



FIVE YEAR GROWTH AND SURVIVAL OF *EUCALYPTUS* HYBRID CLONES IN COASTAL KENYA

Balozi, B. K.^{*1}, Kimani, G.K.², Muchiri, M.² and Kingiri, S.³

^{*1}Corresponding Author; PhD, Lecturer Department of Forestry and Wood Science, Moi University, Chepkoilel Campus, P.O. Box 1125, Eldoret Kenya.

²Kenya Forestry Research Institute, P. O. Box 20214, Nairobi

³PhD; Associate Professor, Department of Forestry and Wood Science, Moi University, Chepkoilel Campus, Box 1125, Eldoret Kenya

Address for correspondence: balozibk@hotmail.com

ABSTRACT

Twelve *Eucalyptus* hybrid clones (6 *grandis-camaldulensis* i.e. GC and 3 *grandis-urophylla* i.e. GU hybrids) and three 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 three sites.

By the end of the first year, trees in Sokoke were more than three times the mean height of those in Gede and Msambweni. However, these growth advantages during the first 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, one 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 third 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.

Key words: *Eucalyptus hybrid* clones, growth, site variation, weeding, germplasm selection

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 estimate 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 and Rauter 1984; Ahuja and 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 five-year growth and survival of thirteen hybrid clones and three “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 five-year-rotations.

MATERIALS AND METHOD

Materials

Twelve hybrid clones and three 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 three planting sites are found in the Coast province of Kenya; Gede and Sokoke in the North Coast and Msambweni in the South Coast.

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

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



Site description

The experiments were established in Gede and Sokoke in the north Coast and Msambweni in the South Coast (more information summarized in the 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.

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 ferralsols, sandy to sandy-clay-loams, well drained deep and very friable.
SOKOKE	10° 59'E and 96° 14'N	700 mm	30°C	325 m	Acrid to Rhodic ferralsols, well drained, deep clay – clay loams, red to dusky red in colour
MSAMBWENI	59 E and 95N	1200 mm	32°C	10 m	Lithosols with ferralic combisols, lithic phase. Dark reddish brown sandy clay loams, well drained but shallow in some areas.

Experimental Design and layout

The Experimental design was 'Randomized Complete Block Design' (RCBD) in all three 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 x 2.5 m, in a 4 x 4 arrangement.

Planting and Management of trials

The experiments were established by Tree Biotechnology staff in collaboration with the Forest 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 within a range of four days at the end of May – beginning of June 2002 (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 termiticide was also added to wad off vermin.



Weeding was done whenever grass threatened to overtop the planted seedlings.

Data collection and analyses

Tree height size (ht) in metres (m) and survival counts were assessed 6 months after planting and annually thereafter, while dbh (diameter at breast height) in centimeters (cm) was assessed from year 2 onwards. The data were keyed into Microsoft Excel (Microsoft office 2000). 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 (SAS 2000). 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

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

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	7.453717		
Corrected	594	7964.705462			
Total					

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 5).

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 <i>a</i>	GU8*	18.50 <i>a</i>	GC14	13.99 <i>a</i>
GC581	18.76 <i>ab</i>	GC167	18.09 <i>ab</i>	GC167	12.60 <i>b</i>
GC14	17.51 <i>bc</i>	GC584	17.10 <i>abc</i>	GC581	12.49 <i>b</i>
GC584	17.01 <i>cd</i>	GC514	17.10 <i>abc</i>	GC514	12.11 <i>b</i>
GC514	16.85 <i>cd</i>	GC540	16.76 <i>bc</i>	GU21	12.00 <i>bc</i>
GC540	16.24 <i>cde</i>	GC14	16.48 <i>cd</i>	GC784	11.44 <i>cd</i>
GC784	16.01 <i>def</i>	GU21	16.26 <i>dce</i>	GC540	11.34 <i>d</i>
GC796*	15.69 <i>def</i>	EC	15.71 <i>cdef</i>	GC584	11.12 <i>de</i>
GU21	15.28 <i>fe</i>	GC785	15.69 <i>cdef</i>	GC785	10.73 <i>e</i>
EC	14.83 <i>f</i>	GC581	15.00 <i>def</i>	EU	9.49 <i>f</i>
GC785	14.82 <i>f</i>	GC784	14.76 <i>ef</i>	ET	9.27 <i>f</i>
ET	12.93 <i>g</i>	GC796	14.42 <i>fg</i>	EC	9.11 <i>f</i>
GU8	12.2 <i>g</i>	EU*	13.03 <i>g</i>	GU7	7.73 <i>g</i>
EU	12.05 <i>g</i>	ET*	10.68 <i>h</i>	GU8	7.65 <i>g</i>
GU7	10.34 <i>h</i>	GU7	<i>DIED</i>	GC796	<i>DIED</i>

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	<i>DEAD</i>	GC796	<i>DIED</i>

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

Generally, trees in Sokoke were more than twice the size of those in Gede and

Msambweni in the first year irrespective of genotype (Figure 1).

