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Survival and Growth of *Podocarpus milanjianus* and *Afrocarpus usambarensis* Seedlings under Field Conditions in Sango Bay, Uganda

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Abstract: Growth rates of *Afrocarpus usambarensis* and *Podocarpus milanjianus* in the Sango Bay forest area in Southern Uganda were evaluated between January 2001 and June 2003. Survival and increase in girth and height of 7,525 seedlings planted on farmers land adjacent to the forest were monitored at 3 months intervals. By the final measurement session, 6,889 seedlings (91.5%) had survived comprising 4,517 *Afrocarpus usambarensis* (66%) and 2,372 *Podocarpus milanjianus* (34%). Data were subjected to a mixed model analysis, taking into account repeated measures and the factorial treatment structure of the data. It was observed that seedlings of *Afrocarpus usambarensis* survived better in the waterlogged soils than *Podocarpus milanjianus*. *Afrocarpus usambarensis* had a higher rate of girth and height increment than *Podocarpus milanjianus* under similar conditions. However, *Afrocarpus usambarensis* grows faster in these conditions than *Podocarpus milanjianus* within the same period. For tree growers, *Afrocarpus usambarensis* would be more suitable than *Podocarpus milanjianus* for on-farm planting.

Key words: Seedling, growth, forest, Sango Bay, Uganda

INTRODUCTION

Afrocarpus usambarensis and *Podocarpus milanjianus* are members of the Podocarpaceae family that are distributed in Africa and follow a discontinuous mountainous belt from Cameroon to Angola in the West and from Ethiopia in the Northeast to the Southern Cape in South Africa (Adie and Lawes, 2011). In Uganda, *Podocarpus milanjianus* is found under montane and upper montane forest while *Afrocarpus Usamberencis* is found in swamp forest that is continuous with the Minziro forests of Tanzania. The success of podocarps is credited to their greater longevity and ability to regenerate in shade compared to angiosperms (Adie and Lawes, 2011). Kitayama also noted that the conditions in monotone forests such as population structure, growth rate and crown light, show that podocarps are shade intolerant and require canopy gaps or sparse canopy for regeneration. Podocarps are often found on low-nutrient soils and this is worsened by the nutrient limitation due to the production of slow decomposing litter. Podocarps grow on a range of soils from relatively fertile (Solomon *et al*., 2002) to infertile soils with most mineral nutrients locked into organic forms (Coomes *et al*., 2005). Nonetheless, the ability of podocarps to grow and compete on infertile sites explains their occurrence in lowland tropical habitats and their dominance on older and phosphorus-limited temperate sites (Coomes and Bellingham, 2010). The presence of abundant as well as long root hairs and mycorrhizas may indicate that podocarps have different functions in nutrient uptake under conditions of poor mineral availability. Cernusak noted that there is a need to understand ecophysiology of podocarps in order to explain why these tropical trees are restricted to wet, infertile environments. Additional there is inadequate information of growth of podocarps in Uganda.

Trees, forests and woodlands cover about 14% of Uganda's land surface and support livelihoods of millions of people. Uganda's current population is 34.9 million, growing at 3.26% per annum (UBS, 2014). Over the last 30-40 year, growth in human population and corresponding increase in demand for forest products for domestic and industrial use, expansion of agricultural land, illegal settlements and weak forest management capacity have accounted for degradation and loss of natural forests in Uganda (M.W.L.E., 2001). Deforestation rate is estimated at 2% per year. Until recently, little attention had been paid to development of commercial

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forestry and promotion of on-farm tree planting in Uganda which should have provided alternative forest products and services to relieve the pressure on natural forests. Out of 4.9 million hectares of forests and woodlands in Uganda, 64% (1,265,471 ha) are found outside the Permanent Forest Estate (PFE) (land set aside for forestry activities and regulated by district local governments). The PFE is 1.9 million ha of which 61.4% is managed by the National Forestry Authority (NFA), 33.6% is managed by Uganda Wildlife Authority (UWA); 4.7% is jointly managed by NFA and UWA and 0.3% by district local governments.

