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Growth Performance of Eucalypt Clones in Tanzania

Pima N.E.[1,*], Chamshama S.A.O.[2], Iddi S.[3], Maguzu J.[1]

[1]Tanzania Forestry Research Institute, Tanzania
[2]Department of Forest Biology, Sokoine University of Agriculture, Tanzania
[3]Department of Wood Utilization, Sokoine University of Agriculture, Tanzania

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Abstract A research study was conducted to assess the growth performance of Eucalypt clones in Tanzania. Eucalypt clones of *Eucalyptus grandis* x *E. camaldulensis* (GC), *E. grandis* x *E. urophylla* (GU), *E. grandis* x *E. tereticornis* (GT) were established in Lushoto, Kwamarukanga, Kibaha and Tabora sites. Survival, Diameter at breast height, height and biomass were collected while volume and basal area were evaluated. All assessed variable were subjected to ANOVA. Significant ($p<0.05$) clonal difference in survival, Dbh, height, basal area, volume and biomass between clones was observed. Survival was >90% in Lushoto and Kwamarukanga sites where as the other sites showed intermediate and low survival. Clones at Lushoto site had highest Dbh, height, basal area, volume, Mean annual increment and biomass followed by clones at Kwamarukanga, Kibaha and Tabora sites. It was concluded that at 8 year old Eucalypt clones showed good survival and growth needed for various uses. This study recommended that GC581, GC584 and GU608 are better for Lushoto, GC15, GC167 and GC940 for Kibaha, GC514, GT529 and GC940 for Kwamarukanga and GC15, GC584 and GC940 for Tabora. The outstanding clones are recommended for planting in areas with climatic conditions similar to the sites where they were tested.

Keywords Eucalypt Clones, Survival, Growth Performance, Productivity, Tanzania

1. Introduction

Eucalyptus is among the most widely cultivated forest trees in the world (over 22 million hectares (ha) [1]. The major Eucalyptus growing countries includes Brazil (3.7 mil ha), India (2.5mil ha) and China (1.7 mil ha). In Africa, South Africa has the largest area under *Eucalyptus* plantations of about half a million ha [2]. In Tanzania, it is estimated that there are about 25 000 ha of Eucalypts plantations [3] of which 4 665 ha are grown by government and the rest are grown by the private sector and small-scale farmers [4]. *Eucalyptus* species that are commonly planted in Tanzania are *E. saligna*, *E. grandis, E. camaldulensis, E. globules, E. viminalis, E. citriodora, E. regnas, E. microtheca, E. tereticornis*, *E. maidenii. E. maculata, E. paniculata, E. resinifera, E.urophylla* and *E. robusta.*

The rapid decrease in indigenous timber tree species coupled with the need for timber and other wood products, has necessitated Tanzania to embark on commercial plantation forestry development in order to meet the increasing demands. Eucalypt clones have been considered as one of the solutions to meet the need for forest products in the country. Eucalypt clones were introduced from Mondi South Africa to East African countries of Tanzania, Kenya and Uganda during the period of 1997 to 2003. In Tanzania, the clones were introduced in 2003 through Tanzania Forestry Research Institute (TAFORI) in order to test their adaptability in the Tanzanian environment before large scale planting. Experiments started in 2004 using *Eucalyptus grandis* x *E. camaldulensis* (GC) clone, *E. grandis* x *E. urophylla* (GU) clone*,* and *E. grandis* x *E. tereticornis* (GT) clones. These clones combine desired traits for two species. *E. grandis x E. camaldulensis* (GC) combines good growth and drought tolerance. *E. grandis x E. urophylla* (GU) combines good growth and disease resistance. *E. grandis x E. tereticornis* (GT) combines good growth and rooting ability. The clones are preferred for their fast growth with a short rotation, wide adaptability to site conditions, produce better quality wood and more uniform stands than most indigenous trees [5]. Eucalypt clones are mainly used in many applications in house construction, production of fuel wood, poles, telecommunication posts, fencing posts, electricity transmission poles, pulp and timber [6]. They contribute significantly to reduce the wide gap between demand and production of wood in the shortest possible time [7], thus reducing pressure from the few remaining natural forests [8].

