

Modeling Growth and Yield of *Grevillea robusta* Grown on Farm Boundary in Nandi County, Kenya

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Abstract

Population pressure has led to changes in land use and livelihood strategies in most highlands of Kenya. This among other factors has contributed to the increased integration of fast growing exotic trees species in to tree-crop production systems on short rotation for socio-economic benefits. *Grevillea robusta* is one of the exotic species in Kenya which is planted along farm boundaries for fuel wood and timber production. It is normally grown at varied linear spacing and different levels of management. It is preferred by most farmers because of its fast growth and yield as well as its suitability to be integrated with crops. This study investigated growth and yield of *Grevillea* trees grown in line configuration boundary planting and their economic implication in Nandi County. Farmers growing *Grevillea* who knew its ages were identified and growth data (height, diameter at breast height-dbh) collected from willing farmers. A total of 985 trees of *Grevillea* of ages ranging from 1-15 years in 39 different locations within the Upper and lower highland agro-ecological zone in Nandi County were measured. Six independent variables, that is; height, dbh, basal area (BA), age, location and spacing were used in modelling. The results revealed significant differences among the trees for height ($P=0.0001$), basal area ($P=0.0001$) and location ($P=0.0001$). Spacing was not significant ($P=0.1993$). Height was modeled using the equation $\text{Height} = -22.1003 + 25.0071 * (\text{Age}^{0.1566})$ while dbh was modeled using the equation $\text{DBH} = -4.4506 + 7.2629 * (\text{Age}^{0.5971})$ for growth while volume was modeled using the equation $V = D^2H$. Results of the socio-economic role of boundary planted *Grevillea* showed that these trees contributed significantly in reducing the gap between supply and demand for wood products in the study area. This study did not find overwhelming evidence ($p > 0.05$) in support of different linear spacing distances thus calling for further research.

Key Words: Modeling, Growth, Yield, *Grevillea robusta*, Farm Boundary

INTRODUCTION

Background

The increasing population densities have led to repeated subdivision of family lands in many areas in Kenya. A rapid decrease in land available for farming and forestry has recorded wood fuel and timber shortages in many highland areas of Kenya (Ngugi & Brabley, 1986). This has led to increased settlement of people in arid and semi-arid areas in Kenya which in turn has increased demand for timber in such areas (Okello *et al.*, 2001) and other tree products due to the rapid degradation of Kenyan forests to meet householders' needs and provide land for cultivation. This shortage is partly because of reduction in farm lands but also because farmers are not encouraged to take forestry as a

business through a proper logical analysis of tree growth and yield at a given time and place for them to make proper decisions and planning. Easy access to quality forest seeds and seedlings of all tree species suited to a given area is another factor to be considered.

Nandi County is located at an altitude of 1300-2500 meters above sea level, latitude of 0° and 0° 34', longitude of 34° 34'/35° 25'E and with a total area of 2,784km². The increasing population in this area (was at 752,965 in 2009) has continued to experience a rapid subdivision of available land to small holdings. This has led to a decline in the existing forests cover and if action is not taken to support the present forest cover, then a serious deficit will be realized. Some years ago, Lake Victoria Environmental Management Project (LVEMP) has tried to salvage the situation by encouraging farmers to plant trees on their farms in small woodlots and boundary planting. The LVEMP interventions in the Nandi County's catchments have involved seedling production, strengthening the Kenya Forest Department's extension services; capacity building among local farmers in tree establishment and management. According to Matano and Ogwen (2003) over 15.57 million seedlings have been planted, of which 85% being on farms and over 80% of these seedlings are *Grevillea robusta* and *Eucalyptus saligna*, which are planted on farms as woodlots, along boundaries and within homesteads. *Eucalyptus saligna*, *Cupressus lusitanica* and *Grevillea robusta* seedlings were targeted (because they are fast growing species) for fuel wood and timber (Ogwen *et al.*, 2001). This intervention may not succeed much if farmers are not encouraged to plant trees for their own benefit. The increasing standard of living therefore, calls for an embrace of forestry to provide not only services but financial benefits as well. This will only be done through a serious economic appraisal to ascertain the economic benefits from growing trees compared to other ventures. This will succeed if farmers will be provided with a growth and yield model that will enable them make decisions and plan for this venture. A model will show them how the trees will grow and how much volume they will expect at a given time.