Uganda government has made policy adjustments in the forest sector with major attention focused on promotion of on-farm tree planting, collaborative forest management and large scale-tree plantation establishment by the private sector. Consequently, there is increased need for identification and establishment of tree species outside forests that can provide products and relive pressure on natural forests. *Afrocarpus usambarensis* and *Podocarpus milanjianus* have been growing in the Sango Bay forests for a long time and regenerating from forest floor seeds and soil seed bank. The trees have been heavily exploited for timber and their natural populations threatened. Local people in the Sango Bay forest area indicated that the trees grew slowly and take long to mature thus, they are not motivated to plant them on-farm. However, the trees can be grown on farm to reduce pressure on natural populations if information on the seedling survival and their height and girth growth rates is available. These aspects together with effect of site on girth and height increments were examined in this study.

MATERIALS AND METHODS

Study area: Sango Bay forest area (0°47'-1°00' S and 31°28 -31°43'E) covers 576 km^2 on the Western shores of Lake Victoria (Fig. 1). It is the largest tract of swamp forest

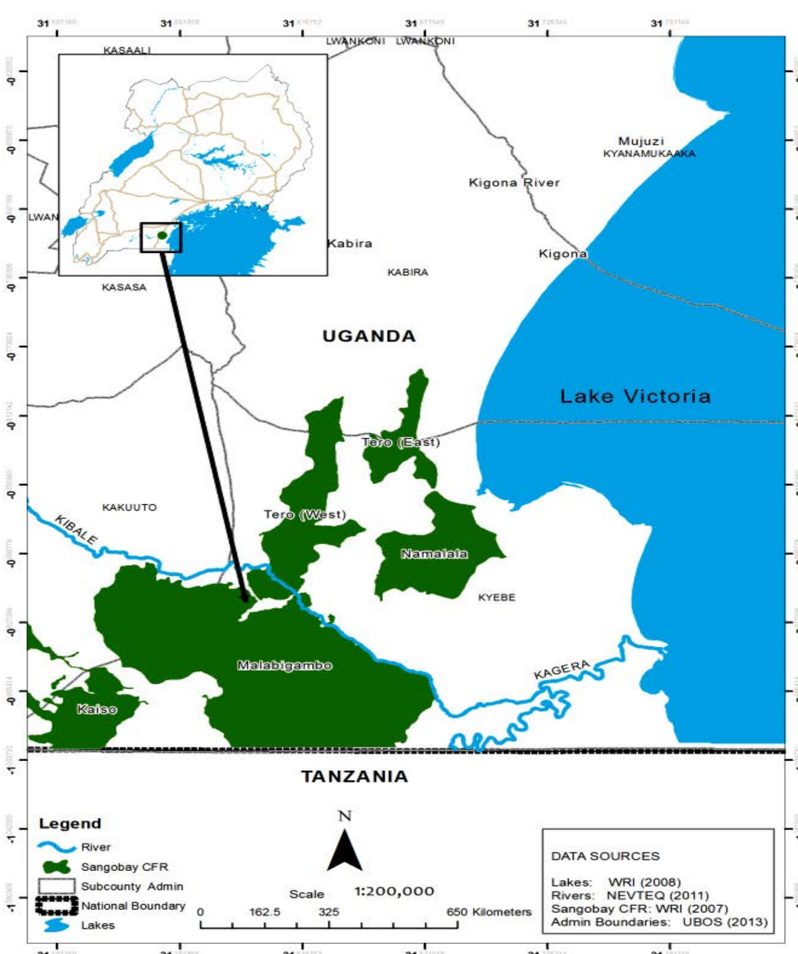

Fig. 1: Map of Sango Bay forest

ecosystem in Uganda that is continuous with the Minziro forests of Tanzania and is found now here else in East Africa (UFD., 1996, 2001). The reserve forms part of the transitional and regional forest/wetland ecosystem and represents a unique relict forest/wetland community of considerable bio-geographical significance. It receives 1,250-2,125 mm of rainfall per annum. There are two distinct rainy and dry seasons: the long rains are received in March to May and the short rains from end of September to November. The mean annual temperature ranges from 16-26°C. The relative humidity ranges from 80-90% in the morning and decreases to from 61-66% in the afternoon from January to May. From June to August the relative humidity decreases to about 77% in the morning and to about 50-57% in the afternoon (UFD., 1996).