Several studies have reported the significant growth performance of Eucalypt clones in the world [9-10]. The results from these studies shows that Eucalypts hybrid has similar or better growth than their parent and significant differences in growth between hybrid clones may be attributed to genetic constitution as well as environmental factors like soil pH, mean annual rainfall and mean temperature. In Tanzania, only a study by [11] reported the growth and survival of 4 year old Eucalypt hybrid clones. The results showed significant survival and growth difference within and between sites. The results also show species site specific performance where GCs and GT survived and performed well in low land areas. However, little research has been done on the growth and survival of these clones at eight year old although there is significant/considerable area planted with Eucalypt clones. Thus, the main objective of this study was to assess the growth performance of Eucalypt hybrid clones in four sites. Therefore, the result from this study provides information on the best clones to be grown in a given agro-ecological zone of Tanzania.

2. Materials and Methods

Study area Description

The study was conducted in four agro-ecological zones of Tanzania namely Highland (Lushoto), Coast (Kibaha), Inland Plateux (Tabora) and Lowland (Kwamarukanga) (Table 1).

Experimental Design

The experiments were established by TAFORI in 2004 using Eucalypts clonal material from Mondi South Africa. Randomized complete block design with four replications and 12 treatments (Eucalypt clones) was used to set up these experiments at Lushoto, Kibaha and Kwamarukanga sites and 10 treatments at Tabora site. Each clone type was represented once in each block. Each plot comprised 16 trees spaced at 2.5 x 2.5 m in a 4 x 4 arrangement. The experiments have 2 guard rows planted to avoid edge effect.

Data Collection

Growth assessment

Data on survival, Diameter at Breast Height (Dbh), height and biomass were collected at the age of 8 years in 2012. All trees in the plot were measured for Dbh, while 6-12 trees per plot (small, medium and large size) were measured for height. The tally of diameter growth also gave tree survival data. The Dbh measurements were used to calculate the mean plot basal area. Basal area was derived by summing the individual basal areas of trees within a plot and then the plot basal areas were computed by summing basal area of individual trees in a plot. To obtain basal area per ha (m^2ha^{-1}), plot basal areas were divided by plot area in ha. Height, Dbh and survival data were first used to determine three best performers in each studied site.

Sampling and Laboratory Procedures

Three superior Eucalypt clones in terms of survival, Dbh and height (*i.e* GC 581, GC 584 and GU 608 for Lushoto; GC 15, GC 167 and GC 940 for Kibaha; GC 514, GT 529 and GC 940 for Kwamarukanga and GC 15, GC 584 and GC 940 for Tabora) were selected. Subjective sampling was applied to select thirty trees (<10 cm, 10-20 cm and >20 cm) from three clone type at each site for volume and above ground biomass determination. Before felling, trees were measured for Dbh and height and the total length of the tree were measured after felling. Sampled trees were divided into two main parts: aboveground and belowground. The aboveground part was considered as all biomass above a stump height of 15 cm and it was further divided into sections namely stem, branches including tops (up to a minimum diameter of 2 cm) and twigs (with diameter less than 2 cm). Stems and branches were trimmed and cross cut into manageable billets ranging from 1 to 1.5 m in length. Mid diameter and length of each billet were measured for volume determination. Three sample discs from stem and one disc sample from branches (about 2 cm thick cut from bark to pith) were extracted and weighed. Stem and branch billets were then weighed and the green weight recorded. Twigs were collected into separate bundles and the green weight of each was taken. Leaves were also collected and the green samples were weighed. The total fresh weight of each component was taken in the field using a balance.

