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Assessment on Growth of *Eucalyptus maidenii* in Horizon Sopyrwa Forest in Nyabihu District, Northwest Rwanda

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ABSTRACT

The research has investigated the growth and predicts the volume/hectare to be harvested after 15 to 60 years in five age groups of *Eucalyptus maidenii* in two woodlots in Horizon Sopyrwa forest in Nyabihu District, Northwest Province of Rwanda. The growth and stocking parameters such as diameter at breast height (DBH), Tree height, basal area/ha (G), the volume/ha(V) and the Mean Annual Increment at the age of 15 years were measured in stand 1(Aidel) and stand 2 (Nyaruhonga) of the plantations. The mean tree volume obtained was 0.8963±0.1725m^3 and 0.3537±0.1302m^3 for stands 1 and 2, respectively while the corresponding mean volume/ha on the sites was 363.9031±32.7623m^3 and 116.1364±21.6221m^3, respectively. A higher mean annual increment in volume of 24.2603 m^3/ha/year was obtained in stand 1 whereas 11.8669m^3/ha/year in stand 2. The results clearly indicated that, the harvestable yield for stand 1at the recommended biological rotation age of 42 years will be 1413m^3/ha while the stand 2 at 53 years will be 1390m^3/ha. Thus, it can be concluded that in Horizon Sopyrwa, stand 1 is more productive as compared to stand 2.

Key words: Basal area, Diameter at breast height (DBH), Growth, Mean annual increment, Stocking parameters, Tree height and Volume.

INTRODUCTION

Forest resources in Rwanda have been steadily decreasing over time, especially since the beginning of this century, due to rapid population growth, a limited land base and growing competition for resources (Thomas, 1983; Anderson, 1985; Arora and Mukherjee, 1997). Despite the dwindling tree resources, the cultivation and management of woody species remains important in Rwandan farming systems. Trees are the primary sources of energy and construction material. Their cultivation is encouraged to prevent soil erosion, to increase soil fertility through mulching and green manure, and to provide products such as fruit, medicine and fibers. Over time, farmers have generated extensive knowledge about the management of indigenous tree species for these purposes. In addition, they have acquired and adapted knowledge about exotic species and silvicultural practices introduced since the 1930s (Nduwamungu et al., 2007). However, researchers have generally paid little attention to farmers' knowledge-building processes which allow them to adapt to environmental, political and socio-economic changes (FAO, 2005). Diminishing natural forest resources are being compensated by rapid expansion of the use of planted exotic trees worldwide (Bangroo et al., 2011; Bren and Papworth, 1993; Scott, 1998; Macdicken, 1997).

In Rwanda, exotics species represent a lower percentage of trees grown in the country due to their low adaptability to local climatic conditions and unavailability of seeds and others propagation stock materials. Among the exotic species that have been widely promoted in Rwanda include *Eucalyptus*, *Pinus, Accacia* species, *Alnus* *acuminate*, etc. Rwanda's high population density and large number of internally displaced refugees has pushed an ever- increasing number of people onto ecologically sensitive areas, such as Rwanda's remaining natural forests (Bangroo et al., 2011; Bren and Papworth, 1993; Scott, 1998; Macdicken, 1997). The degradation of forests in Rwanda results from demand for its products, fuel wood, building posts, casterite, gold, browse for livestock, wildlife and other products valued by local populations and the international community. This shortage of fuel for cooking is one of the many problems faced by people and many local sources of firewood are highly exhausted, leading people to travel further and further afield or to dig up tree roots, eliminating any chance of the trees growing again (Thomas, 1983; Anderson, 1985; Arora and Mukherjee, 1997). In Rwanda, particularly in volcanic region, insufficient firewood due to high demand for firewood and charcoal, leads to the use of inappropriate tree species in rural area, schools, tea industries and prisons for. This poses the main threat to the environment (Thomas, 1983; Anderson, 1985; Arora and Mukherjee, 1997). Eucalyptus species is most commonly used for plantation forests and on-farm woodlots. Since its introduction at the beginning of 19^{th} century, harvesting of poles from the first plantations was reported at Save (Huye District, Southern province) which made up more than 60% of all plantations in the country, and continued to dominate the landscape in plantations and woodlots (Nduwamungu et al., 2007). It is estimated that in 1989 there were more than 150,000 ha of eucalypt plantations and woodlots in Rwanda (Nduwamungu et al., 2007). In most parts of the country, eucalyptus is not well managed because of high demographic pressure which leads to exploitation and deforestation in order to get the land for agriculture and other products like fire wood.

