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Growth performance of 5-year old *Pinus caribaea* var. *hondurensis* (Barr. and Golf.) in selected districts of Uganda

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Abstract

Variation in growth characteristics of *Pinus caribaea* var. *hondurensis* (PCH) has been reported across the major pine growing areas of Uganda. We assessed the growth performance of PCH from July 2012 to August 2013 in order to generate information needed to guide future interventions for improved pine management in the country. Growth parameters of 5-year-old PCH plantations were assessed in terms of height, diameter at breast height (DBH) and foxtailing in six districts. Data were analysed in the R statistical environment (version 3.1.1). Results showed that the pine trees registered good growth rates in Gulu and Mubende districts and poor growth rates in Nakasongola District. In Gulu and Mubende districts, the mean DBH was 17.29 cm and 14.44 cm, respectively, while the corresponding mean height was 12.39 m and 11.38 m. Growth of the pine trees in Nakasongola District was substantially slower, with mean DBH of 9.89 cm and mean height of 9.01 m. These growth rates correspond to mean annual increments (over bark) of between 15 and 19 m^3 ha^{-1} y^{-1} on sites in Gulu and Mubende districts and 4.6 m^3 ha^{-1} y^{-1} on sites in Nakasongola district. The percentage of foxtailing in all the study districts was 7.1. We recommend a longer time study of about 20 years to the age when the trees are expected to achieve full maturity. This will provide a more elaborate understanding of the influence of site and stand factors on growth performance of PCH in Uganda.

Key words: Diameter, foxtailing, height, increment, volume

Introduction

Pinus caribaea var. *hondurensis* (Senecl) Barr.et Golf. (PCH) is widely grown in the African tropics and subtropics (Louppe *et al.*, 2008). In its natural habitat in central America and the Caribbean Basin, PCH performs best at low altitudes (approximately 700 m asl) and on fertile, well-drained soils with mean annual rainfall (MAR) of 1200 mm per year and mean annual temperatures ranging from 20 °C to 27°C (Dupuy and Mille, 1993). In Africa, PCH is reported to be adaptable to a wide range of climates and elevations (Francis, 1992; Oteng-Amoako and Brink, 2008). In Uganda, Kaboggoza (2011) found that PCH grows well in shallower soils on lower elevation sites and performs well on fairly dry sites. Overall, PCH is recommended for growing in the central, western, northern, and southern regions of the country (Wortmann and Eledu, 1999).

Natural forests have long been the main source of timber and other wood products in Uganda. Following the forest sector reform augmented by the National Forest Policy (2001) and the National Forestry and Tree Planting Act (2003), forest plantations expanded rapidly. *Pinus caribaea* (mainly var. hondurensis) and *Eucalyptus grandis* are the dominant species grown on both forest reserves and private lands. Because of its fast growth rate coupled with its ability to adapt to a wide range of climatic conditions, PCH is widely planted by farmers throughout Uganda (Jacovelli *et al.*, 2009). For instance, assessments conducted by Kaboggoza (2011) towards the end of 2010 found out that 54% of private forest plantations and 75% of government-managed soft wood plantations in Uganda, respectively, were planted with PCH.

Farmers have also reported considerable variations in growth characteristics across the major pine growing regions in Uganda. Whether this variation is significant and related to site factors or stand conditions remains unclear. As such, the mean annual increment (MAI) of PCH (reportedly between 20 and 30 m^3 $ha^{-1}year^{-1}$) may not be realised in many locations (Sawlog Production Grant Scheme, 2007; Kaboggoza, 2011). In this study, we assessed the growth performance of PCH in the major pine-growing districts of Uganda in order to generate information that could be used to guide future interventions aimed at improving the productivity of pines in Uganda. Specifically, we compared growth performance of PCH in six major pine-growing districts of Uganda.

Materials and methods

Study sites

The study was conducted in Gulu, Nakasongola, Kiboga, Mubende, Jinja and Mayuge districts (Fig. 1) where *Pinus caribaea* is commonly grown (Jacovelli *et al.*, 2009; Kaboggoza, 2011). A summary of the characteristics of the study sites is provided in Table 1.