Table 1. Study area description

Site characteristics	Sites			
	Lushoto	Kwamarukanga	Kibaha	Tabora
Latitude	$04^0$47’15’’S	$05^0$15’48’’	$06^0$42’39.’’	$04^0$82’86’’
Longitude	$38^0$17’40’’ E	$38^0$30’28’’	$38^0$52’52’’	$32^0$62’97’’
Altitude (m.a.s.l)	1393 – 148	70	104	1175
Mean annual rainfall (mm)	1070	1000	900	700 – 1000
Mean temperature (°C)	7 – 30	19 – 32	23 – 35	18 – 28
Soil pH	4.4 – 4.5	3.8 – 4.7	4.5 – 4.9	4.8 – 6.2
Soil Organic carbon (%)	2.7 – 3.6	1.8 – 2.6	0.68 – 1.7	1.7 – 2.9.
Soil texture	Sandy	Sandy clay	Sandy	Sandy

Stem, branches and twigs samples were oven dried to constant weight at 103± 20C while leaves were oven dried at 700C for 48 hours and after that changes in weight were monitored at intervals of 6 hours until there was no change in weight. The wooden blocks from the stem, branch billets and twigs were soaked in water for one week and then measured for green weight using kitchen scale. The volume of each wood block was determined by water displacement method [12]. Biomass was determined using biomass ratios of sample trees and were computed as the ratio of oven dry weight to the green weight for each tree component namely whole tree, stems, branches, twigs and leaves.

Model Development, Selection and Evaluation

The biomass for each tree component was computed as the product of biomass ratio and total fresh weight. Site specific models for above ground biomass, stem biomass and volume were developed. Models predicting biomass and volume were based on Dbh only, and on a combination of Dbh and height, as independent variables. Numerous model forms have previously been applied when developing biomass models [13-14]. Four model forms for prediction of biomass (dry weight), which have been commonly adopted previously, were tested. Two of the model forms include Dbh only and two include height in addition.

$$Y = \beta_0 dbh^{\beta 1} \quad \text{(Model form 1)}$$

$$Y = Exp(\beta_0+\beta_1 ln(htxdbh^2) \quad \text{(Model form 2)}$$

$$Y= \beta_0 dbh^{\beta 1}\ ht^{\beta 2} \quad \text{(Model form 3)}$$

$$Y = \beta_0 + \beta_1 dbh + \beta_2 dbh^2 \quad \text{(Model form 4)}$$

Where

Y = Biomass (kg) or Volume (m^3)

Dbh = Diameter at breast height (cm)

Ht = tree total height (m)

β_0 β_1 and β_2 are regression coefficients.

The best-fit models were selected based on the Akaike Information Criterion (AIC). AIC takes into account the number of parameters in the models and penalizes them accordingly [13]. R^2 reported for all tested models were not used as criteria for selecting final models because the tested model forms had different numbers of parameters. With an increase in number of parameters, a model tends to have larger R^2 values regardless of their contribution in explaining the variation in the response variable. Models with insignificant parameter estimates were excluded during the selection process irrespective of AIC values. All models were analysed using Non Linear Programming procedure in SAS programme to estimate the model parameters (βo, β_1, and β2). The procedure produces the least squares estimates of the parameters of a nonlinear model through an iteration process. Goodness of fit and model comparisons was evaluated using bias percent. Models with lower bias and AIC were selected and used to predict total volume and tree biomass for trees sampled at Lushoto, Kibaha, Kwamarukanga and Tabora sites (Table 2).

Table 2. Final weighted equations for the aboveground biomass and volume model

Sites	Biomass model	R^2	AIC
Lushoto	Y=0.1274*Dbh^2.6110	0.95	290.53
Kibaha	Y=0.1379*Dbh^2.4369	0.93	256.71
Kwamarukanga	Y=0.4124*Dbh^2.1128	0.9	256.75
Tabora	Y=0.7759*Dbh^1.7913	0.9	236.84
Volume model			
Lushoto	Y=0.000324*Dbh^2.3988	0.96	61.03
Kibaha	Y=0.000311*Dbh^2.2087	0.96	78.4
Kwamarukanga	Y=0.000628*Dbh^2.07599	0.90	69.66
Tabora	Y=0.000811*Dbh^1.8565	0.94	87.08