Study design, planting materials and sites: The study was conducted on farm for two main reasons; firstly, farmers do not grow trees under controlled environment; therefore it was important to monitor the survival and growth of seedlings under a farm setting and secondly, farmers grow trees on land holdings of different sizes. A complete randomized design with factorial treatment structure was used in this study. The factors considered included site at three levels (Kigazi, Ssekond-Kateera and Natural forest boundary) and species at two levels (*Afrocarpus usambarensis* and *Podocarpus milanjianus)*.

Seedlings of *Afrocarpus usambarensis* (*A. usambarensis*) and *Podocarpus milanjianus* (*P. milanjianus*) were raised in a tree nursery established outside Sango Bay forest. Three planting sites were selected, taking into account availability of land and farmers willing to plant and protect the seedlings from damage by livestock and fire as follows: Kigazi (black loamy soils); Ssekonda-Kateera (sandy soil) and (waterlogged natural forest boundary). The forest boundary exhibited a swamp forest condition that supported natural populations of the two species in Sango Bay forest area. In the experimental design, it was assumed that altitude, rainfall and temperature were uniform except soil and drainage that varied.

Seedling survival, girth and height measurement: At each of the planting sites, the seedlings were marked using white paint and a masking tape and serially numbered at the time of planting. These helped to identify, locate and confirm the number of seedlings that survived at the time of measuring the girth and height. A total of 7525 seedlings (4720 *Afrocarpus usambarensis* and 2805 of *Podocarpus milanjianus)* were planted as follows: site 1 (525 seedlings), site 2 (3000 seedlings) and site 3 (4000 seedlings). Girth was measured using a collar girth clipper while height was measured using a tape measure at three months intervals from January 2001 to December 2003.

Data analysis: Exploratory data analyses were used to describe and explore trends in the data (i.e., line graphs and summary statistics) and spread of the data was computed to show variations in girth and height increments within and between the different sites. Due to lack of independence in data within and between fixed effects (through time), the data collected on seedling growth over time were analyzed with a linear mixed model using Genstat version 12 and considered as a repeated factor (repeated in time) based on (Schabenberger and Pierce, 2009). The fixed effects were assessed at 5% significance level. In the second stage, data were subjected to a mixed model of analysis of variance, taking into account the repeated measures and factorial treatment structure of the data. Various covariance structures were fitted to the data and assessed using Akaike Information Coefficient (AIC) and Schwarz Information Coefficient (SIC). The covariance structure with the lowest AIC and SIC was chosen and fitted to the data. It was assumed that seedling girth and height increased at different rates (Synott, 1975; Lieth and Reynolds, 1986; McGraw and Garbutt, 1990) and that growth in the earlier months influenced growth increments in the subsequent months.

RESULTS AND DISCUSSION

Survival of *Afrocarpus usambarensis* and *Podocarpus milanjianus* seedlings

Site 1: Kigazi (black loam soils): Out of 525 seedlings planted, 320 was *A. usambarensis* and 205 was *P. Milanjianus*; thus, about 63% *A. usambarensis* and 58% *P. milanjianus* survived. There was no significant difference ($z = 0.652$, $p>0.05$) in the survival of *A. usambarensis* and *P. Milanjianus* seedlings.

Site 2: Ssekonda-Kateera (sandy soil): Out of 3,000 seedlings planted, 2200 was *A. usambarensis* and 800 was *P. Milanjianus*; about 24% of *A. usambarensis* and 38% *P. milanjianus* survived. Survival rate of *A. usambarensis* seedlings was higher at Kigazi than Ssekonda-Kateera site while *P. milanjianus* seedlings survived better at Ssekonda-Kateera. There was a significant difference in survival of *A. usambarensis* and *P. Milanjianus* ($z = 5.33$, $p<0.05$) thus indicating that *P. milanjianus* survives better (by 14%) in sandy soils than *A. usambarensis*.