The northern and western sides of the country is characterized as upland areas where the most grown *Eucalyptus* species was *E. maiden* due to its potential to adapt to this types of agro ecological characteristics, beside to the requirements of plantations in the area. This species can be planted in different niches such as mixed stands, pure stands, road boundaries, woodlots to satisfy the needs of people in terms of forest and non-forest products and furthermore, for income generation (Bangroo et al., 2011; Bren and Papworth, 1993; Scott, 1998; Macdicken, 1997). However, these studies show that *Eucalyptus species* grown differently when planted according to the niche in which they have been established for different purposes. This indicates that, when *Eucalyptus* species has to be planted, there should be the objectives of the plantation and the ecological requirement for the best growth of the targeted species should be considered to address the targeted purposes. Additionally, the management input required for each species of plantation depends on the ecology where we are planting and the purposes of the plantation. For example, if we need for fuel wood and or poles or any other construction purposes, the management activities and the species types to be planted is considerable. Hence, the current study has assessed the growth of *E. maidenii* grown in two woodlots in Horizon Sopyrwa at Nyabihu district, Northwest province of Rwanda.

MATERIALS AND METHODS

Study Area

Nyabihu District is situated to the Northwest of Rwanda. The administrative limits are: to the North, the Musanze District and the Democratic Republic of Congo (RCD), to the South Ngororero District and Rutsiro, in the East, Gakenke and Musanzes Districts and to the west Rubavu District. The relief of the District is very damages and is characterized by high mountains of which the culminating points are the karisimbi volcano and the Mountain of Muhe. The altitude is situated between 1.460 m and 4.507 m. There is also the lake of Karago that spreads on a surface of 27 ha. The district has an average temperature of 15°C and of the abundant precipitations, approaching 1400 mm per year. The flora of Nyabihu District constitutes Eucalyptuses, Cypresses, Pines and the herbaceous trees. There is also the natural forest of Gishwati and the Volcanoes National Park which is the cradle of various animal and plant species.

RESEARCH METHODOLOGY

Data Collection

GPS (GARMIN model GPSMAP® 62s) was used to map out the study area, to determine the total area to be sampled. A diameter tape (10 m) was used to measure the tree diameter at 1.30 m above the ground level to determine the DBH. Haga clinometer was used to take height measurement of the trees. The measuring tape of 30 m was used to demarcate the sample plots area. The Forest Inventory Form was used to record all the data obtained in the field that is the number of plots sampled, the number of trees per plot, height and DBH. The inventory work was divided into three stages: the pre-field stage, the field stage and post field stage. A survey was first conducted to map the forest area using GPS (GPSMAP® 62s) coordinates. Systematic sampling method was used to allocate samples in a different stands and size of samples was 0.04 ha represented by 20×20 m square plots which was systematically sampled with plots separated by 50 m. The collected data was used to calculate the number of stems per hectare (N) estimated by counting the number of trees in small representative sample plots of known area and divided by the plot area in hectares (Petit and Montagnini, 2004). Basal area is the cross section of tree at breast height (1.3 m above the

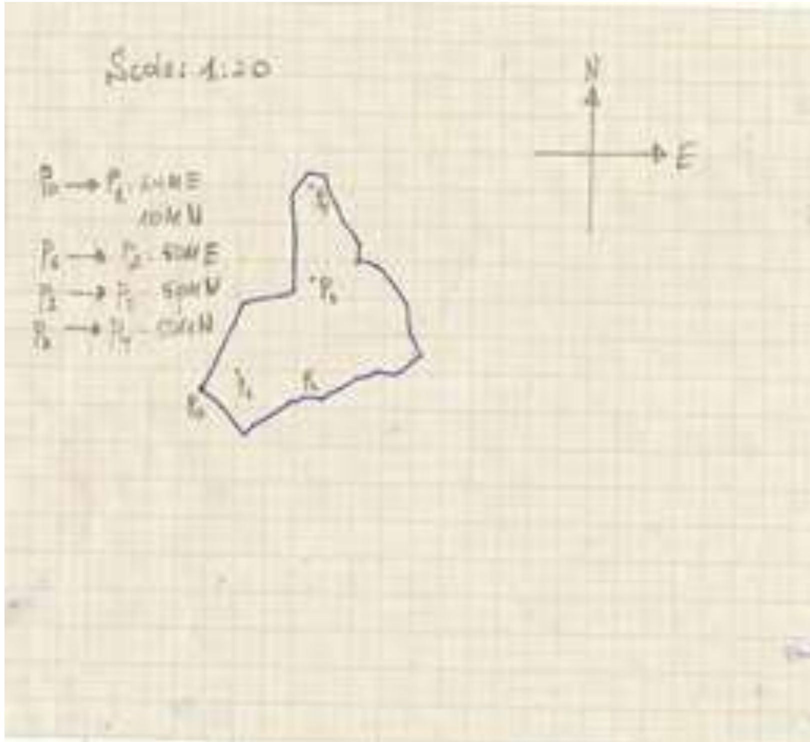

Figure 1. Map of *E. maidennii* plantation in Aidel forest of Horizon Sopyrwa.