Boundary planting of trees is therefore a convenient way to increase tree cover. Farmers will welcome the decision because this way, will not interfere with what they are doing in their farms and at the same time expect economic return. *Grevillea robusta* as discussed by Imo *et al.* (2001) is a third preferred exotic species in the Nandi County after *Eucalyptus saligna* and *Cupressus lusitanica*. The tree has been adopted as a major agroforestry tree species and has become a major timber species on small-scale farms, where it is significantly contributing to household income (Holding *et al.*, 2006). Most farmers in Nandi County therefore plant this tree species on the boundary of their farms and homestead because of its fast growth and suitability to be integrated with other crops.

The growth and yield of trees varies spatially from plantations, woodlot to edge or boundary plantings calling for spatial modeling approach (Muchiri *et al.*, 2002). Spatial modeling of growth and yield of this species grown on boundary of farms is important as a short-term strategy for monitoring growth and yield as a basis for studying the social and economic benefits of *Grevillea robusta*. Management decisions in forestry have the potential to impact greatly both the financial well-being of the forest owner and the future ecological condition resulting from timber and wood fuel management. It is important to understand the growth and yield potential of trees in a given area to optimize these decisions to meet the management goals at hand. It is a risk that any manager or a tree

owner would make a tree management decision without consulting the output from at least one growth and yield model. Models are even used in the formulation of policy concerning forest resources (Meadows & Robinson, 2002). It is a long-term goal of growth and yield modeling to build models of greater accuracy over larger domains of applicability.

While various authors have reported on growth and yield models of trees, the main concern of this research was to model growth and yield of boundary plantings (line spacing) of *Grevillea robusta* in Nandi County. Height, Dbh, Volume models and the effect of spacing on growth and yield was the main concern of this paper.

MATERIALS AND METHODS

The study was carried out in Nandi County located in the Great Rift Valley at a latitude of 0° and 34°, longitude of 34° 34' / 35° 25E with an altitude of 1300-2500. Nandi County has an area of 2, 884.2 Km² and a population of 752,965 (Males – 50% [376,477], Females – 50% [376,488]) which amounts to a population density of 261 people per Km², Kenya National population and Housing census (2009). This study was carried out in Kenya's Lower Highland (LH) and Upper midland (UM) agro-ecological zones in Nandi County (Jaetzold & Schmidt, 1983).

Height measurement was done through the aid of the following instruments: Suunto Clinometer, Tape measure, Height pole, and a Calculator while Diameter was measured using the Diameter tape.

This study investigated growth and yield of *Grevillea robusta* trees grown in line configuration boundary planting and their economic implication in Nandi County. Farmers growing *G. robusta* who knew its age were identified and growth data (height, diameter at breast height – dbh) collected from willing farmers. A total of 985 trees of *Grevillea robusta* of ages ranging from 1-15 years in 39 different locations within the Upper Midland and Lower Highland agro-ecological zone in Nandi County were measured. Six independent variables, that is; height, diameter at breast height (dbh), basal area (BA), age, location and spacing were used in modelling.

A topographic and agro-ecological zone map was used to identify farming areas. Accessible, unequal sized sample plots (farms) were randomly and proportionately selected along agro-ecological gradients. In each sample plot (farm), complete enumeration of trees was done. Tree age was calculated from the year of planting. The main measurements of data collected were; height, Dbh and spacing. Date of planting was obtained from the farmer's record and upon calculation, tree age was calculated.

