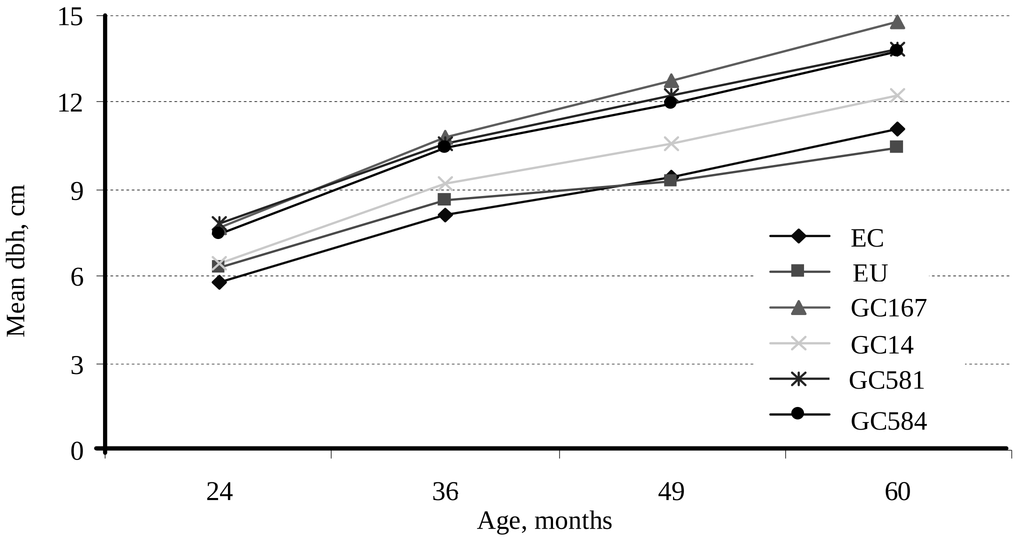


Figure 2 Mean dbh of 4 best clones and 2 best landraces in the 3 sites.

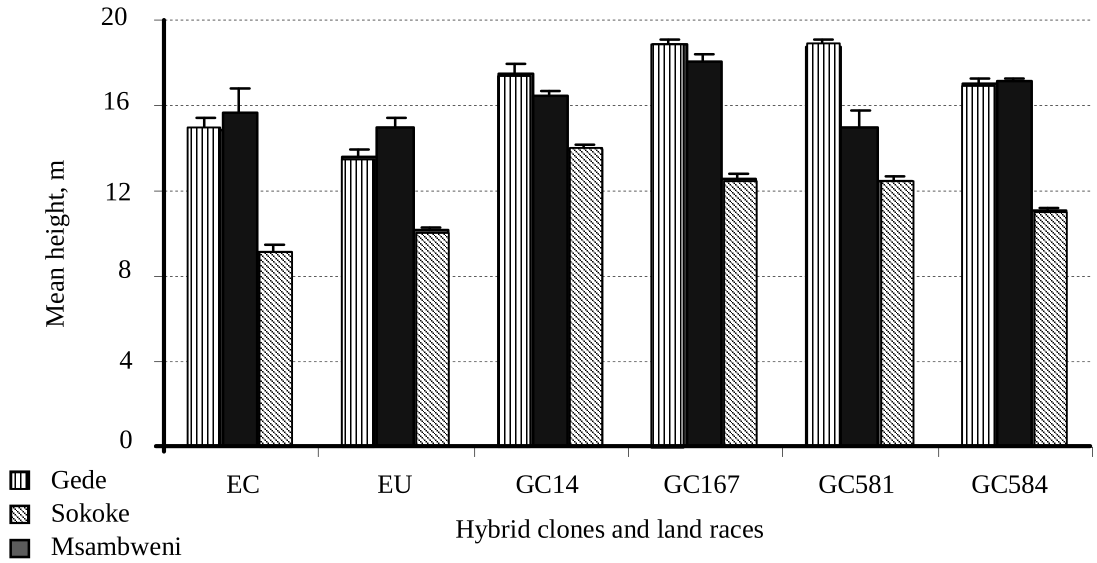


Figure 3 Fifth year mean height of 4 best clones and 2 best landraces in the 3 sites.

(Figure 5). In Sokoke, EC had the poorest survival of the landraces at 21%.

