Reference No. 15

Maesopsis eminii - a challenging timber tree species in Uganda - a production model for commercial forestry and smallholders

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Abstract

Maesopsis eminii is a colonising tree species of the central African rainforest, occurring naturally in the triangle between Liberia, Uganda and southern Angola. It was introduced to India, Malaysia, Indonesia and the Caribbean for timber plantations due to its timber value. In addition, it was used in Agroforestry systems because the light canopy allows crops to be raised underneath.

In Uganda *Maesopsis eminii* attracts increasing attention because most of the natural forests have disappeared or are highly degraded. In addition, the remaining timber plantation area is smaller than 8,000 ha and owing to the steadily improving political and economic situation, the demand for construction timber and the prices are steadily increasing. However, management models for *Maesopsis eminii* are lacking. This is one reason why exotic timber species like *Eucalyptus grandis* and *Pinus caribaea* are preferred by plantation investors in the region.

The objective of the current study was to develop a single-tree management model and to use this model to compare growth rates and the economic performance of *Maesopsis eminii* with *Pinus caribaea*, the main timber plantation species in Uganda.

The single-tree management model is based on site index and diameter growth curves, the strong correlation between DBH and crown projection area and a bole length model. This model can predict the necessary growing space at pre-defined rotation period and harvesting diameter.

The model was parameterised based on a nationwide survey on *Maesopsis eminii* throughout its natural distribution range in Uganda. A total of 29 stands in 8 different regions were investigated, with tree dimension and quality parameters recorded from 396 trees. In addition to this primary data, secondary data from sampling plots gathered in the 1970s was used.

The preliminary site index curves indicate that at a reference age of 10 years, a site index between 10 SI and 25 SI can be reached. At the same age, a diameter at breast height of between 18 and 46 cm can be achieved, depending on site condition and spacing. However, in comparison to other broad-leaved trees, *Maesopsis eminii* requires an exceptionally large growing space to utilize its full growth potential. The mean annual increment was between 11 and 17 m^3 per ha and year.

In comparison to *Pinus caribaea,* the investigated species has lower area but higher individual tree productivity. In addition, *Maesopsis eminii* is an excellent agroforestry tree.

Keywords: *Maesopsis eminii*; tropical plantation forestry, single-tree management model, agroforestry

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1 INTRODUCTION

Forestry in Uganda

A severe timber shortage is expected to occur in Uganda within the next 10-15 years, when the plantations established in the 1970s are predicted to be exhausted. Natural forests cover 21 % of the land area, but most of these forests are highly degraded and have a low production capacity. The remaining timber plantations of less than 8,000 ha are in poor condition because management has been neglected. Considering the current GDP growth rates, it was estimated that 4,000 ha of timber plantations have to be established annually to meet the increasing demand (KAZOORA & TYLER, 2001).

Besides difficulty in access to capital and lack of confidence in the political stability, insufficient technical expertise and incomplete information about different species' growth potential are severe constraints for plantation investors in Uganda. *Eucalyptus grandis*, *Pinus caribaea* and *Pinus oocarpa* are the preferred plantation species. For these species management information is readily available. *Maesopsis eminii* is the only fast-growing native timber species in Uganda. However, the information available is basic and was gathered in the 1970s when volume production was the main management objective. Modern silvicultural management concepts aiming to reduce the rotation period and to increase timber quality are not available in Uganda. The aim of the study is a two-tier approach: a) to develop a single-tree management model based on a nationwide survey and b) to compare the growth and economic performance of *Maesopsis eminii* with *Pinus caribaea*.

1.1 Review of *Maesopsis eminii* in Uganda

In Uganda, most existing plantations have been established in the 1970s and a few plots after 1995. Natural stands do exist in Budongo Forest and other tropical high forest reserves. DAWKINS (1963a), KRIEK (1970) and KINGSTON (1974) investigated the superior growth characteristics of *Maesopsis eminii* in Uganda. According to these records, a maximum tree height of 40 m and a DBH of 120 cm can be reached in its natural range. Management regimes recommended a high tree density in order to maximize volume production. Accordingly, rotation periods of 25 to 55 years were proposed with a final harvesting diameter at breast height (DBH) of 50 to 60 cm.

However, modern silvicultural concepts focussing on the production of quality timber of a given dimension in a short rotation period seem to be more appropriate today. Recent studies on the self-pruning characteristics and the exceptional heliotropic growth of *Maesopsis eminii*, i.e. the development of bent boles in case of irregular light competition, demonstrated that the rotation period to produce quality timber of a given dimension can be substantially reduced if tree densities are reduced (BUCHHOLZ, 2003). Therefore, in this study, single-tree management regimes maximizing the individual tree performance will be developed. Potential drawbacks of these management regimes, in the form of lower timber density or higher sapwood/heardwood ratio, must be considered (MUGASHA, 1980). However, from a wood utilization perspective these concerns seem to be negligible (SPECK, 2003; personal communication).