Data Analysis

For each tree variable namely survival (%), Dbh (cm), height (m), basal area (m^2ha^{-1}), volume (m^3ha^{-1}) biomass production ($t\ ha^{-1}$) were subjected to analysis of variance using treatment means. Significant clones' means were separated by Duncan's Multiple Range Test. An ordinal ranking scheme was devised to differentiate overall performance for each clone type when significantly different growth was found. Ranking of treatments in six tree parameters namely survival, height, Dbh, basal area, volume and biomass production was used. For each variable which showed significant variation was assigned the best (assigned 1 point) to worse (assigned 12 points) Lushoto, Kibaha and Kwamarukanga sites or 10 for Tabora. Therefore, ranks were added, averaged and the overall score was taken as a basis of the overall clone performance ranking.

3. Results

Survival

The survival of Eucalypt clones differed significantly ($p<0.05$) between clones within a site (Table 3). The best overall survival of Eucalypt clone at Lushoto site was obtained for GC 10, GC 15, GC 167, GC 785 and GC 796 (100%) whilst the poorest was 84% for GC 514. For Kwamarukanga, GC 940, GT 529 and GC 514 were the best survivors with survival of 98.44%, 97.10% and 96.98% respectively compared to the rest of the clones. At Kibaha site, GC 940, GC 15 and GT 529 had highest survival of 76.34%, 66.88% and 62.08% respectively over the other clones. At Tabora, survival of 60.94 and 51.56% was recorded for GC 940 and GC 584 respectively compared to the other clones.

Table 3. Survival of 8 year old Eucalypt clones across different sites

Treatment	Survival (%)			
	Lushoto	Kwamarukanga	Kibaha	Tabora
GC 10	100.00a	41.32fg	34.38f	40.63bc
GC 14	99.08a	42.28f	50.89de	43.75bc
GC 15	100.00a	93.95bc	66.88ab	39.06bcd
GC 167	100.00a	95.98abc	54.89cd	35.94bcd
GC 514	84.52e	96.98ab	58.33bcd	42.19bc
GC 581	98.89a	89.22d	31.70f	7.81g
GC 584	99.05a	95.13abc	61.75bc	51.56b
GC 785	100.00a	92.19cd	44.29e	17.19fg
GC 796	100.00a	75.23d	20.31g	-
GC 940	93.75b	98.44a	76.34a	60.94a
GT 529	91.52c	97.10ab	62.08bc	-
GU 608	88.68d	37.5g	33.52f	4.69gh

Mean values in the same column with same following letters do not differ significantly (p>0.05).

Table 4. Mean Dbh and height of 8 year old Eucalypt clones

Treatment	Lushoto		Kwamarukanga		Kibaha		Tabora	
	Dbh	Height	Dbh	Height	Dbh	Height	Dbh	Height
GC 10	14.74def	24.39bcd	11.15b	21.97ab	12.44g	18.36bc	13.27abcd	16.27ab
GC 14	14.53f	24.93bcd	11.53ab	22.24a	13.30fg	19.14abc	12.56abcd	16.15ab
GC 15	15.71bcd	25.94bcd	12.09ab	21.19ab	15.59abc	20.76a	13.38abcd	15.63ab
GC 167	15.60bcde	24.05cd	11.19b	19.18bc	15.27abcd	19.53abc	13.21abcd	14.63ab
GC 514	15.08cdef	26.36bc	12.61a	21.05ab	15.09bcde	18.94abc	10.99cd	13.16bc
GC 581	16.05bc	25.90bcd	11.16b	19.72abc	14.23cdef	18.32bc	16.98a	17.5a
GC 584	16.14b	26.96b	12.18ab	20.95ab	14.94bcdef	20.88a	13.29abcd	16.04ab
GC 785	14.35f	23.37d	11.01bc	19.38bc	13.73defg	17.91c	11.41bcd	13.83abc
GC 796	14.38f	24.04cd	9.99c	18.20c	16.7a	17.75c	-	-
GC 940	14.67ef	25.73bcd	12.50a	19.80abc	14.86bcdef	19.50abc	13.82abcd	14.5abc
GT 529	14.46f	27.05b	12.56a	22.43a	13.53efg	19.43abc	-	-
GU 608	19.15a	30.81a	12.52a	20.03abc	15.95ab	20.33ab	10.00d	10.83c