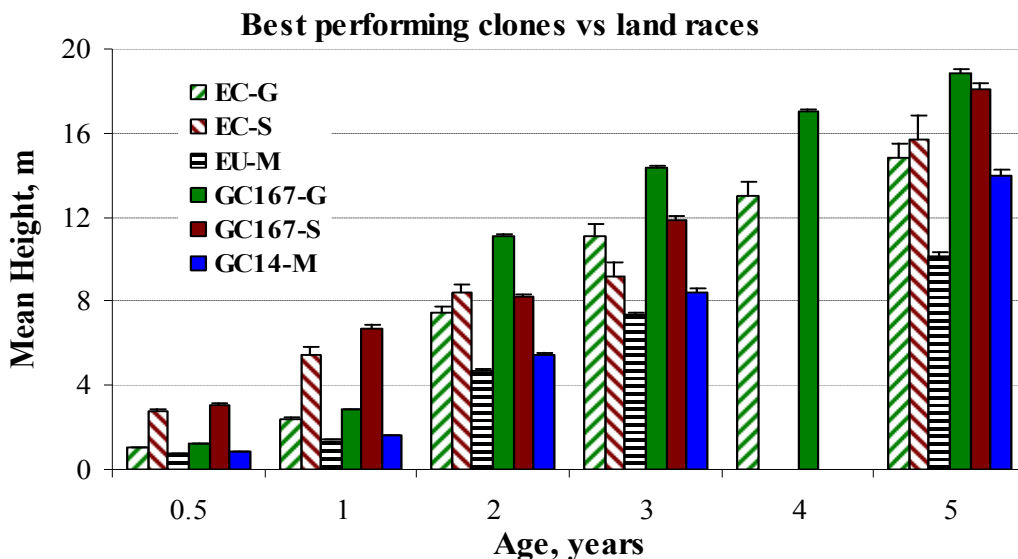


Figure 1: Best performing hybrid clones and land races in all three sites

(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).

The clones outperformed the local landraces in both height and dbh growth (Table 4 and 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

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).

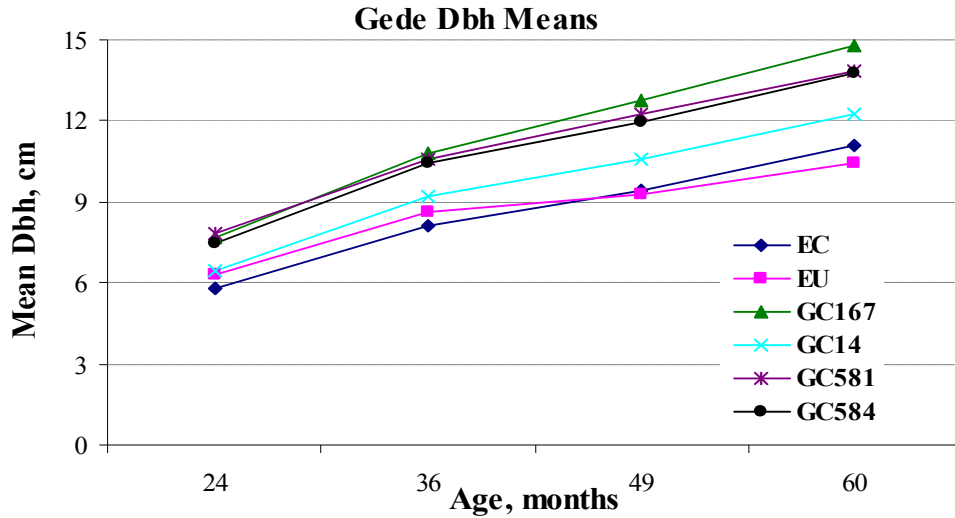


Figure 2: Mean dbh of four best clones and two best landraces in the three sites

Comparisons of the best four hybrid clones and the best two 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), (Figures 3 and 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 (Figures 3 and 4).