Currently the medium density timber of *Maesopsis eminii* is primarily used for inside construction purposes. It is not termite resistant and therefore can not be used for outside construction. The timber is also highly appreciated for peeling. The local plywood industry uses it for veneer. In this application, the cylindrical shape and the absence of buttresses are highly desired characteristics (TACK, 1953).

1.2 Single-tree management model

KINGSTON (1974) developed the first yield table for *Maesopsis eminii* in Uganda. Based on different site conditions, his model aims for volume maximisation.

However, in this model the individual tree potential is not fully utilised and the tree characteristics mentioned in the previous chapter are not considered (FRANCIS, 1997; BUCHHOLZ, 2003).

Single-tree management models aim to maximize individual tree performance and accordingly can be adapted to different management regimes (commercial tree growing, agroforestry). The model is based on the relation between DBH and the crown cover area expressed by the crown width and the relation between height growth, growing space and self-pruning dynamic. Similar models have been developed for several broad-leafed trees of the temperate zone (SPIECKER, 1991; NUTTO, 1999; HEIN, 2003) and the tropics (DAWKINS, 1963a; 1963b; OHLAND, 1998; TENNIGKEIT, 2000).

The management strategy implied in the model is that, on the one hand, the crown develops under minimum competition (similar to a solitary tree, no canopy closure). Accordingly, the diameter development reflects mainly site conditions and age. On the other hand, a sufficient branch-free bole length (referred to as "bole length" in this study) is crucial for high-quality timber production and depends on the tree genetics and the available light conditions determined by the crown length.

The development of a single-tree management model as well as a comparison of the growth and economic performance of *Maesopsis eminii* with exotic tree species requires subsequent model development and assessment steps. The following preliminary models were developed, in order to aid in the creation of a complete single-tree management model:

- Site index curves;
- A DBH development model;
- A crown width model;
- A bole length model describing the relation between tree height, stand density and bole length.

2 MATERIAL AND METHODS

2.1 Site

The climate in Uganda is characterized by a bimodal rainfall pattern, with a rainy season from March to April and one from September to November. Naturally, *Maesopsis eminii* occurs in regions of Uganda between altitudes of 700 - 1,500 m with a mean annual rainfall of 1,500 - 2,000 mm (HALL, 1995). Study sites were distributed all over the natural distribution range of *Maesopsis eminii* in Uganda.

The survey of *Maesopsis eminii* trees was conducted between November 2002 and February 2003. This primary data contains 29 stands at 8 sites, totalling 389 trees. The stands presented in Table 1 were established both naturally and artificially, growing in mixed stands and evenaged plantations with different stand densities. There were no observable damages to the trees or signs of senescence. Records of stand age were available for most stands.

Table 1: Overview on primary data collected in Uganda.

LOCATION	SITE HEIGHT (m a.s.l)	SITE PREC. (mm/a)	MAT (°C)	NO. OF STANDS	SAMPLE SIZE	STAND DENSITY (N/ha)	AGE (yrs.)	DOM. TREE HEIGHT (m)	DBH_{DOM} (cm)	MEAN DBH (cm)	MEAN BOLE HEIGHT (m)
Entebbe	1,155	1,624	21.55	2	32-30	239-768	6-14	12.2-17.7	17 - 30	13-24	7.9-11.7
Matiri	1,553	1,218	20.35	1	31	96	37	34.3	57	41	18.7
Mubende	1,553	1,218	20.35	1	27	54	37	33.1	55	44	15.7
Budongo	1,146	1,304	22.7	2	15-30	150-212	4-8	13.6-18.3	27-34	22-30	5.9-10.9
Mabira	1,175	1,312	22.15	1	29	88	38	36.0	66	49	20.0
Kifu	1,219	1,610	20.7	6	5 - 24	54-78	1.5-9	16.1-19.3	12-41	9-37	2.4-7.5
Bukaleba	1,175	1,312	22.15	2	29 - 31	131-296	4 - 5	12.4 - 12.9	21-25	17-21	5.8-4.8
Kampala	1,148	1,296	21.75	1	29	179	8	18.7	30	24	10.4

2.2 Secondary data

The primary data was accomplished with growth records for *Maesopsis eminii* from previous studies. After undergoing a plausibility check, the secondary dataset contained records from KRIEK taken between 1967 and 1968 in Uganda (according to FENTON et al., 1977) but also from MORTON (1975, according to FRANCIS, 1997) and WARSOPRANOTO et al. (1966; according to FENTON et al., 1977) taken in Malaysia.