ground). The basal area per hectare (m^2/ha) was determined by use of the formula below.

$$G=\left(\frac{\pi}{40000} * d^2\right) n \text{ (Samsudin et al., 2003)} \quad (1)$$

Where: G= basal area, d is the average DBH and n is the number of trees per hectare. The volume per hectare (m^3/ha) was determined by a volume equation designed for *E. maidennii* as proposed by (Petit and Montagnini, 2004).

$$V=\frac{\pi \times dbh^2}{40000} \times h \times \text{for } V=G \times h \times f \quad (2)$$

Where: V= volume; h =Total height; dbh = diameter at breast height; f = form factor; G = basal area.
The average mean annual growth rate in volume (m^3/yr) was determined by dividing the volume of trees at 15 years by the number of years (15 years) (Montagnini et al., 1995).

$$MAI = \frac{\text{Volume at age of consideration (X years)}}{\text{Number of years (X years)}} \quad (3)$$

The biological rotation, was determined using Mean Annual Increment and Current Annual Increment.

Data Analysis

Inventory data was analyzed by using JMP IN 10.0.2 where means that were highly variable were separated by using Student t' at $P \leq 0.05$. GROWFOR Software was used to predict the harvestable yield and obtained Mean Annual Increment and Current Annual Increment at 20^{th}, 25th, 30th, 35th, 40th, 45th, 50th, 55th and 60^{th} years of *E. maidennii* in Horizon Sopyrwa stands after planting.

RESULTS AND DISCUSSION

Mapping and Area Calculation of Horizon Sopyrwa Forest

A map derived from inventory conducted on 15 years of *E. maidennii* plantation in Horizon Sopyrwa stand 1(Aidel) is represented in the Figure 1 derived from using coordinates in Appendix 2. The total area of the plantation was calculated by use of the GPS (GARMIN model GPSMAP® 62s) and was found to be 3.67ha. A map derived from inventory conducted on 15 years of *E. maidennii* plantation in Horizon Sopyrwa stand 2 (Nyaruhonga) is represented in the Figure 2 derived from using coordinates in Appendix 3. The total area of the plantation was calculated by use of

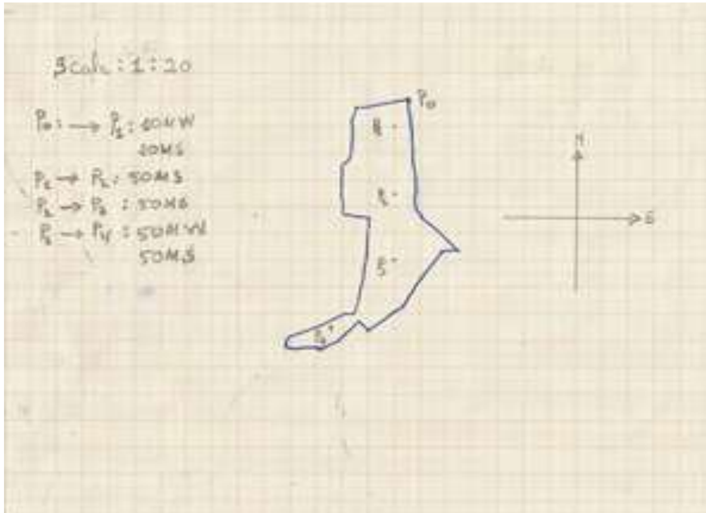

Figure 2. Map of *E. maidennii* plantation in Nyaruhonga forest of Horizon Sopyrwa.

