Growth Performance of Eucalypt Clones in 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 whereas 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 (m²ha⁻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 | Lushoto | Kwamarukanga | Kibaha | Tabora |
|----------------------|---------|--------------|--------|--------|
| Latitude             | 04°47'15"S | 05°15'48" | 06°42'39" | 04°52'56" |
| Longitude            | 38°17'40"E | 38°30'28" | 38°52'52" | 32°52'97" |
| 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± 20°C while leaves were oven dried at 70°C 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.

\[
Y = \beta_0 \cdot \text{dbh}^{\beta_1} \\
Y = \exp(\beta_0 + \beta_1 \ln(h + \beta_2 \cdot \text{dbh}^2)) \\
Y = \beta_0 + \beta_1 \cdot \text{dbh} + \beta_2 \cdot \text{dbh}^2
\]

Where

\[Y = \text{Biomass (kg) or Volume (m}^3)\]
\[\text{dbh} = \text{Diameter at breast height (cm)}\]
\[h = \text{tree total height (m)}\]
\[\beta_0, \beta_1, \text{ and } \beta_2 \text{ are regression coefficients.}\]

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]. R² 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 R² 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 (\(\beta_0, \beta_1, \text{ and } \beta_2\)). 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 | R²   | 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|

### Data Analysis

For each tree variable namely survival (%), Dbh (cm), height (m), basal area (m²ha⁻¹), volume (m³ha⁻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 over the other clones. At Kibaha site, 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 | 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| 39.06bed|
| GC 167    | 100.00a | 95.98abc      | 54.89cd| 35.94bcd|
| GC 514    | 84.52e  | 96.98abc      | 58.33bed| 42.19bc|
| GC 581    | 98.89a  | 89.22d        | 31.70f | 7.81g  |
| GC 584    | 99.05a  | 95.13abc      | 54.89cd| 35.94bcd|
| GC 785    | 100.00a | 92.19cd       | 44.29e | 17.19fg|
| GC 796    | 100.00a | 75.23d        | 20.31g | 17.19fg|
| GC 940    | 93.75b  | 98.44a        | 76.34a | 60.94a |
| GT 529    | 91.52c  | 97.10abc      | 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 Ddbh and height of 8 year old Eucalypt clones

| Treatment | Lushoto | Kwamarukanga | Kibaha | Tabora |
|-----------|---------|---------------|--------|--------|
|            | Ddbh    | Height        | Ddbh   | Height |
| GC 10     | 14.74def| 24.39bcd      | 11.15b | 21.97ab|
| GC 14     | 14.53f  | 24.93bcd      | 11.53ab| 22.24a |
| GC 15     | 15.71bcd| 25.94bcd      | 12.09ab| 21.19ab|
| GC 167    | 15.60bcd| 24.05cd       | 11.19b | 19.18bc|
| GC 514    | 15.08cdef| 26.36bc      | 12.61a | 21.05ab|
| GC 581    | 16.05bc | 25.90bcd      | 11.16b | 19.72abc|
| GC 584    | 16.14b  | 26.96b        | 12.18b | 20.95ab|
| GC 785    | 14.35f  | 23.37d        | 11.01bc| 19.38bc|
| GC 796    | 14.38f  | 24.04cd       | 9.99e  | 18.20c |
| GC 940    | 14.67ef | 25.73bcd      | 12.50a | 19.80abc|
| GT 529    | 14.46f  | 27.05b        | 12.56a | 22.43a |
| GU 608    | 19.15a  | 30.81a        | 12.52a | 20.03abc|
|            |         |               | 15.95ab| 20.33ab|

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

### Diameter and Height

The mean Ddbh 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 Ddbh 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 Ddbh 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 GC 608 at Tabora.

As in Ddbh, 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 m²ha⁻¹ for GU 608 compared to 17.20 m²ha⁻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 m²ha⁻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 m²ha⁻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 286.85 t 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\(^3\)ha\(^{-1}\) for GT 529 to 385.23 m\(^3\)ha\(^{-1}\) for GC 608 at Lushoto. As in Lushoto, the volume of clones at Kwamarukanga ranged from 37.81 to 124.3 m\(^3\)ha\(^{-1}\) 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\(^3\)ha\(^{-1}\) respectively while GU 21 and GC 584 recorded mean volume ranging between 7.92 and 70.88 m\(^3\)ha\(^{-1}\) respectively for Tabora. As in volume, MAI was recorded ranging from 19.13 to 41.10 m\(^3\)ha\(^{-1}\) yr\(^{-1}\) for Lushoto, 3.41 to 21.34 m\(^3\)ha\(^{-1}\) yr\(^{-1}\) at Kwamarukanga (Table 6), 3.32 to 17.47 m\(^3\)ha\(^{-1}\) yr\(^{-1}\) for Kibaha and 0.31 to 13.76 m\(^3\)ha\(^{-1}\) yr\(^{-1}\) for Tabora (Table 7).