Data collection and analysis

Study sites were selected based on availability of secondary data from the National Forestry Authority and the District Forestry Services . Five-year-old PCH stands of at least 2 ha were purposively selected from each site. At this age, the trees were approaching the end of the juvenile stage and the stands had not been thinned. The 2 ha stand size was considered optimal for establishment of at least two Temporary Sample Plots (TSPs) of 15 x 15 m. To ensure comparability of growth rate, only stands with spacing of 3 x 3 m were selected. The number of TSPs established in a given stand varied according to stand size. The TSP approach was suitable for this study as it permitted rapid collection of data (Magnussen and Reed, 2004). The TSPs were positioned 20 m away from the stand boundary to minimise the edge effect and 100 m apart to lessen the effect of various micro-habitats within the stand. Since thinning had not been done, all trees in each plot were counted to establish the stocking (survival) at 5 years. All trees in each plot were measured for height and diameter at breast height (Dallmeier, 1992), defined as 1.3 m above the ground (Walker *et al.*, 2011). Such growth traits have been used previously to assess

Figure 1. Map of Uganda showing the study sites.

Table 1. Characteristics of the study sites

District	Forest reserve	Mean altitude (m asl)	Annual rainfall (mm)	Annual temperature (°C)
Kiboga	Kikonda	1119	1000 - 1500	21 - 23
Mubende	Kasana-Kasambya	1228	1223	20.3
Nakasongola	Katuugo	1088	1000 - 1250	22
Jinja	Nsube, Ngereka	1131	1324	22.2
Mayuge	Bukaleba	1204	>1,200	>20
Gulu	Opok, Opaka	1115	1555	23

Source: Adapted from Wortmann and Eledu (1999) and Wesige (2009); http://www.worldweatheronline.com/; http://www.climatedata.eu/

growth performance of PCH (Lynch, 1958; Hodge *et al.*, 2001; Gapare and Musokonyi, 2002). Height and DBH have also been used in tree growth modelling (von Willert *et al.*, 2010). Volume and MAI were computed using height and DBH data. Site indices derived from soil and climate data were not utilised in this study. MAI is an integrated index based on the sum result of site-specific factors (rainfall, temperature, and soil) and was used as a measure of growth performance. The status of foxtailing was recorded as 0 = no foxtail and 1 = foxtail exists. Foxtailing is an undesirable genetic trait in pines that is strongly influenced by site and climatic conditions (Lückhoff, 1964; Slee and Nikles, 1968; Ibrahim and Greathouse, 1972).

To compare the differences in height, DBH, volume, and MAI in the study districts, we used linear mixed-effect model fitted with the *lme* function in the *nmle* package in the R statistical programme (R Core Team, 2014). We used districts as fixed factors and plots as a random variable. To account for spatial auto-correlation among plots within a given district, we nested plots within districts. Because volume and MAI were not normally distributed, they were transformed into square roots to improve normality. In all analyses, we chose Nakasongola as a reference district because its mean altitude and topography were similar to the native conditions of PCH. When there were differences in the performance indicators among the districts, we used Tukey's post hoc test at 95% family-wise confidence level to separate the means. We used Tukey's test because its distribution is unaffected by sample sizes (Upton and Cook, 2006). We calculated the proportion of foxtailed trees in each plot and comparisons were made among the six districts.

Results and discussion

Growth performance of PCH in the study districts

The mean DBH and height was 13.42 cm and 10.54 m, respectively. Generally, growth performance of PCH was highest in Gulu district, moderate in Mubende district and lowest in Nakasongola district (Table 2). The mean DBH in Gulu district was 17.29 cm, while in Mubende and Nakasongola districts the means were 14.44 cm and 9.89 cm, respectively. The mean height was highest in Gulu district (12.39 m), moderate in Mubende (11.38 m) and Kiboga districts (11.42 m), and lowest in Nakasongola district (9.01 m). The differences in DBH and height across study districts could be due to differences in site factors and stand conditions. The main site-specific factors relevant to PCH growth are rainfall availability, soil fertility (Dupuy and Mille, 1993), and disturbances (Mugerwa and Emmanuel, 2014). For instance, mean annual rainfall differed across the study districts with Gulu receiving the highest amount of rain (Table 1). Tree height is considered to be a good indicator of site productivity for a given species (Lynch, 1958; Skovsgaard and Vanclay, 2008). The trees were taller in Gulu district possibly because the site quality was better than in the other study districts. The literature indicates that productive sites at low altitudes tend to have reduced stocking of pine stands, which accounts for larger diameters (Menzies *et al.*, 1989). This situation was observed in Gulu district, which had a low stocking rate. The low growth performance in Nakasongola district was