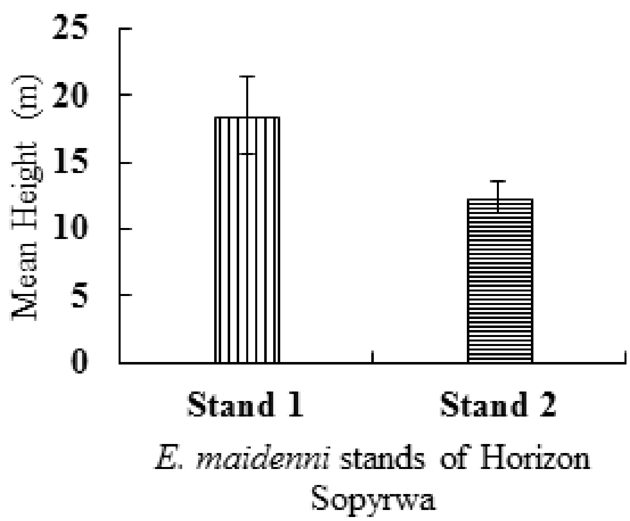

Figure 3. Mean diameter of *E. maidenni* stands of Horizon Sopyrwa in Nyabihu District.

the GPS (GARMIN model GPSMAP® 62s) and was found to be 2.86ha.

Growth and Stocking Parameters of *E. Maidennii* Plantation DBH

The mean diameter obtained from *E. maidennii* of Horizon Sopyrwa stands sampled was 21.6±1.2 cm. A higher mean diameter of 24.3±1.7 cm was obtained from stand 1 in comparison to 18.9±0.5 cm in stand 2 as indicated in Figure 3. These means were significantly different at p=0.0004. This mean diameter obtained from *E. maidennii* sampled in Horizon Sopyrwa stands is lower in comparison to 20.3 cm obtained in New Zealand for the same species at the age of 8 years (Thomas, 1983; Anderson, 1985; Arora and Mukherjee, 1997). According to (Rowan et al., 2009), a lower diameter of *E. maidenii* could be as a result of the high density in some plots implying a lot of competition for nutrients, light, water and space leading to suppressed growth in DBH.

Height (M)

The mean height of *E. maidennii* sampled in the different stands of Horizon Sopyrwa was 15.2±1.3 m. The mean height of trees in stand 1 (Aidel) was 18.5±2.0 m and was

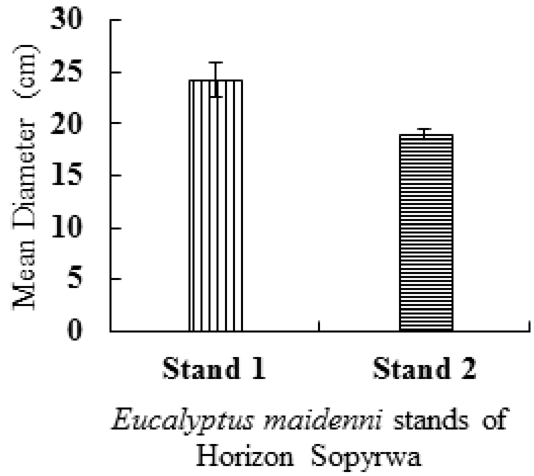

Figure 4. Mean height of *E. maidenni* stands of Horizon Sopyrwa in Nyabihu District.

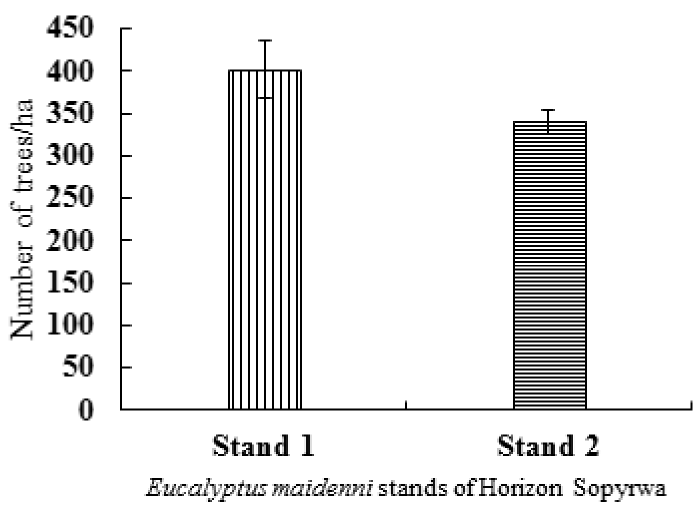

Figure 5. Number of trees/ha of *E. maidenni* stands stands of Horizon.

significantly higher (p=0.0083) than the height of 12.4±1.2 m attained by trees in stand 2(Nyaruhonga) as indicated in Figure 4. The mean height obtained from those both stands was generally low in comparison to the expected height of 24.7 m (81 feet) at the age of 8 years (Stewart, 2010). This lower height can be accounted for by the lack of nutrients and water, mismanagement, and presence of weeds leading to competition (Thomas, 1983; Anderson, 1985; Arora and Mukherjee, 1997).