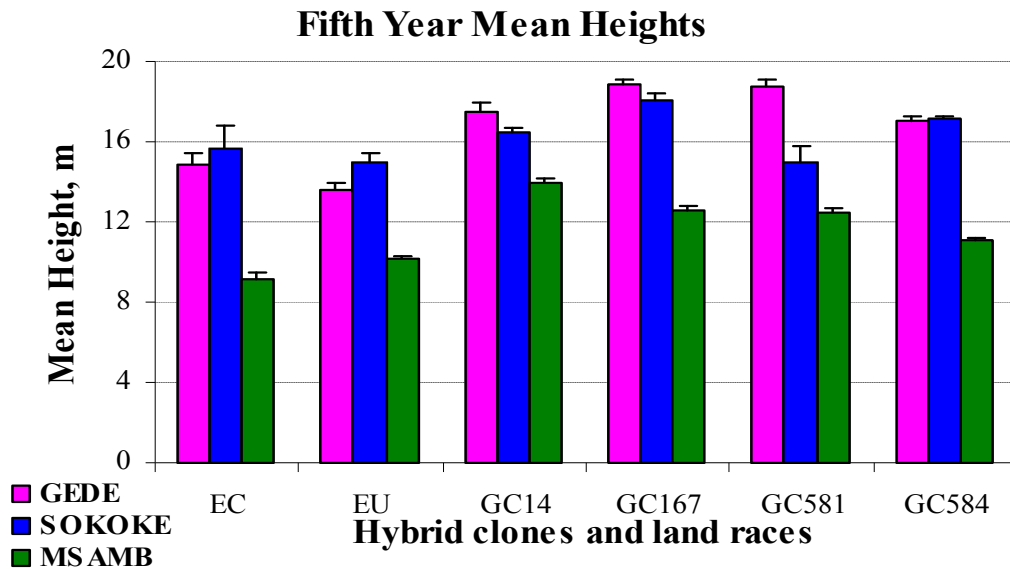


Figure 3: Fifth year mean height of four best clones and two best landraces in the three sites

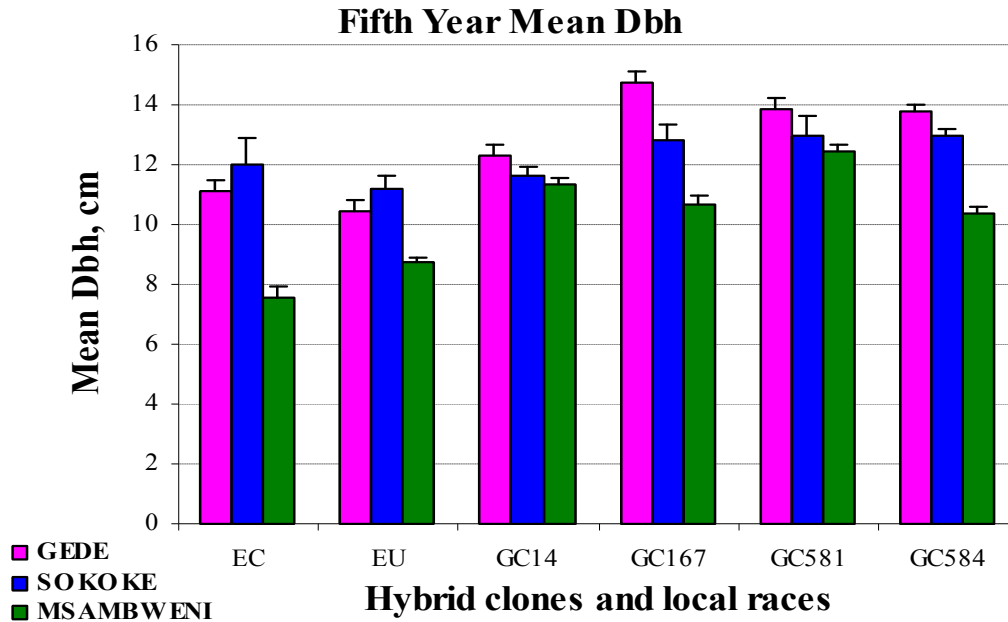


Figure 4: Fifth year Mean dbh of four best clones and two best landraces in the three sites

The survival of the hybrid clones and local landraces were mixed in all the three 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% (Figure 5). In Sokoke, EC had the poorest survival of the landraces at 21%.