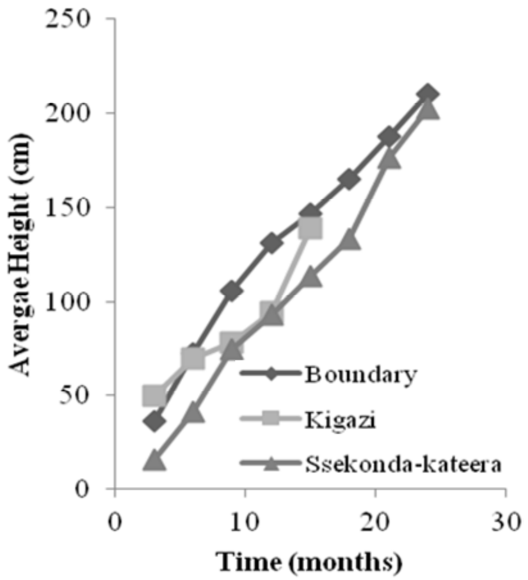

Fig. 2: Height increment over time for *A. usambarensis*

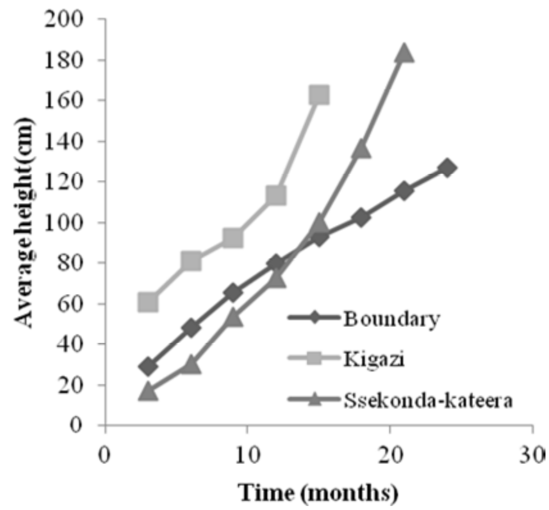

Fig. 3: Height increment over time for *P. milanjianus*

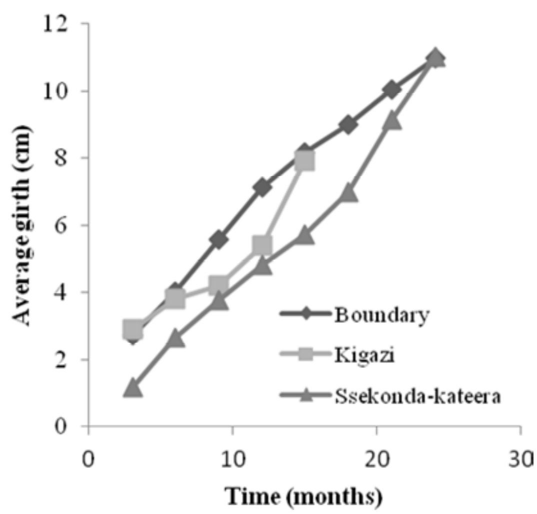

Fig. 4: Girth increment for *A. usambarensis*

Site 3: Waterlogged natural forest boundary: Out of 4000 seedlings planted, 2200 was *A. usambarensis* and 1800 was *P. milanjianus*. Nearly half (49%) of *A. usambarensis* seedlings survived in the water logged clayey soils along the natural forest boundary and slightly less than one-third (27%) of *P. milanjianus* survived. There was a significant difference ($z = 10.42$, $p<0.05$) in the survival of *A. usambarensis* and *P. Milanjianus* thus indicating that *A. usambarensis* survives better (by 22%) in water logged clayey soils than *P. milanjianus*.

Growth of *A. usambarensis* and *P. milanjianus* seedlings: Growth of seedlings was indicated by increment in girth and height. Mean profile plots were used to assess the changes in seedlings height and girth. There was higher increment in height of *A. usambarensis* seedlings growing at the natural forest boundary than those growing at Kigazi and Ssekonda-kateera sites (Fig. 2). On the other hand the height of *P. milanjianus* seedlings increased more at Kigazi site than on the forest boundary (Fig. 3). Seedlings of *A. usambarensis* exhibited higher increment in girth at the natural forest boundary than at Kigazi and Ssekonda-kateera sites (Fig. 4). On the other hand, *P. milanjianus* seedlings had higher height increment at Kigazi site (Fig. 5).