The data collected from 985 trees of various ages and from various locations (farms) were analyzed using SAS/STATS (2006) to identify the best growth and yield models (Height model, Dbh model and Volume model). Modelling tree height, Dbh and Volume and further analysis of the effect of spacing on tree growth and yield were the two steps in this procedure.

RESULTS AND DISCUSSIONS

Height Model of *Grevillea robusta* in Nandi County

Height increment per age over 15 years in Nandi County showed that trees increased in size over time. The different colors and symbols describe observations in each of the 39 locations. The disparity in height and dbh is due to different levels of management by the farmers. However, this study could not ascertain this. The trend illustrated in Figure 1 shows that trees increased in height with age. Residual by predicted plots showed acceptable trends of normality as illustrated in Figures 2

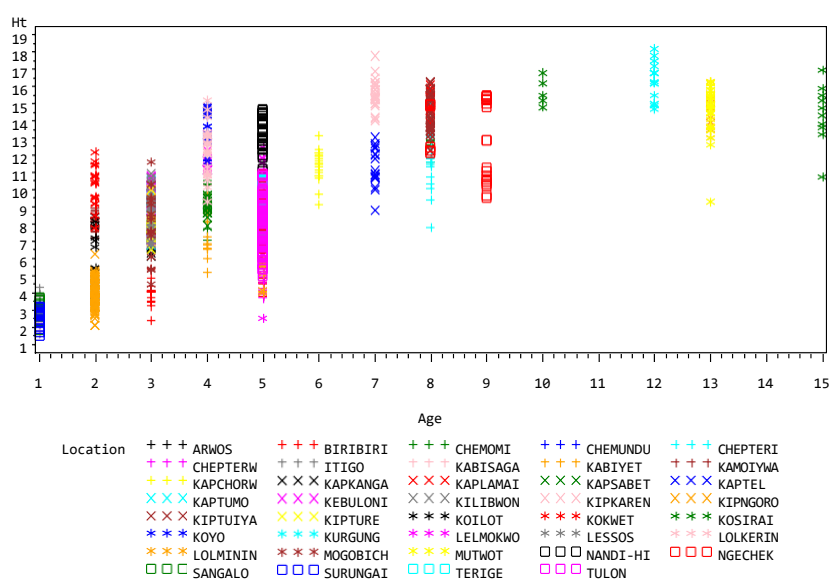


Figure 1. Plot of *Grevillea robusta* mean height by age in Nandi County

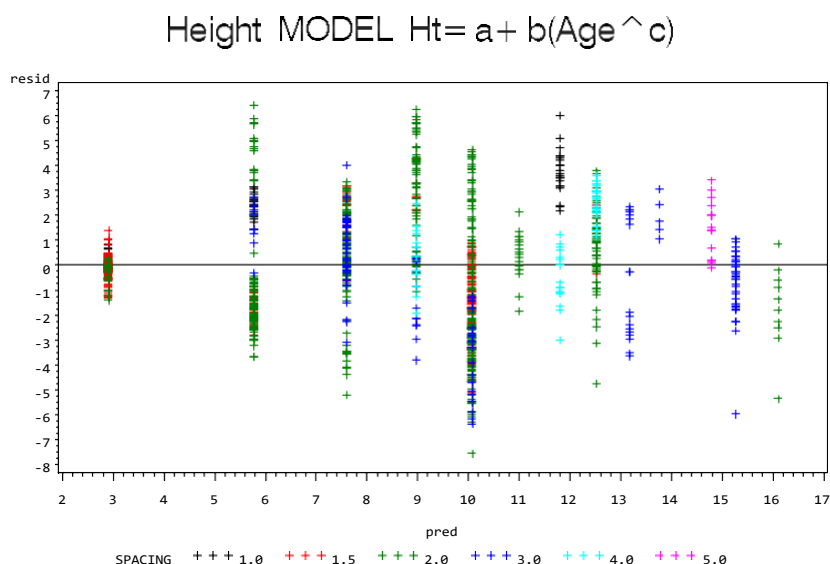


Figure 2. Predicted verses residual for height

Height was modeled using the exponential equation, $Y = a + b*(\text{Age}^c)$ in Nandi County where; Y = Tree height, Age = Age of the tree (years) and a, b, c are estimated regression coefficients as shown in table 1.