Table 2. Growth performance of PCH in the six study districts

Variables	Districts					
	Gulu	Jinja	Kiboga	Mayuge	Mubende	Nakasongola
Avg stocking* (trees per ha)	925	1041	896	1051	1000	992
DBH (cm) (mean ± SD**)	17.29±3.73	13.39±2.29	13.22±2.88	12.70±2.24	14.44±3.92	9.89±2.42
Height (m) (mean ± SD**)	12.39±2.47	10.07±1.86	11.42±2.08	9.27±1.27	11.38±1.7	9.01±1.84
Volume ($m^3 ha^{-1}$) (mean ± SD**)	92.46±28.69	49.79±12.23	47.19±13.93	41.17±4.05	78.43±44.12	23.02±3.51
MAI ($m^3 ha^{-1} yr^{-1}$) ± SD**	18.49±5.74	9.96±2.45	9.44±2.79	8.23±0.81	15.69±8.82	4.6±0.7

Avg stocking* refers to average stocking at 5 years; SD** is standard deviation

due to disturbances by grazing animals and fires. This is in agreement with the findings of Mugerwa and Emmanuel (2014) who found out that such disturbances cause stunted growth of pines. It is also possible that other factors such as seedling source (Salazar, 1986) may have contributed to the observed trends in diameter and height of PCH in the study districts.

Variation in tree MAI in the study districts

Generally, the overall growth performance of PCH was highest in Gulu and Mubende districts and lowest in Nakasongola district. MAI was 18.49, 15.69 and 4.6 $m^3 ha^{-1} y^{-1}$ in Gulu, Mubende and Kiboga districts, respectively (Table 2). The MAI was significantly higher in Gulu ($P<0.001$) than in the other districts except Mubende (Table 3). Furthermore, the MAI of PCH in Mubende was significantly higher ($P<0.001$) than that in Nakasongola. Generally, PCH grows best in areas that receive more than 1500 mm of mean annual precipitation and have loamy soils of about 1 m in depth (Dupuy and Mille, 1993; Dvorak *et al.*, 2000). It appears that the altitude of Gulu district at 1115 m asl and MAR of about 1555 mm (Table 1) present better growing conditions for PCH than the other districts. Earlier yield models had predicted lower values for *Pinus caribaea* at 5 years in Uganda (Alder *et al.*, 2003). The MAI of 5-year-old pines in Mubende falls within the acceptable range of 11-18 $m^3 ha^{-1} y^{-1}$ (estimated for good sites in Uganda) (von Willert *et al.*, 2010).

Incidence of foxtailing in Pinus caribaea

Foxtailing, which normally occurs in the first 4 years of pine establishment, is an inherited growth phenomenon and a genetic condition associated with the absence of latewood (Lückhoff, 1964; Kozlowski and Greathouse, 1970). As a result, foxtailing affects wood quality and reduces economic return to investment. The expression of foxtailing of pines in the tropics is modified considerably by site and climatic factors (Slee and Nikles, 1968; Ibrahim and Greathouse, 1972). The proportion of foxtailing was highest in Gulu, Mayuge, and Jinja districts and lowest in Nakasongola, Mubende, and Kiboga districts (Fig. 2). Overall, foxtailing was 7.1%, ranging from 3% in Nakasongola to 12% in Gulu, indicating that incidences

Table 3. Tukey's test of contrasts in MAI between study districts at 95% family-wise confidence interval