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

| Treatment | Lushoto Basal | Lushoto Biomass | Kwamarukanga Basal | Kwamarukanga Biomass | Kibaha Basal | Kibaha Biomass | Tabora Basal | Tabora Biomass |
|-----------|---------------|-----------------|---------------------|---------------------|--------------|----------------|--------------|----------------|
| GC 10     | 19.21e        | 170.56d         | 3.97f               | 27.45g              | 4.16e        | 22.30e         | 5.67d        | 32.07bc        |
| GC 14     | 18.29f        | 159.23efg       | 4.62f               | 32.12f              | 4.16e        | 23.16e         | 6.13d        | 34.88bc        |
| GC 15     | 21.02d        | 186.58c         | 11.69b              | 82.09b              | 14.61a       | 86.35a         | 6.64d        | 37.67bc        |
| GC 167    | 21.24cd       | 192.75b         | 10.14c              | 70.59c              | 11.44b       | 67.74b         | 5.84d        | 33.09bc        |
| GC 514    | 17.20g        | 153.60gh        | 12.77a              | 89.76a              | 10.69b       | 61.94b         | 4.61d        | 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\(^2\)ha\(^{-1}\)) and Biomass (t ha\(^{-1}\)).

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

| Treatment | Lushoto Volume (m\(^3\)ha\(^{-1}\)) | MAI (m\(^3\)ha\(^{-1}\)yr\(^{-1}\)) | Kwamarukanga Volume (m\(^3\)ha\(^{-1}\)) | MAI (m\(^3\)ha\(^{-1}\)yr\(^{-1}\)) |
|-----------|----------------------------------|-------------------------------|----------------------------------|-------------------------------|
| GC 10     | 116.14f 160.31e 161.81f 239.99d | 25.65d 60.96 60.11f 61.30f 38.22g | 75.36a 64.44b 81.95d 98.05c 15.0d |
| GC 14     | 111.75g 155.30f 166.91e 225.67e | 26.2cd 53.55f 62.70e 60.47f 44.64f | 75.36a 64.44b 81.95d 98.05c 15.0d |
| GC 15     | 139.82b 193.5b 199.54a 269.3bc | 29.20b 67.14c 84.44b 98.92b 113.7bc | 14.61a 84.12a 10.51a 58.82a |
| GC 167    | 111.33g 140.8g 140.77i 215.73f | 19.81g 67.8bc 82.37b 97.78b 124.3a | 19.5b  |
| GC 514    | 134.19d 182.14c 182.94c 262.88c | 26.91c 75.36a 84.44b 98.92b 113.7bc | 19.1bc  |
| GC 581    | 137.7bc 193.6b 194.13b 277.16b | 29.88b 63.69d 74.67c 92.79c 114.3b | 18.61c  |
| GC 785    | 122.35e 175.2d 173.81d 222.40e | 24.11e 57.96e 63.65e 76.35e 92.21d | 19.5b  |
| GC 796    | 135.4ed 182.37e 185.99e 230.60e | 22.07f 48.26g 52.01g 58.77f 62.83c | 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    | 113.66g 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\(^3\)ha\(^{-1}\)yr\(^{-1}\)), Mean values in the same column with same following letters do not differ significantly (p>0.05).
Table 7. Volume and MAI of 8 year old Eucalypt clones

| Treatment | Kibaha 2007 | Kibaha 2008 | Kibaha 2009 | Kibaha 2012 | MAI | Tabora 2007 | Tabora 2008 | Tabora 2012 | MAI |
|-----------|-------------|-------------|-------------|-------------|-----|-------------|-------------|-------------|-----|
| GC 10     | 38.84d      | 38.08e      | 38.56e      | 28.07e      | 4.18f | 14.10cd     | 16.70f      | 39.88bc     | 6.31ab |
| GC 14     | 34.66d      | 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       | 57.46a      | 65.28b      | 80.92b      | 13.22c | 22.18a      | 35.01b      | 41.13bc     | 6.81ab |
| GC 514    | 46.71c      | 57.08c      | 58.74e      | 74.87b      | 12.14c | 13.52ed     | 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    | 46.9c       | 57.46c      | 65.28b      | 80.92b      | 13.22c | 22.18a      | 35.01b      | 41.13bc     | 6.81ab |
| GC 785    | 39.12d      | 43.23d      | 41.73e      | 44.27d      | 6.12e  | 12.25d      | 19.98fe     | 22.30def    | 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 (m³ha⁻¹y⁻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* × *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 Cameroon [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\(^\circ\)C and 30\(^\circ\)C. 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 lowland 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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