Values in the same column with same following letters do not differ significantly (p>0.05). Dbh (cm) and Height (m)

Diameter and Height

The mean Dbh and height obtained from the four sites with respect to the clones studied are presented in Table 4. GU 608, GC 584 and GC 581 had best performance in Dbh at Lushoto site while the least were GC 785, GC 796 and GT 529. GC 796, GU 608 and GC 15 outshone the other clones in Dbh at Kibaha site while GC 514, GT 529 and GU 608 outperformed GC 785, GC 796 and GC 10 at Kwamarukanga and GC 581, GU 125 and GU 21 performed relatively better than GC 514, GC 785 and GU 608 at Tabora.

As in Dbh, height of Eucalypt clones differed significant ($p<0.05$) between clones within a site. Clone GU 608, GC 584 and GT 529 achieved significantly higher height compared to the rest of Eucalypt clones at Lushoto while GT 529, GC 14 and GC 10 had relatively higher mean height at Kwamarukanga. At Kibaha, clone GC 584, GC 15 and GU 608 showed satisfactory mean height values compared to GC 581, GC 785 and GC 796. However, GC 581, GU 125 and GC 10 showed satisfactory values of mean height compared to GC 514, GC 796 and GU 608 for Tabora.

Basal Area and Biomass Production

Basal area and Biomass production of Eucalypt differed significant ($p<0.05$) between clones within a site (Table 5). The best clone at Lushoto site had basal area value of 28.18 m^2ha^{-1} for GU 608 compared to 17.20 m^2ha^{-1} for GC 514. GT 529, GC 940 and GC 514 showed significantly higher basal area values of 12.66, 12.70 and 12.77 m^2ha^{-1}respectively at Kwamarukanga site over the other clones. For Kibaha site, GC 15 and GC 940 showed significant higher basal area values of 14.1 and 14.61 m^2ha^{-1} respectively over the other clones. However, at Tabora site, GC 584 and GC 940 outperformed the other clones in basal area.

The clones at Lushoto had biomass production ranging from 147.87 to 286.85t ha^{-1} with the highest biomass attained by GU 608. Kwamarukanga site had biomass production ranging from 27.33 to 89.92 t ha^{-1} while at Kibaha, clones had biomass ranging 22.30 to 86.35 t ha^{-1} and 4.66 to 58.82 t ha^{-1} for Tabora site (Table 5).

Volume and MAI

Volume and MAI of Eucalypts differed significantly ($p<0.05$) between clones in all sites (Tables 6 and 7). Average volume of trees at 8 years ranged from 209.23 m^3ha^{-1} for GT 529 to 385.23 m^3ha^{-1} for GC 608 at Lushoto. As in Lushoto, the volume of clones at Kwamarukanga ranged from 37.81 to 124.3 m^3ha^{-1} for GU 608 and GC 514 respectively. At Kibaha, GC 10 and GC 15 recorded average volume ranging between 28.07 and 103.29 m^3ha^{-1} respectively while GU 21 and GC 584 recorded mean volume ranging between 7.92 and 70.88 m^3ha^{-1} respectively for Tabora. As in volume, MAI was recorded ranging from 19.13 to 41.10 $m^3ha^{-1}yr^{-1}$ for Lushoto, 3.41 to 21.34$m^3ha^{-1}yr^{-1}$ at Kwamarukanga (Table 6), 3.32 to 17.47 $m^3ha^{-1}yr^{-1}$ for Kibaha and 0.31 to 13.76 $m^3ha^{-1}yr^{-1}$ for Tabora (Table 7).