2.3 Preliminary models for a single-tree management model

2.3.1 Site index model - relation age to height

Site index curves are based on the stand dominant[1] tree height (H_{dom}). The age of 10 years served as the base, i.e. the site index curves were labelled according to the assumed dominant tree height of the stands at the age of 10 years. A combination of two types of equations was used to describe the height growth of *Maesopsis eminii*:

The CHAPMAN-RICHARDS equation (1) is well-adapted to simulate the growth of pioneer trees as its shape is characterized by an early inflection point in growth, simulating an early culmination in tree height (see ALDER et al., 2003; VAN LAAR & AKÇA, 1997).

(1) $h = b_0 * (1 - \exp(-b_1 * A))^{b_2}$ (Chapman Richards)

where h is the height, b_0, b_1, b_2 are parameters and A is the age.

Accordingly, site index curves were calculated with equation (2):

(2) $h = SI / (1 - \exp(-b_1 * A_i))^{b_2} * (1 - \exp(-b_1 * A_j))^{b_2}$

where SI is the site index, A_i the site index base age and A_j the actual age.

The CHAPMAN-RICHARDS equation described the height growth of *Maesopsis eminii* well up to an age of 10 years. In order to identify the regression parameter, all stands younger than 25 years were included in the analysis. However, due to missing stand records corresponding to ages of 10 to 30 years, this type of equation did not satisfactorily describe the height growth of *Maesopsis eminii* when exceeding the age of 10 years. Therefore, the

[1] According to KRAMER & AKÇA (1995), the dominant tree height was calculated by averaging the height of the 20 % largest diameter trees of a stand, i.e. trees growing under a minimum of competition

SCHUMACHER equation (3) (VAN LAAR & AKÇA, 1997) was used to describe height growth development of *Maesopsis eminii* stands past an age of 10 years. All stands above an age of 5 years were used to identify the regression parameter. Overlapping of the dataset to calculate the parameters for the two different equations resulted in a smooth interface (I think that's what you mean) of the curves at age 10.

$$(3)\ \ h = \exp(b_3 + b_4 * (1/A)$$

where b_3 and b_4 are parameters and A is the age.

Accordingly, site index curves were calculated with equation (4):

$$(4)\ \ h = \exp(\ln(SI) + b_4 * (1/A_j - 1/A_i)$$

2.3.2 Diameter growth model

The management model aims to maximize DBH growth. There was a lack of data about DBH development in time series of *Maesopsis eminii,* with no records of individuals growing without competition. Therefore, the DBH development of dominant trees (DBH_{dom}) of false time series taken from the primary data was used to develop a diameter growth model.

The regression analysis applied the following equation (5):

$$(5)\ \ DBH_{dom} = b_5 + (b_6 * \ln(A)) * b_7 * SI$$

where b_5, b_6 and b_7 are parameters, A is the age and SI the site index.

2.3.3 Crown width model

The crown width model was intended to confirm the model developed for *Maesopsis eminii* by DAWKINS (1963a) in order to predict a tree's canopy surface depending on a desired DBH. The idea of this model is that the part of the tree crown directly exposed to the light is the photosynthetically most active area. As a result, the crown projection area is a good indicator of expected diameter growth. The relationship between available crown projection area and diameter growth was determined by DUCHAFOUR (1903). In his model, site and age were not factors.

The crown projection area for each tree was calculated according to KRAMER & AKÇA (1995).

2.3.4 Bole length model

A sufficient bole length is necessary for high-quality timber production. Branches influence internal stem knottiness and therefore timber quality. The best timber quality for any construction purposes requires a long, branch-free cylindrical bole with sufficient diameter.

A tree's natural bole length is influenced by its own genetically determined self-pruning habit and by neighbouring trees that compete for light, i.e. stand density. As a result of increasing shade of the developing crown or increased light competition with neighbouring vegetation, branches located at the crown base die and break off close to the bole. This results in branch-free boles favourable for timber purposes. In the case of *Maesopsis eminii*, this self-pruning tendency is exceptionally strong, as the self-pruning process takes place under light shade compared to other tree species (BUCHHOLZ 2003).

Subsequently, bole length is affected by stand density development, i.e. the intensity of competition for each tree. Unfortunately, competition information was not available for any of the stands and therefore could not be considered. However, the DBH can be used as a

substitute indicator for competition (NUTTO 1999). High competition results in decreased diameter growth. Therefore, trees with the same height but different competition history will differ in DBH. Subsequently, dominant trees were investigated on their bole length depending on height, age and DBH.

2.3.5 Taper functions

The absence of taper functions valid for *Maesopsis eminii* led to the application of a modified BRINK function and the associated parameters for *Fagus sylvatica,* as described by NAGEL et al. (2003). The function was used to calculate tree volume and products (assortments).