Tree growth is mainly influenced by 3 factors; genotype, environment, and management. In the trial reported in this paper, the hybrid clones outperformed the local land races (*E. tereticornis*, *E. Urophyla*, and *E. camaldulensis*) showing that they were of higher quality genetic material than the unhybridized local landraces. Growth also varied depending on the site, for example Msambweni performed poorly compared to the other 2 sites, i.e. Sokoke and Gede (Figure 3 and Figure 4); showing the influence of environment on tree growth.

The initial high growth in Sokoke which was not sustained (Figure 1 age 0.5–1) may have been due to the fact that Sokoke was a 'virgin' site and possibly more fertile, initially, than Gede or Msambweni. However, this is a conjecture as no site quality assessments were done at the start of the experiment. The reduction in growth rate of trees in Sokoke after year 1 (Figure 1) is an example of a type I response, where initial high growth rates are not sustained over a long period of time (Snowdon and Khana 1989) but 'flatten' after a period of time unless new applications of the treatment are applied (for example fertilizer). Such effects arise, for example, following fertilization or weed control (Mason *et al*. 1997; Snowdon & Khana 1989). This is in agreement with our supposition that the fast growth at Sokoke, may have been due to its 'new' nature and thus may have been more fertile than the other two sites i.e. Gede

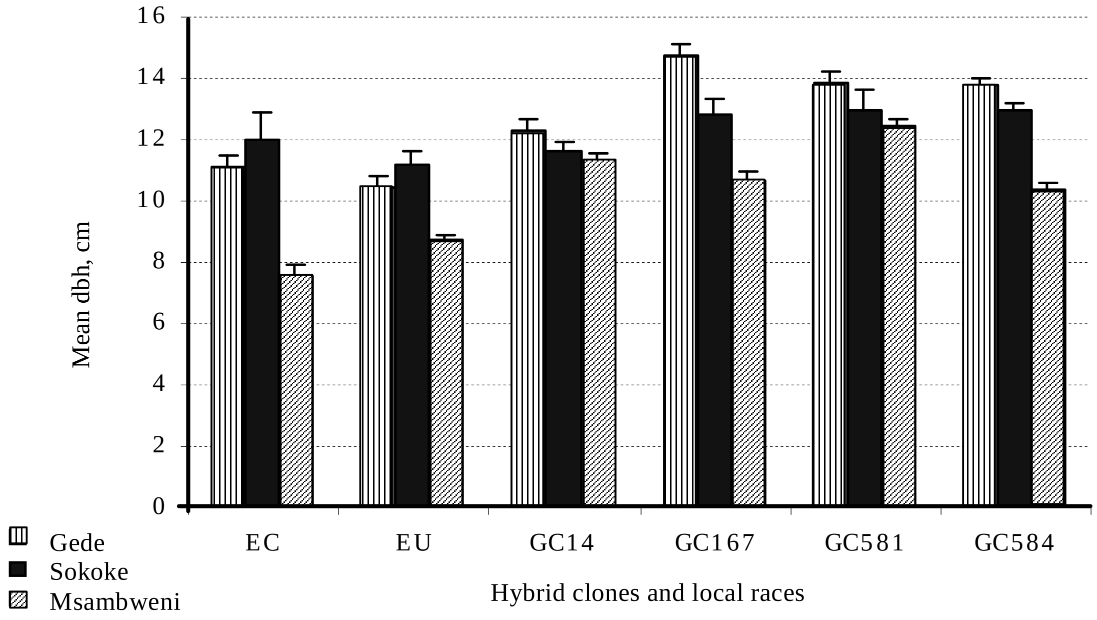


Figure 4 Fifth year Mean dbh of 4 best clones and 2 best landraces in the 3 sites.