Number of Trees/ha (N)

The mean number of *E. maidennii* trees/ha was 371 trees/ha in the different Horizon Sopyrwa forest stands. Stand1 had 402 trees/ha in comparison to 340 trees/ha obtained in stand 2 as shown in Figure 5 and the difference in means was statistically significant (p=0.0013). The mean number of *E. maidennii* trees/ha obtained from both stands of Horizon Sopyrwa was very low in comparison to the other studies that have shown a stocking density of between 2400-1100 stems/ha at age of 7 years (Nicholas and Hall, 2010). This density was also lower compared to 578 trees/ha obtained in UR/ CAVM forest stand (Thomas, 1983; Anderson, 1985; Arora and Mukherjee, 1997; Bangroo et al., 2011; Bren and Papworth, 1993; Scott, 1998; Macdicken, 1997). The low density could be as a result of low survival rates at the beginning and failure to beat up the stand. Illegal felling was also observed within

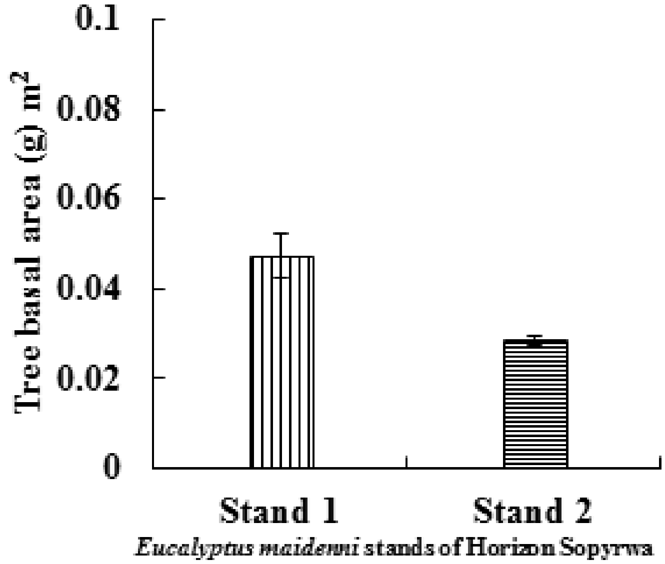

Figure 6. Mean tree basal area (m^2) of *E. maidenni* stands of Horizon Sopyrwa in Nyabihu.

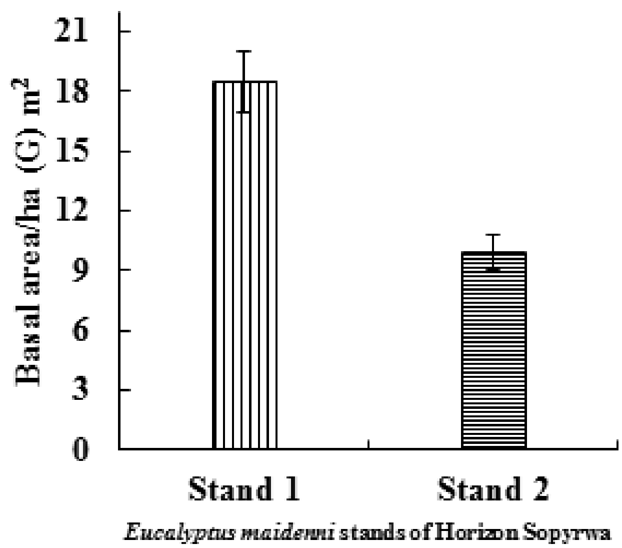

Figure 7. Mean basal area/ha (m2) of *E. maidenni* stands of Horizon Sopyrwa in Nyabihu.

the stand and could account for the low density.

Tree basal area/ha

The basal area of individual *E. maidennii* sampled was 0.0379±0.0042 m^2. The mean basal area of trees in stand 1(Aidel) was 0.0472±0.0049 m^2 whereas the tree basal area in stand 2 (Nyaruhonga) was 0.0286±0.0011 m^2 as indicated in Figure 6. Analysis of Variance indicated that these means were highly different at p=0.0001. The basal area/ha *E. maidennii* trees in Horizon Sopyrwa stand 1 (Aidel) was higher (18.5087±2.5585 m^2) than those in Horizon Sopyrwa stand 2 (Nyaruhonga) (9.9356±1.4779 m^2). These means were significantly different at p=0.001. The overall mean for the two stands was 14.2221±1.9476 m^2 (Figure 7). This results were comparable to that 14.2 m^2 obtained in UR/CAVM forest stand (Musanganizi, 2013). However, this basal area/ ha is very lower