Table 5. Basal area and Biomass production of 8 year old Eucalypt clones

Treatment	Lushoto		Kwamarukanga		Kibaha		Tabora	
	Basal	Biomass	Basal	Biomass	Basal	Biomass	Basal	Biomass
GC 10	19.21e	170.56d	3.97g	27.45g	4.16e	22.30e	5.67cd	32.07bc
GC 14	18.29f	159.23efg	4.62f	32.12f	4.16e	23.16e	6.13cd	34.88bc
GC 15	21.02d	186.58c	11.69b	82.09b	14.61a	86.35a	6.64cd	37.67bc
GC 167	21.24cd	192.75b	10.14c	70.59c	11.44b	67.74b	5.84cd	33.09bc
GC 514	17.20g	153.60gh	12.77a	89.76a	10.69b	61.94b	4.61de	26.74cd
GC 581	21.76bc	196.29b	9.34d	64.95d	5.04e	28.70e	2.78ef	14.82ef
GC 584	21.94b	197.77b	11.74b	82.20b	11.16b	65.22b	10.00ab	57.16a
GC 785	18.07f	156.84fg	9.54d	66.35d	6.42d	36.01d	3.09ef	18.13de
GC 796	18.49f	163.92e	6.53e	45.11e	4.18e	25.98e	-	-
GC 940	18.06f	160.64ef	12.70a	89.07a	14.61a	84.12a	10.51a	58.82a
GT 529	16.88gf	147.87h	12.66a	89.92a	9.54c	52.57c	-	-
GU 608	28.18a	286.85a	3.88g	27.33g	6.67d	39.35d	0.78f	4.66f

Values in the same column with same following letters do not differ significantly ($p> 0.05$). Basal area (m^2ha^{-1}) and Biomass (t ha^{-1})

Table 6. Volume and MAI of 8 year old Eucalypt clones

Treatment	Volume (m^3ha^{-1})				MAI	Volume (m^3ha^{-1})				MAI
	Lushoto					Kwamarukanga				
	2007	2008	2009	2012		2007	2008	2009	2012	
GC 10	116.14f	160.31e	161.81f	239.99d	25.65d	60.96	60.11f	61.30f	38.22g	7.59g
GC 14	111.75g	155.30f	166.91e	225.67e	26.2cd	53.55f	62.70e	60.47f	44.64f	7.92g
GC 15	134.19d	182.14c	182.94c	262.88c	26.91c	75.36a	84.44b	98.92b	113.7b	19.1bc
GC 167	139.82b	193.5b	199.54a	269.3bc	29.20b	67.14c	69.59d	81.95d	98.05c	15.0d
GC 514	111.33g	140.8g	140.77i	215.73fg	19.81g	67.8bc	82.37b	97.78b	124.3a	19.5b
GC 581	139.46b	198.57a	198.96a	274.94b	29.89b	61.92d	70.78d	81.51d	90.26d	14.22e
GC 584	137.7bc	193.6b	194.13b	277.16b	29.78b	63.69d	74.67c	92.79c	114.3b	18.61c
GC 785	122.35e	175.2d	173.81d	222.40ef	24.11e	57.96e	63.65e	76.35e	92.21d	13.72e
GC 796	135.4cd	182.37c	185.99c	230.60e	22.07f	48.26g	52.01g	58.77f	62.83e	9.33f
GC 940	120.44e	156.18f	156.22g	225.86e	21.21f	70.38b	83.76b	98.51b	123.4a	19.7b
GT 529	113.66fg	143.6g	145.73h	209.23g	19.13g	75.09a	87.54a	114a	123.2a	21.34a
GU 608	150.83a	198.21a	200.06a	385.23a	41.10a	31.28h	25.47h	31.61g	37.81g	3.41h

Note: MAI in ($m^3ha^{-1}y^{-1}$), Mean values in the same column with same following letters do not differ significantly ($p>0.05$).