Table 1. Results of fitting height equations to the data

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence	
			Lower Limit	Upper Limit
a	-22.1003	11.2263	-44.1310	-0.0696
b	25.0071	11.0676	3.2880	46.7263
c	0.1566	0.0573	0.0441	0.2690

DBH Model of *Grevillea robusta* in Nandi County

Figure 3 shows a scattergram of dbh with age of *Grevillea robusta* in the 39 locations. Trees increased in dbh with age. The different symbols and colors describe dbh measured in the different locations. The disparities in dbh explain the difference in management of the farmer which this study could not ascertain. Residual by predicted plots showed acceptable trends of normality as those for height as illustrated in Figures 4.

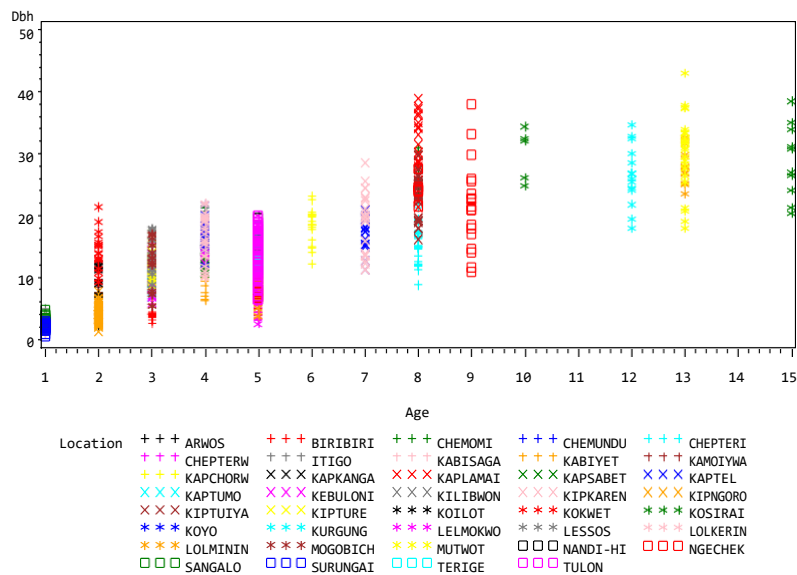


Figure 3. Plot of mean Dbh by age of *Grevillea robusta* trees in Nandi County

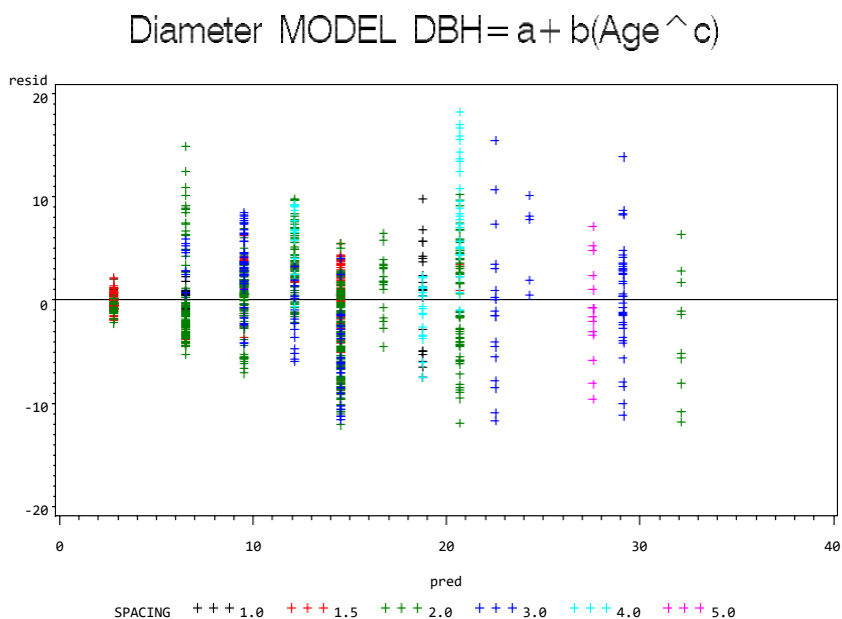


Figure 4. Predicted verses residuals for dbh in Nandi County

The model $Y = a + b * (\text{Age}^c)$ in Nandi County fitted well to the Dbh data where Y = Tree diameter at 1.3M, Age = Tree age (in years) and a, b, c are estimated regression coefficients as shown in table 2.