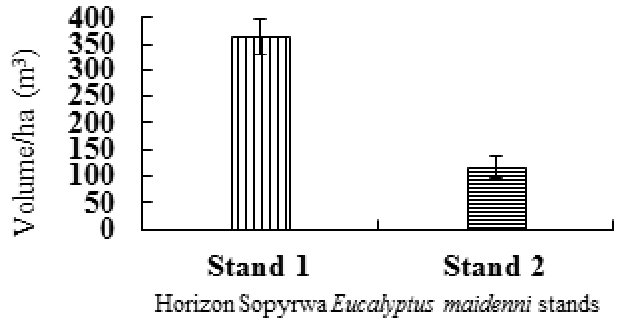

Figure 8. Mean volume/ha (m3) of *E. maidenni* stands of Horizon Sopyrwa in Nyabihu.

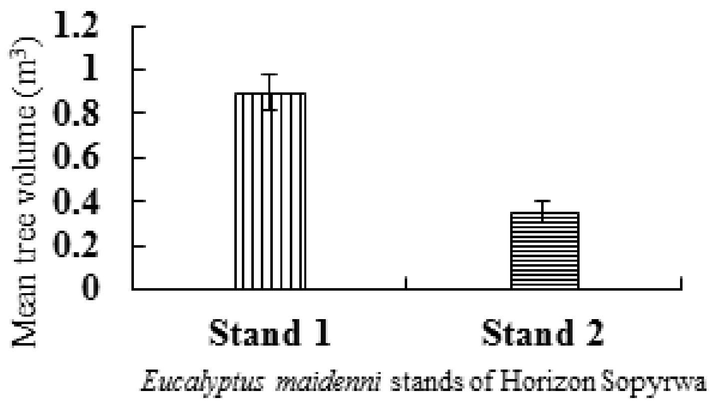

Figure 9. Mean Tree volume (m3) of *E. maidenni* stands of Horizon Sopyrwa in Nyabihu.

compared to the basal area/ha of 23.48 m^2/ha at the age of 8 years (Thomas, 1983; Anderson, 1985; Arora and Mukherjee, 1997). Stand basal area is a very useful parameter for quantifying a forest stand. It may be seen as a summary of the number and the size of trees in a stand and can be used to estimate stand volume or as a useful measure of the degree of competition or the density of a stand (Bangroo et al., 2011; Bren and Papworth, 1993; Scott, 1998; Macdicken, 1997). The lower basal area is due to competition resulting in smaller DBH and fewer number of trees/ha which are attributes used to calculate basal area.

Tree Volume/ha (V/ha)

The mean tree volume obtained from the two stands was 0.6250±0.1233 m^3. However, the mean tree volume obtained from stand 2 (0.3537±0.1302m^3) was significantly lower at p=0.0004 in comparison to tree volume in stand 1 which was 0.8963±0.1725 m^3 (Figure 8). The mean volume obtained from the two stands was 240.1364±26.1363 m^3. The mean volume/ha in Horizon Sopyrwa stand 1 was 363.9031±32.7623m^3 whereas the volume/ha obtained in Horizon Sopyrwa stand 2 was 116.1364±21.6221m^3 (Figure 9). These means were significantly different at p=0.0013. The mean volume obtained in Horizon Sopyrwa stand 1 was higher than 294.04 m^3 obtained in UR/ CAVM forest stand and that of 260 to 270 m^3 at the age of 14 to 16 years in New Zealand (Musanganizi, 2013) but lower volume/ha of 116.1364±21.6221m^3 obtained in forest Horizon Sopyrwa stand 2 in comparison to the two cases as mentioned above. Volume is dependent on density and height (Williams, 1998; Macdicken, 1997; Zbonak et al., 2007; Martin, 1982; FAO, 2010; MINICOFIN, 2010; Montagnini et al., 1995; Mulugeta, 2004; Roesch and Scott, 1989; Scott, 1998; Ason et al., 2003) and that is why in comparison to the same species, at the age of 7 years and density of 1100-2400 stems/ha, a yields of 194-297 m^3/ha volume can be realized (Nicholas and Hall, 2010).

Mean Annual Increment (MAI) in Volume (m^3)

The mean annual increment as indicated by the results obtained in volume was 24.26m^3/ha/year Horizon Sopyrwa stand 1 and 11.87m^3/ha/year in Horizon Sopyrwa stand 2.

Table 1. Yield prediction model for stand 1from the age of 15 years to 50 years old in Horizon Sopyrwa.