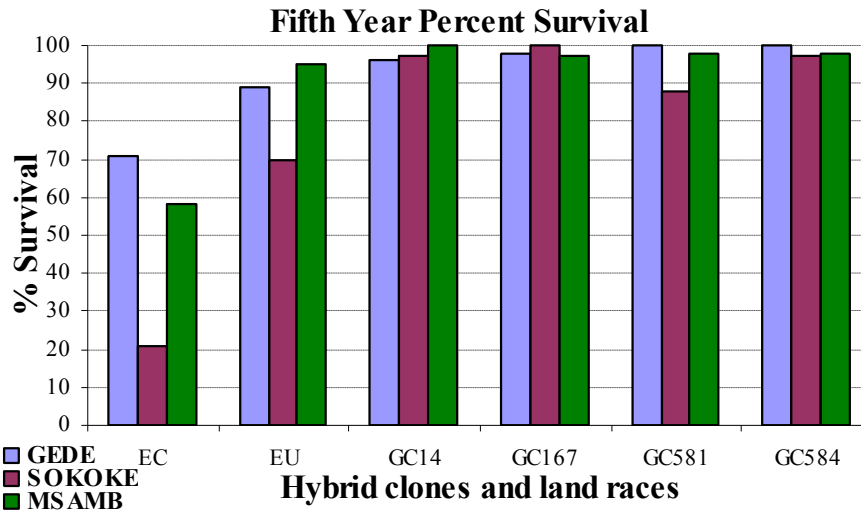


Figure 5: Fifth Year Survival percent at age 5 of the four best clones and two best landraces in the three sites



DISCUSSION

Tree growth is mainly influenced by three factors; genotype, environment and management. In the trial reported in this paper, the hybrid clones outperformed the local land races (*E. tereticornis*, *E. urophylla* 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 two sites, i.e. Sokoke and Gede (Figure 3 and 4); showing the influence of environment on tree growth.

The initial high growth in Sokoke which was not sustained (Figure 1 age 0.5 to age 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 and 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 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 saplings. 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 favourable tree growth (Richardson 1993; Kirongo 1996a).

The initial lack of proper weeding (Kimani G. K. 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.* 1998; Kirongo *et al.* 2002b). The reduced growth in the first 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 G. K. 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 and Sands 1993; Nambiar and Zed 1990; Sands and 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 and 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. urophylla*, 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 (Tables 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 and 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 two (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.

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

There were significant height and dbh growth differences among hybrid clones.

Local land races traditionally grown in the Coast (*E. tereticornis*, *E. europphylla* and *E. camaldulensis*) performed poorly compared to the hybrid clones. Msambweni had lowest growth compared to the other two 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. While some clones performed very well in the first two (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. 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. While the clones have shown favourable 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 unfavourable 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.

REFERENCES

- Adams, P.R., Smethhurst, P.J., Beadle, C.L. and Mendham, N.J., 1998. Mechanisms of grass competition in a young *Eucalyptus globules* plantation. IN: Wagner, R. G. and Thompson, D. G. (Eds.). Third International Conference on Forest Vegetation Management: Popular Summaries. Ontario Forest Research Institute, Canada. Pp. 35-37.
- Ahuja, M.R. and Libby, W.J., 1993. Clonal forestry II: Conservation and application. Springer verlag. Pp. 240.
- Balozi, B.K., 1996a. Effects of non-crop vegetation on growth and productivity of young radiata pine. MSc. Thesis, University of Canterbury, Christchurch, New Zealand. pp. 152.
- Balozi, B.K., 1996b. Successful plantation establishment: need for effective and timely weed control. IN: The state of forest research and management in Kenya, Balozi, B. Kirongo and Rolf Schulzke (eds.), Proceedings of the joint KEFRI-FD national conference, Muguga, Kenya, (pp. 26-30).
- Gede Office reports, 1986. *Eucalyptus urophylla* provenance trials; fourth year growth summary reports. KEFRI - Gede.