Table 2. Parameter Estimates from the fitting of Dbh model to the data

Parameter	Estimate	Approx Std Err	Approximate 95% Confidence Limits	
			Lower Limit	Upper Limit
a	-4.4506	1.6148	-7.6195	-1.2817
b	7.2629	1.2840	4.7432	9.7826
c	0.5971	0.0541	0.4909	0.703

Volume Model of *Grevillea robusta*

The increase in volume over 15 years is illustrated in Figure 5. Tree volume increased with age, as expected, however, effects of management were evident from the scatter plot (see for example figure 5 ages 8 and 9) where huge variations in volumes were observed.

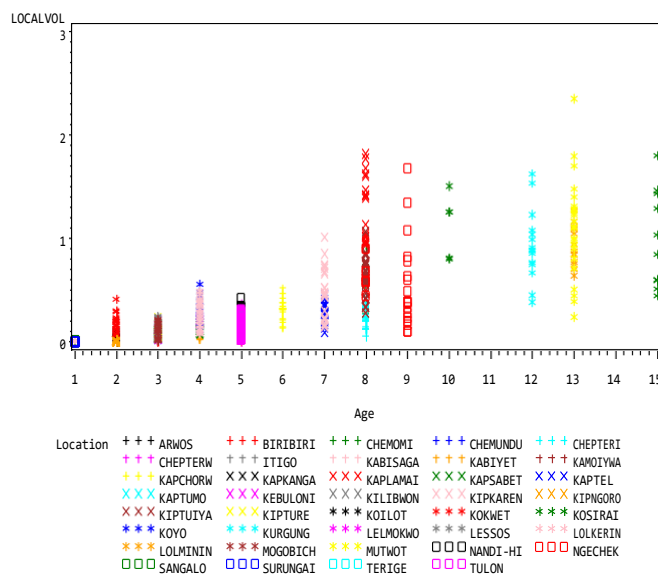


Figure 5. Plot of *Grevillea robusta* trees volume by age in Nandi County

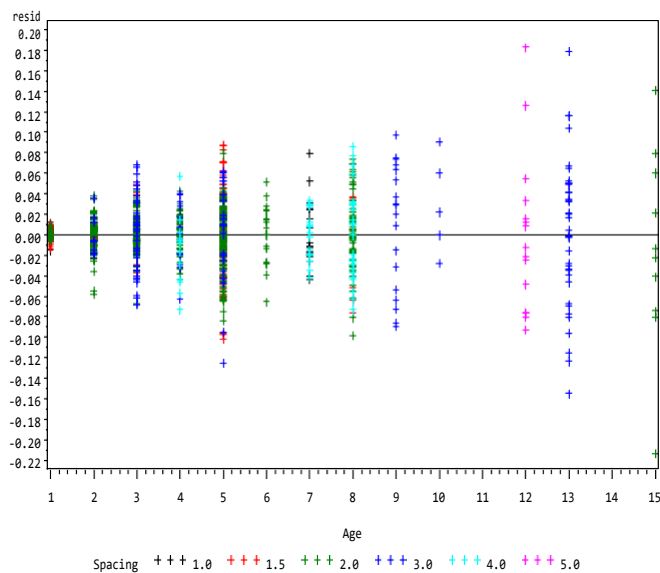


Figure 6. Residuals by age

The model $V = D^2H$ where V = Tree volume, D = Tree diameter and H = Tree height was chosen as the best volume model. Table 7 statistically illustrates the significance of the model. The p value of < 0.0001 shows that the model is significant.