Age	Top Ht	Number of trees/ha	DBH	BA/ha	V/ha	CAI	MAI
15	18.6	402	24.2	18.5	363		
20	24.4	393	35	37.8	457	51	23
25	29.3	382	41.6	51.9	713	51	29
30	33.4	370	46.4	62.6	950	47	32
35	36.7	356	50.3	70.8	1162	42	33
40	39.4	343	53.5	77.3	1347	37	34
45	41.5	331	56.3	82.4	1505	32	33
50	43.2	319	58.7	86.5	1640	27	33

Table 2. Yield prediction model for stand 2 from the age of 15 years to 60 years old in horizon Sopyrwa.

Age	Top Ht	Number of trees/ha	DBH	BA	V/ha	CAI	MAI
15	12.4	340	19.4	10	116		
20	17	344	31.7	27.2	229	32	11
25	21.3	345	38.6	40.5	409	36	16
30	25.2	343	43.5	50.8	591	36	20
35	28.6	337	47.2	59	766	35	22
40	31.7	331	50.3	65.7	930	33	23
45	34.3	324	53.0	71.3	1082	30	24
50	36.6	316	55.3	72.9	1221	28	24
55	38.5	309	57.3	79.8	1347	25	25
60	40.2	302	59.2	83.1	1459	22	24

The results from stand 1 were higher than those obtained by Nicholas and Hall (2010) of MAI ranging from 17 to 18m^3/ha in New Zealand and 19m^3/ha in UR/CAVM by Musanganizi (2013). However, MAI obtained in stand two was lower in comparison to other findings elsewhere.

Harvestable Stand Prediction

If the *E. maidennii* of stand 1 (Table 1) would be harvested for each 5 years after planting, the age will be 20, 25 and 30, 35, 40 and 50 years. The harvestable yield would be 457m^3/ha, 713 m^3/ha, 950 m^3/ha, 1162 m^3/ha, 1347 m^3/ha, 1505 m^3/ha 1640 m3/ha, respectively. For stand 2 (Table 2), if the *E. maidennii* would be harvested for each 5 years after planting to the age of 60, that is at 20, 25, 30, 35, 40,45, 50, 55 and 60 years, the harvestable yield (volume) would be 229m^3/ha, 409 m^3/ha, 591 m^3/ha,766 m^3/ha, 930 m^3/ha, 1082 m^3/ha, 1221 m^3/ha, 1347 m^3/ha and 1459 m^3/ha, respectively.

Recommended Biological Rotation Age for Stand 1 of Horizon Sopyrwa

The recommended age of harvesting or harvesting is typically given by the point where MAI and CAI intercept (Thomas, 1983; Anderson, 1985; Arora and Mukherjee, 1997). From the analysis using JMP10 and GROWFOR, the biological age of rotation for *E. maidennii* for stand 1 is 42 years as shown in Figure 10. It means that when the *Eucalyptus* attains this age, harvesting should be mandatory in order to maximize long-term yield (Williams, 1998; Macdicken, 1997; Zbonak et al., 2007; Martin, 1982; FAO, 2010; MINICOFIN, 2010; Montagnini et al., 1995; Mulugeta, 2004; Roesch and Scott, 1989; Scott, 1998; Ason et al., 2003). The recommended age of harvesting/biological rotation age for harvesting as given by the point where MAI and CAI intercept (Musanganizi, 2013; Scott, 1990; Williams, 1998; Yang and Chao, 1987; Zbonak and Grzeskowiak, 2007; Roesch et al., 2009; Montagnini et al., 1995) for *E. maidennii* for stand 2 is 53 years as shown in Figure 11. This means that for full productivity to be realized, felling of the trees in stand 2 should be done when they attain.

Comparisons of the Productivity of Horizon Sopyrwa Stand 1 And 2

The harvestable yield for stand 1 in Horizon Sopyrwa at the recommended biological rotation age of 42 years will be 1413m^3/ha whereas the for stand 2 at 53 years will be 1390m^3/ha (Figure 12). This clearly indicates that despite the fact that trees in stand 2 will take a longer time for clear felling to take place (11 years) it still yields a lower volume by 1.65% in comparison to stand 1. The differences in the productivity can be linked to differences in site conditions with regard to both climatic and soil factors (Komakech et al., 2007; FAO, 2010; Grosenbaugh, 1949; Kauppi et al., 1997; Macdicken, 1997). The survival and initial stocking density also plays a key role in the final harvest as the higher the number of tree that are there, the higher the harvestable volume (King, 1990; Kleinn, 2007; Lamprecht, 1989; Martin, 1983; Thomas, 1983; Williams, 1998; Yang