Variation in girth and height increment of *P. milanjianus* and *A. usambarensis* seedlings: Analysis of three covariance structures showed that Auto Regressive (AR) 1 had the smallest AIC and BIC values (Table 1). Fitting the model with the girth and height increment data using AR (1) covariance structure generated the results given in Table 2. There were significant variations in the girth and height increments of *P. milanjianus* and *A. usambarensis* seedlings at the three sites. There were significant interactions among the following terms: site×species×time; site×species; site×time; species×time, thus, indicating that seedlings height significantly increased in the different sites and varied over time and among the two species. Results also indicate that height increment was influenced by time and this differed among the species (Table 2). Significant site effect indicates that increment in height differs for the

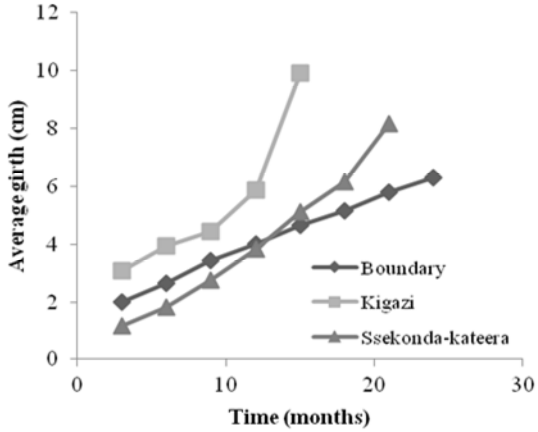

Fig. 5: Girth increment for *P. milanjianus*

Table 1: Fit statistics for mixed model analysis of height and girth of seedlings using Compound Symmetry (CS), 1st order Autoregressive (AR 1) and Unstructured (UN)

	Covariance structures					
	Height			Girth		
Fit statistics	CS	AR (1)	UN	CS	AR (1)	UN
AIC	73937	73921	74101	46485	46472	46489
SIC	73957	73952	74115	46506	46510	46503

Compound Symmetry (CS), 1st order Autoregressive (AR 1) and Unstructured (UN)

Table 2: Modeling distribution of height for both seedlings

Fixed term	Wald statistic	Nem df	F statistic	Den df	p-values
Site	649	2	325	2111	<0.001
Species	229	1	229	2665	<0.001
Time	3922	1	3922	7	<0.001
Site×species	1009	2	504	1457	<0.001
Site×time	162	2	81	128	<0.001
Species×time	77	1	77	197	<0.001
Site×species×time	244	2	122	250	<0.001

Nem df = Numerator degrees of freedom, Den df = Denominator degrees of freedom

different sites where height of *A. usambarensis* seedlings increased more at the natural forest boundary than at other sites while *P. milanjianus* seedlings height increased more at Kigazi site than others.

There were significant interactions among the following terms: site×species×time; site×species; site×time; species×time, thus indicating that the girth of seedlings significantly increased at the different sites and varied over time and among species. Results also indicate that girth increment was influenced by time and this differed among the species (Table 3). Significant site effect indicates that increment in girth differed at the different sites with *A. usambarensis* registering higher girth increment at the natural forest boundary than those growing on other sites. At the same time, the girth