Table 3. ANOVA table for local volume equation

Source	DF	Sum of Squares	Mean Square	F Value	P > F
Model	42	111.7008775	2.6595447	2220.25	< 0.0001
Error	942	1.1283845	0.0011979		
Corrected Total	984	112.8292620			

The normal curve and the frequency distribution of residuals in Figure 7 and 8 are acceptable. The slight disparity was due to different levels of management by the farmers which this research could not explain.

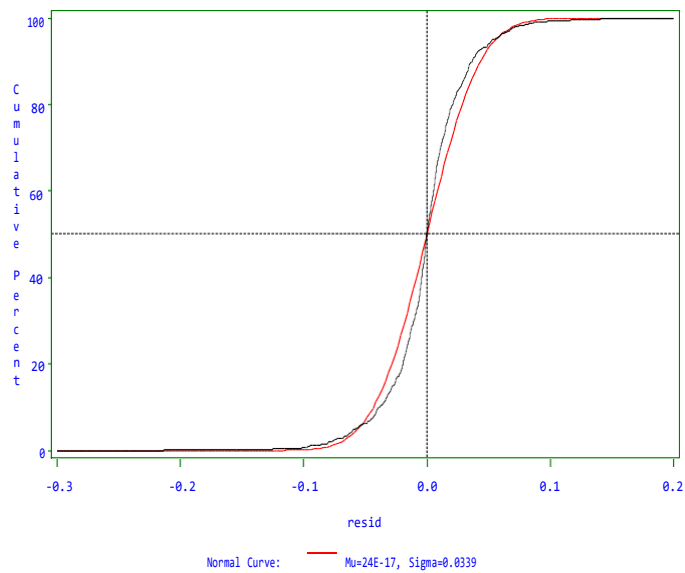


Figure 7. Normal curve for volume

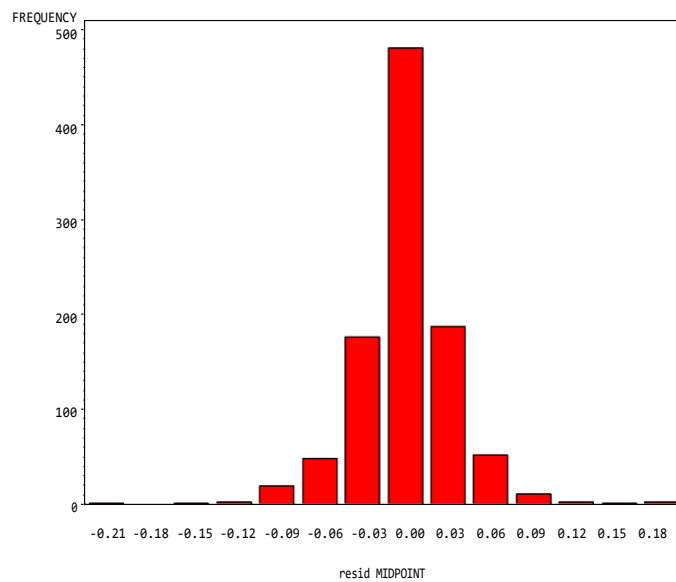


Figure 8. Graph of frequency distribution of residuals

Fitted Regression Model for Local Volume of *Grevillea robusta* Trees Grown in Linear Spacing

In a bid to understand the most significant variable influencing volume (Local Volume = D^2H), a regression was fitted using the forward approach method. The independent variables tried were Basal area, Height, Age, Spacing and Location. The results showed that Basal area (BA), Height, Age and Location had significant effects ($P < 0.0003$), however, spacing was not significant $P = 0.1993$ as shown in Table 8. This might be because of the fact that linear spacing, unlike in square or rectangular spacing where trees face competition from neighbors all around and thus may experience significant resource deficits (Kironko 2000, Kironko 1996), in linear spacing the competition is unidirectional (along the line). However, the tree faces no competition on the other two sides.