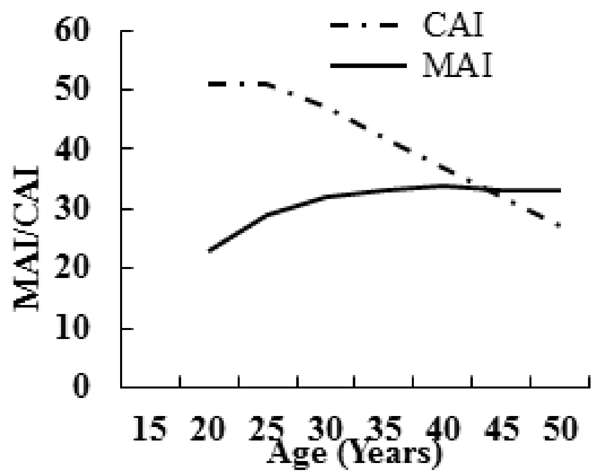

Figure 10. MAI and CAI for *E. maidenni* in stand 1 of Horizon Sopyrwa.

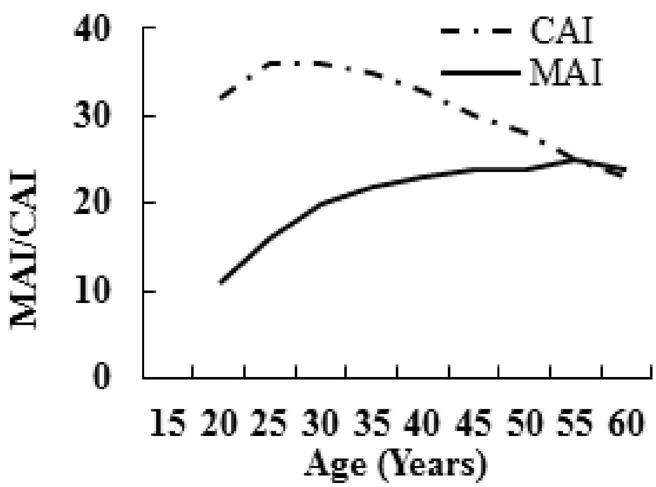

Figure 11. MAI and CAI for *E. maidenni* in stand 2 of Horizon Sopyrwa.

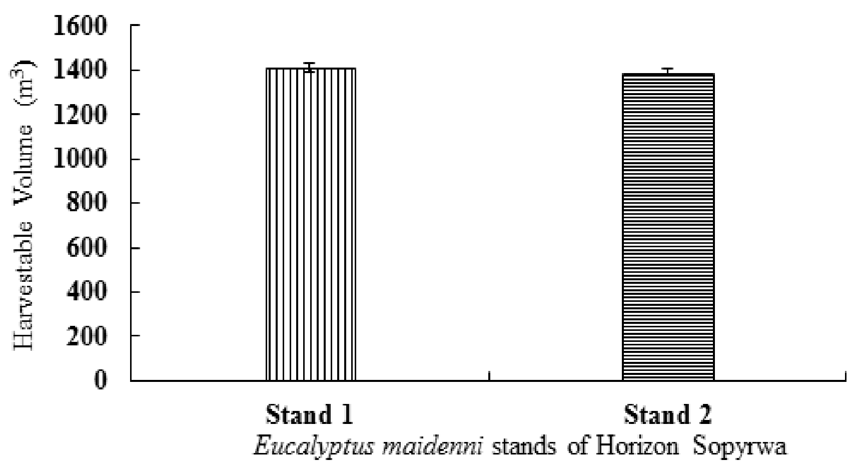

Figure 12. Comparison of the productivity of Horizon Sopyrwa stands 1 and 2.

and Chao, 1987).

CONCLUSION

The overall objective of the study was to assess the growth of *E. maidenii* grown in two woodlots by Horizon Sopyrwa in Nyabihu distric, Western province. From the results a difference in growth and stocking parameters of the trees in the two sites was deduced. The mean DBH was 21.6±1.2 cm for both stands, average height was 15.2±1.3 m. The overall mean basal area/ha (G) of *E. maidennii* at the age of 15 years for the two stands was 14.2221±1.9476 m^2; the mean volume obtained from the two stands was 240.1364±26.1363 m^3 and The mean annual increment as indicated by the results obtained in volume was 24.2603 m^3/ha/year Horizon Sopyrwa stand 1 and 11.8669 m^3/ha/year in Horizon Sopyrwa stand 2. It is clear from the results that the tree growth and stocking parameters investigated in this study showed that stand 1 performed better in comparison to stand 2. The harvestable yield for stand 1 in Horizon Sopyrwa at the recommended biological rotation age of 42 years will be 1413m^3/ha whereas for stand 2 at 53 years will be 1390m^3/ha.

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