Table7. Volume and MAI of 8 year old Eucalypt clones

Treatment	Kibaha				MAI		Tabora		MAI
	2007	2008	2009	2012		2007	2008	2012	
GC 10	38.84d	38.08e	38.56e	28.07e	4.18f	14.10cd	16.70f	39.88bc	6.31ab
GC 14	34.664	27.82f	25.2g	28.57e	3.32f	12.12d	27.76cd	43.29bc	9.95ab
GC 15	58.06a	71.44a	84.36a	103.29a	17.47a	25.71a	43.54a	46.82bc	8.77ab
GC 167	46.9c	57.46c	65.28b	80.92b	13.22c	22.18a	35.01b	41.13bc	6.81ab
GC 514	46.71c	57.08c	58.74c	74.87b	12.14c	13.52cd	21.84def	33.01cd	5.67ab
GC 581	34.70d	40.70de	42.55e	34.99e	6.04e	23.23a	40.75a	18.78def	8.14ab
GC 584	55.37ab	61.86b	68.78b	78.47b	13.19c	14.74bcd	25.86cd	70.88a	10.98ab
GC 785	39.12d	43.23d	41.73e	44.27d	6.12e	12.25d	19.98fe	22.30de	5.66ab
GC 796	32.12e	21.57g	26.28g	30.25e	5.34e	-	-	-	-
GC 940	52.37b	71.62a	81.09a	102.01a	15.73b	25.51a	45.08a	73.42a	13.76a
GT 529	45.87c	54.12c	50.92d	65.24c	9.02d	-	-	-	-
GU 608	35.42de	28.87f	32.73f	45.12d	6.25e	13.87cd	16.44f	5.69f	0.31b

Note: MAI in ($m^3ha^{-1}y^{-1}$), Mean values in the same column with same following letters do not differ significantly ($p>0.05$).

Ordinal Ranking

The overall best performing clones for each site were ranked. GC 581, GC 584 and GU 608 showed better performance for Lushoto while GC 15, GC 167 and GC 940 showed better growth performance at Kibaha. GC 514, GT 529 and GC 940 performed better at Kwamarukanga while GU 15, GC 584 and GC 940 scored higher than other clones at Tabora site. Ordinal ranking values reported in this study show that, GC 940 grows well in different climatic conditions. This indicates that rainfall, temperature, soil and altitude of the study sites are within the optimal range for the survival and growth of GC 940.

4. Discussion

Eucalypt clones studies have yielded mixed results both in terms of survival, growth performance and productivity. The survival of most of clones at Lushoto and Kwamarukanga were more than 95%. These finding are similar to those reported by [15-16] that the survival percentage of the majority of clonal plantations is more than 95%. Moreover, the difference in survival between clones within a site observed was probably a result of genetic differences between the clones which interact differently with the various climatic and soil conditions. The varied survival trends between clones within a site showed a strong environment clone interaction, an observation supported by [10, 17]. For Tabora site, low survival was probably due to fire outbreak which occurred in 2009 and other human disturbances. Survival in general is influenced by several factors, which include site management, especially the weeding frequency and the protection of the seedlings from pests and diseases, drought and seedling handling during planting period [18].

With respect to Dbh, Eucalypt clones studied showed similar Dbh trends as reported by various researchers. For example, [19-21] in Congo, Kenya and North Iraq reported that 5 to 8 year old Eucalypt clones had a mean Dbh of 14 to 16 cm while [22] reported mean Dbh of 13 cm of 8 year old *Eucalyptus nitens* in coastal Ireland. Similarly, significant differences in Eucalypt clones have been reported by various researchers. For example, [10, 23] observed significant differences for growth attributes among seven species of Eucalypt clones and found that, Indian clones had higher promising performance for Dbh than the results of this study. These differences in Dbh between clones within a site may be attributed to genetic difference [17].