Table 4.1 ANOVA results

Source	DF	Type III SS	Mean Square	F Value	P > F
BA	1	17.28002529	17.28002529	14425.7	< 0.0001
Ht	1	0.02792965	0.02792965	23.32	< 0.0001
Spacing	1	0.00197637	0.00197637	1.65	0.1993
Age	1	0.01606938	0.01606938	13.42	0.0003
Location	38	1.45469109	0.03828134	31.96	< 0.0001

Famer's Level of Management on Growth and Yield of *Grevillea robusta*

The growth of *Grevillea robusta* trees was different even where trees were of the same age and from same agro-ecological zone. This was attributed to the micro-site characteristics (e.g. Kironko 1996) and the famer's level of management. From field observations, farmers who weeded and fertilized their trees recorded good growth while those who left the trees in competition with others such as grass were not performing well. Similar results have been reported by other researchers in tree growth and modelling e.g. Kironko (1996, 2000) in studies of juvenile radiate pine growth in New Zealand. This evidence calls for further research as in the current study; management is confounded with spacing and location. Table 8 shows that at $\alpha = 0.05$, location was statistically significant, therefore, location significantly affected the growth and yield of trees. Spacing in linear spacing did not give overwhelming evidence but contributed significantly as trees increased in size. This is given in detail below.

Effects of Spacing on Growth and Yield of *Grevillea robusta* Trees

Eventhough results in Table 8 from the ANOVA indicated that spacing was not significant, but further analysis showed that it had significant influence on growth in height and dbh as the trees advanced in age (Table 9). Height and dbh was not sensitive to spacing at ages below 3 years because the trees had enough growing space but as from 4 years and above, tree height and dbh was sensitive to spacing because there was competition for resources. This is almost similar to a study on growth of Casuarina (Kironko *et al.*, 2012) in which at year 3 (2006) all treatments in the 1-by-1 spacing suffered severe mortality with the best plot recording only 26% down from 75% the previous year (2005). Other results similar to this have been reported (Shainsky *et al.*,

1992; Kirongo, 1996; Kirongo, 2000) where trees suffered growth reduction due to competition for limited resources. Similarly, Kirongo *et al.* (2012) in a study of spacing of Eucalypts in a Nelder design reported poor growth of trees in the inner circles (0.4×1m spacing) and better growth for trees in the outer circles (2.4×1m spacing) of the Nelder which further supports the fact that closely spaced trees grow poorly compared to those with wider spacing. In this study therefore, there was a significant difference ($\alpha=0.05$) in height and dbh of trees grown at wider spacing. Tables 9 and 10 show this observation.

Table 9. Mean separation of effects of spacing at age 4 for height (Alpha 0.05)

The GLM Procedure	
Tukey's Studentized Range (HSD) Test for Ht	
NOTE: This test controls the Type I experimentwise error rate.	
Alpha	0.05
Error Degrees of Freedom	93
Error Mean Square	1.344352
Critical Value of Studentized Range	3.69972
Comparisons significant at the 0.05 level are indicated by ***.	
Spacing Comparison	Difference Between Means
2 - 1.5	0.0328
2 - 4	2.5717 ***
2 - 3	4.1578 ***
1.5 - 2	-0.0328
1.5 - 4	2.5389 ***
1.5 - 3	4.1249 ***
4 - 2	-2.5717***
4 - 1.5	-2.5389***
4 - 3	1.5861 ***
3 - 2	-4.1578***
3 - 1.5	-4.1249***
3 - 4	-1.5861***