Contrast	Estimate	Std. Error	t value	p value
Jinja - Gulu	-8.5348	1.9357	-4.409	<0.001
Kiboga - Gulu	-9.0535	2.0351	-4.449	<0.001
Mayuge - Gulu	-10.2589	2.0351	-5.041	<0.001
Mubende - Gulu	-2.8069	2.3499	-1.194	0.8332
Nakasongola - Gulu	-13.8876	1.6616	-8.358	<0.001
Kiboga - Jinja	-0.5187	2.2644	-0.229	0.9999
Mayuge - Jinja	-1.7241	2.2644	-0.761	0.9716
Mubende - Jinja	5.7279	2.5511	2.245	0.2353
Nakasongola - jinja	-5.3528	1.9357	-2.765	0.0818
Mayuge - Kiboga	-1.2054	2.3499	-0.513	0.9952
Mubende - Kiboga	6.2465	2.6273	2.378	0.1837
Nakasongola - Kiboga	-4.8341	2.0351	-2.375	0.1847
Mubende - Mayuge	7.4519	2.6273	2.836	0.0696
Nakasongola - Mayuge	-3.6287	2.0351	-1.783	0.4809
Nakasongola - Mubende	-11.0807	2.3499	-4.715	<0.001

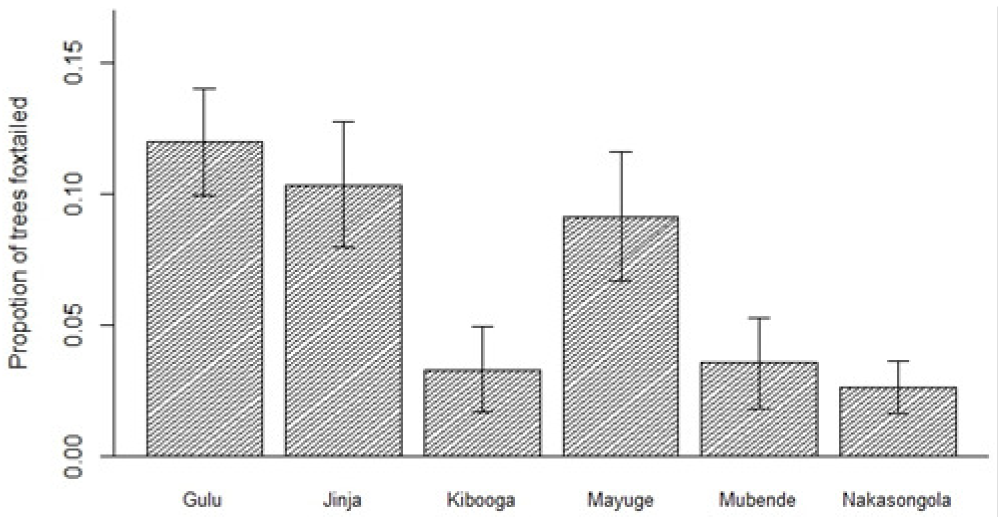

Figure 2. proportion of foxtailing in 5-year old PCH in the study districts.

of foxtailing are lower in Uganda than in other regions of tropical Africa (31%) (Ibrahim and Greathouse, 1972) and Venezuela in Latin America (>25%) (Hodge *et al.*, 2001). Foxtailed trees are usually smaller and taller than the average tree in the stand. Although foxtailing is a negative growth trait, overall its impact on mean height and mean diameter in each of the study districts was negligible given that the proportion of foxtailed trees was very low. Thus, the relatively low incidence of foxtailing observed in the six study districts would not significantly impact timber productivity since foxtailed trees are often removed during the first thinning at 7 years.

Conclusion

Growth of PCH was better in Gulu and Mubende districts than in Nakasongola, Kiboga, Jinja, and Mayuge districts where the growth rates were below the acceptable range for good sites in Uganda. Although this study did not thoroughly investigate the influence of site factors (e.g. soil) and stand condition (e.g. management regime), such factors also accounted for the differences in the growth of the pine trees across study districts. In addition, stand disturbances could also have affected growth performance in some study sites. For instance, the pines planted in the fire-prone districts of Nakasongola, Mayuge, and Kiboga had the lowest MAI. The proportion of foxtailing in 5-year PCH stands was remarkably low in the study districts; thus, it would not affect the final crop performance since foxtailed trees are often removed during the first and second thinning. Although PCH had low growth rates in Nakasongola, Mayuge, and Kiboga districts, identification of suitable microclimatic conditions together with timely application of silvicultural interventions could still greatly improve growth performance. We recommend longer-time studies of the influence of site and stand factors on growth performance of PCH.

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