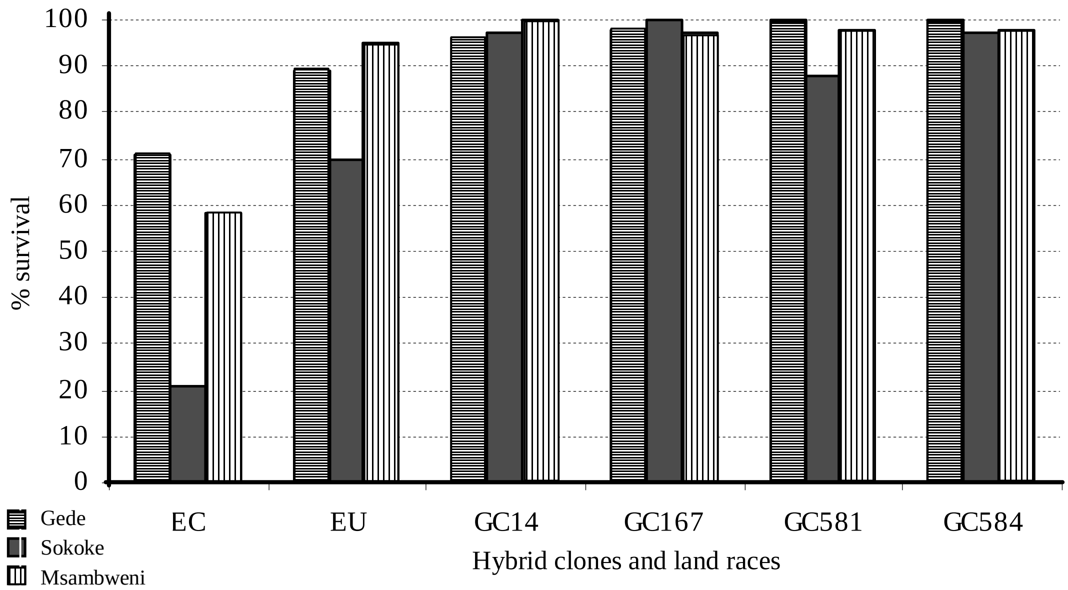


Figure 5 Fifth year survival percent at age 5 of the 4 best clones and 2 best landraces in the 3 sites.

and Msambweni. This brings to point the possibility of using fertilization in intensive short rotation afforestation programmes to support high tree growth. In a study on the effects of fertilization on canopy closure, Lance (2000) found N fertilization to significantly increase diameter growth in *E. grandis* in 1-year-old samplings. Adams *et al.* (1998) report young *E. globulus* trees to respond positively to fertilization and irrigation but only in the absence of weeds. The implication being that weeding is an important prerequisite and may actually override other treatments in terms of promoting favorable tree growth (Richardson 1993; Kirongo 1996a).

The *initial* lack of proper weeding (Kimani GK, pers comm.) may have had significant deleterious effects, as has been reported by many researchers elsewhere (e.g. Mason 1992; Richardson 1993; Kirongo 1996a,b; Adams *et al.*

ISSN: 2087-0469

1998, Kirongo *et al*. 2002b). The reduced growth in the 1st year in Gede and Msambweni is a clear case in point, as these sites were previously cultivated and weeding was not consistently undertaken in the first 6 months after field planting (Kimani GK, pers comm.). It can be assumed that as Sokoke was a virgin forest site, it did not have many agricultural weeds, which tend to be very aggressive competitors for water and nutrients (Nambiar & Sands 1993; Nambiar & Zed 1990; Sands & Nambiar 1984). Limited studies on soil nutrient status in Gede (Machua and Lelon 2004) showed that most sites had very poor levels of Nitrogen and phosphorus to support lavish tree growth. In such sites, it can be expected that weed competition would exacerbate the negative effects on tree growth. Forest managers and other tree growers therefore need to weed properly and on time, before weeds overtop young trees. Kirongo *et al*. (2002a) reports that by the time weeds have formed a dense cover or are taller than the crop trees, the crop trees may have already suffered significant leaf area reduction thus lowering their photosynthetic capacity to very low levels (Kirongo & Mason 2003) which may be unable to support adequate luxuriant growth should conditions become favourable (e.g. following release from competition; Kirongo 2000).

The varied growth trends in the different sites showed a strong environment-by-clone interaction, an observation supported by Wamalwa *et al*. (2007). Thus foresters need to be carefully site-match clones they sell to farmers. The results in Msambweni and Gede have in particular very strong relevance given that both sites were under fallow or grass; conditions which are common in many farmers' shambas in the coast.

The death of some clones and/or very low survivals reported in some of the sites (Table 4 and Figure 5) as well as the general growth reduction in Sokoke (compared to Gede, for example-Figure 1) for all clones by year 2 may have been due to the long drought of 2004, which may have affected potential growth in all sites. But this may also have been due to clones being 'unfit' to adapt to the new sites. The study has shown clearly that recommendations of clones (or any new germplasm introduced to a site) need to be done at the end of the rotation for a particular product/use. Foresters and managers therefore, need to advise farmers accordingly using information from research to avoid future losses from failures of planted clones. It is for this reason that more observations and data gathering need to continue.