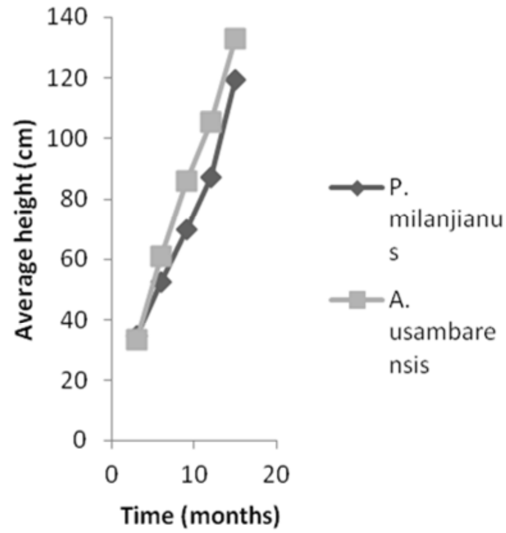

Fig. 6: Interaction plots of time and height

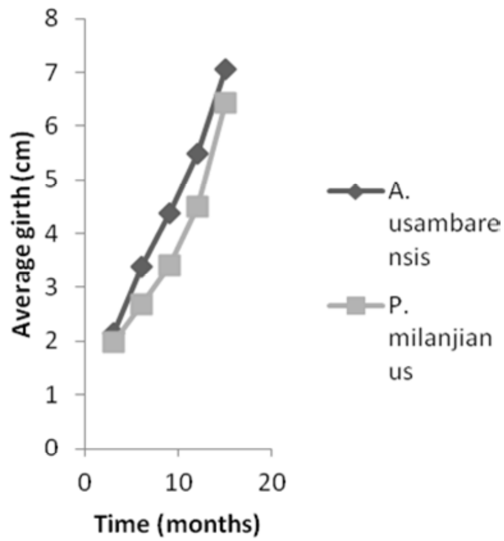

Fig. 7: Interaction plots of time and girth

Table 3: Modeling distribution of girth for both seedlings

Fixed term	Wald statistic	Nem df	F statistic	Den df	p-values
Time	1585	7	226	226	<0.001
Site	68	2	34	34	<0.001
Species	112	1	112	112	<0.001
Time×site	85	11	8	8	<0.001
Time×species	105	7	15	15	<0.001
Site×species	106	2	53	53	<0.001
Time×site×species	42	10	4	4	<0.001

Nem df = Numerator degrees of freedom, Den df = Denominator degrees of freedom

of *P. milanjianus* seedlings increased more at Kigazi than at other sites. Figure 6 and 7 show that increment in height and girth for both species is influenced by time with *A. usambarensis* seedlings exhibiting a higher girth and height increment than *P. milanjianus* seedlings.

We examined the increase in girth and height of *P. milanjianus* and *A. usambarensis* seedlings at three sites in the Sango Bay forest area with different soil types. At the same time, we examined the interaction between the seedlings of *P. milanjianus* and *A. usambarensis* and site conditions (environment) under uncontrolled field conditions. Plant-environment interaction has been widely studied and reported in agricultural and forestry research (Wagoire *et al*., 1999; Montagnon *et al*., 2000; Adugna and Labushchagne, 2002). Understanding plant-environment interactions is vital for improvement and sustenance of productivity of agricultural crops and trees.

In the Sango Bay forest area, the problem of on-farm planting of indigenous trees such as *A. usambarensis* and *P. milanjianus* that grow slowly and take long (>30 years) to mature can be partly addressed by action research in which farmers are involved in on-farm trials of tree species under field conditions. Such approach helps to change farmers' attitudes towards planting of slow growing indigenous tree species. Participatory studies that involve farmers in on-farm trials to monitor the growth performance of trees under field conditions have been practiced for a long time (Rhoades and Booth, 1982; Chambers and Ghildyal, 1985). However, field conditions need to be sufficiently similar as was the case in the Sango Bay area to permit realistic assessment of seedling growth rates.

Planting of indigenous or exotic trees on-farm requires adequate knowledge and clear understanding of plant-environment interaction. At the same time, farmer's participation makes it possible to utilize their knowledge in evaluating seedling growth performance under field conditions. Oeba *et al*. (2009) applied a similar strategy to monitor height and girth growth of Eucalyptus hybrid seedlings on farms in Kenya in an effort to explain seedling-environment interaction. They observed that farmer's roles in such a study need to be clearly defined for instance, fire protection, weeding and livestock control because seedlings in the early stages are vulnerable to damage.

Although, not specifically examined in this study, on-farm weeding enhances height and girth growth of tree seedlings (Evans, 1992). In a related study in the Southern highlands of Tanzania (Msangi *et al*., 2009) reported that 2 year old Eucalyptus seedlings planted on-farm were chocked by couch grass (*Agropyron repens*) due to lack of weeding but girth and height growth improved shortly after clean weeding was introduced. According to Adams *et al*. (1998) and Kirongo *et al*. (2002), competition from grass is more deleterious in the early stages of seedling establishment and growth and can slow down its growth. Therefore, farmers' participation in on-farm trials is critical as their role in weeding ensures survival and growth of the tree seedlings.