On the other hand, mean height of GU 608 at Lushoto was significantly higher than 28 m for a 7 year old Eucalypt clonal plantation in Congo [19], 11 to 14 m for 8 year old *Eucalyptus nitens* [22] and 12.5 m and 19.9 m for Eucalypt clones in Kenya [18]. The performance of Eucalypt clones studied encouraged the expansion of plantations and woodlot forests of Eucalypts to reducing pressure to the few remaining natural forests in Tanzania. However, height growth, especially in Eucalypts which are shade intolerant is strongly affected by stocking i.e. number of stems per unit area [24]. High height growth was observed between clones at Lushoto and Kwamarukanga sites due to high survival rate. However, clones at Kibaha and Tabora sites due to low survival rate resulting into wider spacing with no competition for light, the height growth between clones was observed to be low.

In addition, [26] reported that 15 year old *E. resinifera* had similar basal area to Lushoto site but higher than results from Kwamarukanga, Kibaha and Tabora. Reference [19] Reported lower results compared to clones at Lushoto highland area but higher to the other studied sites. The study results are lower than those reported by [25] for various Eucalypt clones in Brazil. Significant difference observed in basal area between clones within a site suggests that their level of adaptation to site conditions is different. GC clones are more suited for growing in medium agricultural potential areas receiving annual rainfall above 750 mm and at an elevation of less than 1700 m.a.s.l [27]. The GCs are not suitable for growing in semi-arid areas where *E. camaldulensis* does best or above 1700 m.a.s.l. where *E. grandis* grows best. In high rainfall areas with amounts over 1200 mm a year, the growth rate of GCs is lower than that of widely grown local *E. grandis* [17].

The clones at Lushoto, in particular, outshone the other sites in terms of having high biomass production ranging from 147.87 to 286.85 t ha^{-1} with the highest biomass attained by GU 608. Growth differences have been found in many cold tolerant Eucalypt species tested under South African growing conditions [28-29], signifying the importance of site-species matching, as well as site-provenance matching [30-31]. Differences between genetic materials of Eucalypts as to biomass yield and distribution have been attributed to varying adaptability to local conditions as reported by several authors in [32]. Biomass accumulation is a result of greater or more effective capture of growth inducing resources such as water, nutrients and/or solar radiation. Findings from this study compare well with several data presented by [33-34] including biomass production per year of some fast growing *Eucalyptus* species shows clearly the strong potential of Eucalypts for wood production. According to [35] total biomass differed between clones and among *E. grandis* x *E. urophylla* (GU) clones. The findings of this study are similar to those of [19, 36].

Moreover, the productivity of Eucalypt clones falls in the range reported for some Eucalypt hybrid plantations (*E. urophylla* × *E. grandis*) in South Africa, South America, India, Brazil and Cameron [37-39]. The superior volume for clones at Lushoto site might be attributed to sites advantages in good growth in diameter and height ascribed to the favourable climatic conditions, especially the high rainfall and soil type. This implies that Eucalypt clones are better adapted to altitudes ranging from 1393–1486 m.a.s.l with rainfall above 1000 mm and temperature ranging between 7^0C and 30^0C.

The growth of trees is mainly influenced by different factors including genotype, environment and management. It was evident that clones at Lushoto performed better, showing the influence of environment on tree growth. The differences in performance among Eucalypt clones at various sites indicate that some clones are more adaptable to specific sites 17, 40]. According to [10] different sites have different level of fertility, soil texture etc. GU 608 performed well at Lushoto site only, implying that they are not suitable in low land and dry areas. Similar observations have been made by [41] that GUs was not suitable for lowland humid tropics.

5. Conclusions

Eucalypt clones studied showed significant differences in terms of survival, Dbh, height, basal area, volume and biomass production within a site with the greatest growth performance being shown at Lushoto. The productivity of all clones in Lushoto site is better than those obtained elsewhere in the world. It is recommended that, GC 581, GC 584 and GU 608 are better for Lushoto. GC 15, GC 167 and GC 940 better for Kibaha. GC 514, GT 529 and GC 940 recommended for Kwamarukanga and GC 15, GC 584 and GC 940 recommended for Tabora. They are also recommended for planting in areas with climatic and soil conditions similar to the sites where they were tested.

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