The potential of hybrid clones to outperform local *Eucalyptus* species was clearly shown in this study. However, the trial results for the local *Eucalyptus* species in this trial (i.e. *E. camaldulensis, E. tereticornis* and *E. urophylla*) were much poorer especially for *E. urophylla* than experienced at Gede (Gede 1986). For example, in a provenance trial of *E. urophyla*, the mean height at age 4.5 years was 18.4 m with a range of 16.7–20.4 m (Gede 1986). The results in this trial (Table 4) show *E. urophylla* to have attained mean heights of 12.05 m (Gede), 9.49 (Msambweni), and 13.03 m (Sokoke) by age 5 years. However, there is little doubt that the clones showed outstanding growth in both height and dbh. Clones have however, certain risks especially the possibility to be wiped out in a short time if attacked by 'new' pests or diseases. This is due to their genetic uniformity. In fact there are concerns regarding the Blue Gum Chalcid (BGC) which has already infested some regions of the country (Mutitu 2003, Otuoma & Muchiri 2006) and neighbouring Uganda (Mutitu *et al*. 2006). While studies on the control of BGC are on going, it is a threat that should not be taken lightly.

While some clones performed very well in the first 2 years after out planting, these effects were short lived and other clones "caught up". This may indicate that there were some reasonable 'planting shock' effects which may have affected initial tree performance. Transplant shock can be exacerbated by transportation, poor site preparation and poor handling methods (Mason 1992). In our local situation we believe that site preparation and handling methods plus planting quality may have contributed significantly to transplant shock. Moreover, the long haulage of the seedlings from Nairobi to Malindi (600 Km in a lorry) may be a contributing factor.

Based on the overall performance over the first 5 years, 3 clones can be recommended for planting in the three sites viz. Gede: GC167, GC581, and GC584; Sokoke: GC167, GC584, and GC514; Msambweni: GC14, GC167, and GC581.

Based on the overall performance over the first 5 years, 3 clones can be recommended for planting in the three sites viz. Gede: GC167, GC581, and GC584; Sokoke: GC167, GC584, and GC514; Msambweni: GC14, GC167, and GC581.

The recommended clones had highest absolute height or dbh growth or both and survivals of over 80% by age 5 years. In cases where a recommended clone had better absolute growth in one variable only (but not both) it was ensured that the growth differences between the recommended and the one left were not significant. These clones are recommended for products attainable by age 5 years e.g. charcoal, firewood, building poles, and telegraphic poles.

Conclusion

1 There were significant height and dbh growth differences among hybrid clones.
2 Local land races traditionally grown in the Coast (*E. tereticornis*, *E. europhylla* and *E. camaldulensis*) performed poorly compared to the hybrid clones.
3 Msambweni had lowest growth compared to the other sites, viz. Gede and Sokoke, an indication of real site-by-clone interactions. Farmers therefore, need to be very careful in choosing the appropriate clones for their localities.

ISSN: 2087-0469

4 While some clones performed very well in the first 2 years after out planting, these effects were short lived (and other clones "caught up"). This implies that choice of clones for planting in various regions should not be based solely on early (first 1–2 years) performance as the growth rates may not be sustained throughout the rotation length.
5 The following 3 clones are recommended for each site based on the first 5 years' growth data from the trials (Gede: GC167, GC581, and GC584; Sokoke: GC167, GC584, and GC514; and Msambweni: GC14, GC167, and GC581). However, this information should be augmented by data on insects/pests resistance.
6 While the clones have shown favorable growth in all the 3 sites, we recommend that more observations and data collection be continued till rotation ages for the various envisaged products. This is because clones have a high risk factor to attacks by unfavorable environmental effects (weather and pests) than non-clones.

Acknowledgements

The authors wish to thank all staff members at KEFRI Gede Regional Research Centre, especially the enumerators for gathering the data. We acknowledge support from the Centre Scientists and Foresters who have continued to supervise work on the clones in the midst of many challenges, especially Mr. Simon Wairungu and Mr. Martin Welimo. We extend our thanks to KFS (then Forest Department), Tree Biotechnology Project of Karura, and Mondi of South Africa for the collaboration. We thank the KEFRI Directorate for providing logistical support.

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