Survival of *P. milanjianus* and *A. usambarensis* seedlings: Literature on seedling survival in the tropics focuses mainly on results of experiments conducted under controlled conditions for instance. Baberis and Tanner (2005), Coomes and Grubb (1998) and Denslow *et al*. (1991). Coomes and Grubb (2000) reported results of studies on the effects of competition for resources on seedling survival and growth under controlled conditions. On the other hand, Gerhardt (1996) assessed the effect of root competition on tree seedling growth while Barberis and Tanner (2005) evaluated the effect of gaps and trenching on seedling survival and growth in Panama. Both studies concur that across the tropics except in the wettest sites with fertile soils, survival of tree seedlings depend on belowground competition.

We examined and compared survival of the seedlings of *A. usambarensis* and *P. milanjinaus* in three sites with different soil types and drainage. Seedling survival was highest in well drained black loamy soils and lowest in the sandy soils. *Afrocarpus usambarensis* seedlings survived better than *P. milanjianus* seedlings under the same site conditions. This finding concurs with the observations by Eggeling and Dale (1951) and Katende *et al*. (1995) that *A. usambarensis* is more abundant in the Sango Bay forests than *P. milanjianus*.

Generally, seedling survival and growth rates in tropical forests are affected by edaphic factors (Heideman, 1989; Forget, 1991; Pareliussen *et al*., 2006). In this study, seedlings of both *P. milanjianus* and *A. usambarensis* survived more on-farm than on the natural forest boundary perhaps due to the deep and better drained soil conditions. Although, these two species grow in swamp forests, too much water (waterlogging) adversely affects their survival and growth. Gerhardt (1996) reported a similar observation in a study of tree seedling growth in Costa Rica.

In both well-drained black soils and waterlogged clayey soils, seedlings of *Afrocarpus usambarensis* survived more than *Podocarpus milanjianus*. The reason for this, however, is not clear. *P. milanjianus* survived more in the moisture-stressed site indicating that it may be less tolerant to water logging. These findings imply that while both *P. usambarensis* and *A. milanjianus* can be cultivated on-farm, *A. usambarensis* would be more suitable because the demand for its timber is very high (Katende *et al*., 1995).

Effect of site factors on height and girth increment of the seedlings: Literature indicates that seedling growth rates in tropical forests are affected by various factors including shade and soil conditions (Synott, 1975; Heideman, 1989; Forget, 1991; Pareliussen *et al*., 2006). Bergin *et al.* (2008) reported good growth and 80% survival of *Podocarpus tottara* in well drained loam soils in Australia. On the other hand Bellingham and Richardson (2006) examined tree seedling growth rates and survival over 6 years in different micro sites across specific rain forests in New Zealand. They assessed growth rates of *Podocarpus halii* and found that it was affected by soil conditions which is consistent with the findings of this study.

Several studies have pointed out that seedling growth rates in tropical forests are affected by edaphic factors and rainfall (Synott, 1975; Heideman, 1989; Forget, 1991; Barrett *et al*., 1994; Pareliussen *et al*., 2006). We compared girth and height increments of *Afrocarpus usambarensis* and *Podocarpus milanjinaus* seedlings in three sites with different soil types and drainage. Girth and height increments were highest in well drained black loam soils and lowest in the waterlogged clayey soils implying that high soil moisture, like in waterlogged condition, hinders growth of the two species by restricting access to nutrients. In general, seedlings of *A. usambarensis* have a higher girth and height increment than *P. milanjianus* seedlings under similar conditions probably because they are more tolerant to the water logged conditions.

CONCLUSION

A. usambarensis seedlings survived better than *P. milanjianus* seedlings under the same site conditions. In general, seedlings of *A. usambarensis* have a higher girth and height increment than *P. milanjianus* seedlings under similar conditions probably because they are more tolerant to the water logged conditions.

RECOMMENDATIONS

The study recommends that tree farmers can grow *Afrocarpus usambarensis* because it has better growth rates and survival compared to *Podocarpus milanjianus* for on-farm planting. The farmer also need to know that too much water reduces survival and growth of the two species and that the two species should be planted in well drained soils.

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