Table 10. Mean separation of effects of spacing at age 4 for Dbh (Alpha 0.05)

The GLM Procedure	
Tukey's Studentized Range (HSD) Test for Dbh	
NOTE: This test controls the Type I experimentwise error rate.	
Alpha	0.05
Error Degrees of Freedom	93
Error Mean Square	7.824319
Critical Value of Studentized Range	3.69972
Comparisons significant at the 0.05 level are indicated by ***.	
Spacing Comparison	Difference Between Means
4 - 2	2.7556 ***
4 - 1.5	3.3023 ***
4 - 3	8.1536 ***
2 - 4	-2.7556 ***
2 - 1.5	0.5466
2 - 3	5.3979 ***
1.5 - 4	-3.3023 ***
1.5 - 2	-0.5466
1.5 - 3	4.8513 ***
3 - 4	-8.1536 ***
3 - 2	-5.3979 ***
3 - 1.5	-4.8513 ***

Effects of Spacing and Proximity to other Neighbouring Trees on Volume of *Grevillea robusta* Trees

In a study, the growth and survival of *Casuarina* were affected by its closeness to a mature *Eucalyptus* stand experienced at Gede (Kironko *et al.*, 2013). This almost similar observation was experienced with *Grevillea robusta* where trees at Kipkaren were grown at a close proximity to a nearby bush in comparison to trees grown in the open at Kaptel. The volume of these trees in the two locations at $\alpha=0.05$ was significant. Table 11 shows the comparison of volume of trees at the two locations at age 7 years.

Table 11. Mean Separation of volume of trees at Kipkaren and Kaptel at age 7 years

Tukey Grouping	Mean	No of trees	Location
A	0.47143	22	KIPKAREN
B	0.27819	16	KAPTEL

Means are significantly different. Alpha 0.05

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The conclusion drawn from this observation is that, boundary planting (line spacing) of *Grevillea robusta* significantly affects height, Dbh and volume growth of trees. The best growth and yield models to be used in Nandi County are; $Ht = -22.1003 + 25.0071 * (Age^{0.1566})$ for height, $DBH = -4.4506 + 7.2629 * (Age^{0.5971})$ for Diameter at breast height and $V = D^2H$ for volume.

The best spacing for boundary planting (line spacing) of *Grevillea robusta* in Nandi County was found to be 3-4m recommended because they differed significantly from the others but could change if management is improved. *Grevillea robusta* trees are harvestable as from five years and above and are the best option to increase tree cover to the projected 10% and at the same time solving socio-economic challenges of the smallholder famers.

Recommendations

- Boundary planting (line spacing) of *Grevillea robusta* is a recommended system to be adopted in Nandi County more especially as the size of farm lands becomes smaller and smaller, making use of the farm boundaries which would otherwise be left for non-economic use to raise productivity and income and increase tree cover.
- A program should be developed that will make procurement of seeds and seedlings of high quality to nursery owners and farmers respectively available to increase tree growing on farm and the overall increase in tree cover.
- There is need to provide farmers with high quality germplasm of a wider range suited to the diverse environments and socio-economic conditions of smallholder farmers thus will motivate farmers to venture in tree growing.
- Intensive agro ecology-based tree screening and management research

- programmes are essential in the determination of appropriate species for specific areas by employing various tree growth and yield models.
- Provision of incentives such as jembes, pangas, slashers, wheelbarrows, potting polythene bags and seeds to farmers who properly plant and manage trees, will develop farmers' confidence in tree growing and this will minimize the gap between wood demand and supply.
 - There is a need to demonstrate to farmers through an economic appraisal the financial gains they would derive from producing high quality trees by improving their tree management practices such as weeding, fertilization, pruning and thinning and this way will attract more farmers.

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BIO-DATA

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