- Kirongo B.B., Kiriinya, C. and Gedion, K.M., 2002b Growth responses of *Cupressus lusitanica* and *Pinus patula* to different weed control methods in the Kenyan highlands, The Fourth International Conference on Vegetation Management, Popular summaries, Nancy, France, (368-370).
- Kirongo, B.B. and Mason, G.E., 2003. Decline in relative growth rate of 3 juvenile radiata pine clones subjected to varying competition levels in Canterbury, New Zealand, Ann. For. Sci. 60 (585-91).
- Kirongo, B.B., 2000. Modelling growth responses of juvenile radiate pine (*Pinus radiata* D. Don.) clones subjected to different weed competition levels in Canterbury, New Zealand. PhD. Thesis, University of Canterbury (Christchurch), New Zealand.
- Kirongo, B.B., Euan, G.M, and Putranto, A.N., 2002a. Interference mechanisms of pasture on the growth and fascicle dynamics of 3-year old radiata pine clones, Forest Ecology and Management, 159 (159-172).
- Lance T.S., 2000. Fertilization of *Eucalyptus* for rapid canopy closure on the Hamakua Coast in Pa'auilo. Hawaii Agriculture Research Centre. Forestry report 4.
- Libby, J.W. and Rauter, R.M., 1984. Advantages of clonal forestry. The Forestry Chronical, 60(3): 145-149.
- Machua, J. and Lelon J., 2004. A study on soil characterization and nutrient flow analysis at farm and catchment level in Ganda, Goshi and Jilore locations (Malindi district), Kenya. Project report.
- Mason, E.G., 1992. Decision support system for establishing radiate pine plantations in the Central North Island of New Zealand. PhD. Thesis, University of Canterbury (Christchurch), New Zealand.
- Mason, E.G., Whyte, A.G.D., Woollons, R.C. and Richardson, B., 1997. A model of the growth of juvenile radiata pine in the Central North Island of New Zealand: links with older models and rotation length analyses of the effects of site preparation. For. Ecol. And Manage. 97: 187-195.
- Mbinga, J., 2009. Eucalyptus: Misconceptions about water use and allelopathy. Workshop on Eucalyptus growing by farmers, 12th June 2009 at Wagon Wheel Hotel, Eldoret Kenya.
- Microsoft Office Excel 2003.
- Mutitu, K.E., 2003. A pest threat to *Eucalyptus* species in Kenya. KEFRI technical report.
- Mutitu, KE., Otieno, B.E., Oeba, V.O., Nyeko, P. and Day, R. K., 2006. Distribution of Blue Gum Chalcid, *Leptocybe invasa* and its damage on *Eucalyptus* in East Africa. IN: Muchiri, M. N., Kamondo, B, Ochieng', D, Tuwei, P. and Wanjiku, J. (Eds). Forestry Research in Environmental Conservation, improved livelihoods and Economic development: Proceedings of the Third KEFRI Scientific Conference on, 6th – 9th November 2006. Pp. 48-54.
- Nambiar, E.K.S. and Sands, R., 1993. Competition for water and nutrients in forests. Can. J. For. Res. 23: 1955-68.
- Nambiar, E.K.S. and Zed, P.G., 1980. Influence of weeds on water potential, nutrient content and growth of young radiate pine growth. Australian For. Res. (10): 279-88.



- Otuoma, J. and Muchiri, M.N., 2006. Evaluation of Blue Gum Chalcid infestation in Eucalyptus woodlots in Western Kenya. IN: Muchiri, M. N., Kamondo, B, Ochieng', D, Tuwei, P. and Wanjiku, J. (Eds). Forestry Research in Environmental Conservation, improved livelihoods and Economic development: Proceedings of the Third KEFRI Scientific Conference on, 6th – 9th November 2006. Pp. 44-47.
- Richardson, B., 1993. Vegetation management practices in plantation forests of Australia and New Zealand. Can. J. For. Res. 23: 1989-2005.
- Sands, R. and Nambiar, E.K.S., 1984. Water relations of *Pinus radiata* in competition with weeds. Can. J. For. Res. 14: 233-37.
- SAS Institute Inc. 2000.
- Snowdon, P. and Khana, P.K., 1989. Nature of growth responses in long-term field experiments with specific reference to *Pinus radiata*. IN: W. J. Dyck and C. A. Mees (Eds.). Research strategies for long-term site productivity. Proceedings, IEA/BE A3 Workshop, Seattle, WA, August 1998. IEA/BE A3 Report No. 8. Forest Research Institute, New Zealand, Bulletin 152. pp. 173-186.
- Wamalwa, L., Chagala-Odera, E., Oeba, V. and Oballa, P., 2007. Adaptability of four year old *Eucalyptus* species and clones in Kenya. Discovery and Innovation Journal, Vol. 19. Aforinet special Edition No. 4 April 2007.