The same was applied to *Pinus caribaea*. Its production model was supplemented with a PAIN function calculating the individual tree taper (applied parameter calculated for *Pinus sylvestris*; NAGEL et al., 2003).

3 MODULES FOR A SINGLE-TREE MANAGEMENT MODEL - RESULTS AND VALIDATION

3.1 Site index model

Equations (6) and (7) describe the site index curves for ages less than and more than 10 years, respectively. Parameters were generated via a non-linear regression procedure using equations (1) and (3), respectively. The regression functions that do not take site differences into account explain about 50% to 60% of the variance.

(6) $h = 20.3505 * (1 - \exp(-0.1932 * A))^{1.1833}$ (N = 150; R^2 = 0.4973)

(7) $h = \exp(3.6163 + -6.5225 * (1/A))$ (N = 130; R^2 = 0.6941)

where h is the dominant tree height in m and A is the age in years.

Fig 1 visualizes the shape of the resulting site index curves when applying the parameters in the respective site index equations (2) and (4). The lines represent the assumed growth of the stands' dominant tree height and serve as site index.

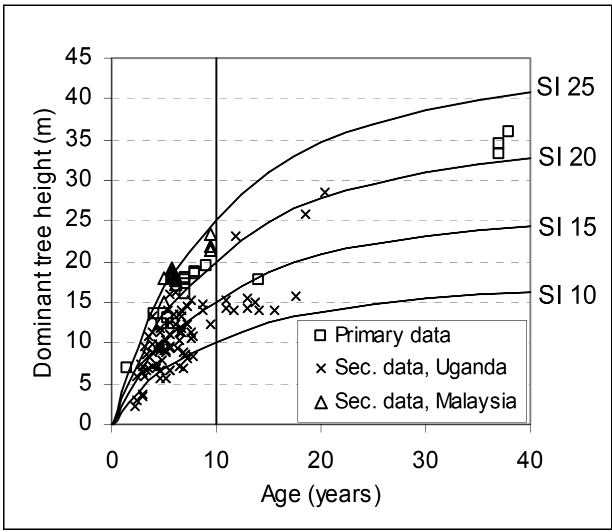

Figure 1: Site index curves.

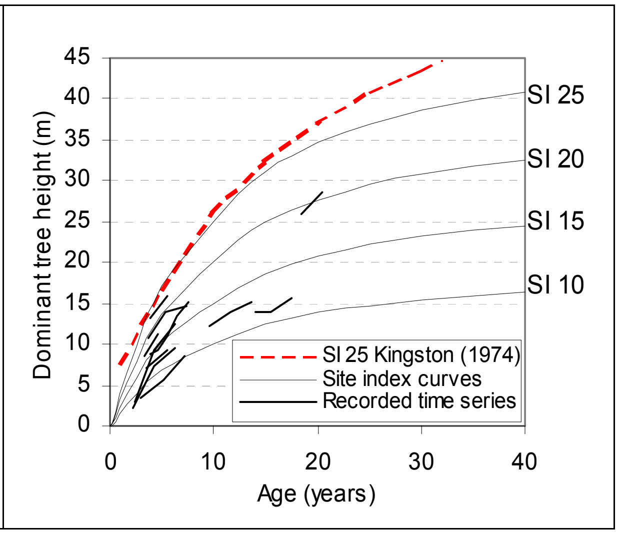

Figure 2: Comparison of site index curves with SI 25 of KINGSTON (1974) and recorded time series.

The dominant tree height development was predicted for stands with a dominant tree height of 5, 10, 15, 20 and 25 m at the age of 10 years, which is the base age (vertical line). Squares represent primary data, triangles and dots secondary data.

It is remarkable that primary data records show a similar vigorous growth as the stands recorded in Malaysia, while older records of *Maesopsis eminii* stands in Uganda tend to demonstrate slower height growth.

3.2 Validation and discussion of the site index model

The site index 25 SI approaches a dominant tree height of around 40 m, which is in line with general maximum height records of different authors (HALL, 1995; BINGELLI, 1997). The dotted line in Figure 2 represents the site index 25 SI modelled according to KINGSTON (1974). The equation is a three polynomial function resulting in unrealistic height in the initial growth that exceeds the general maximum tree height of 40 m already at the age of 25 years.

In order to validate the shape of the site index curves, the curves were compared with the real dominant tree height development of recorded stands (see Figure 2). The cross-lines represent time series of stands recorded by KRIEK (according to FENTON et al. 1977) in Uganda. It can be stated that the shape of lines representing the time series is comparable in shape with the site index curves and does simulate tree height growth better than the site index equations of KINGSTON (1974).

3.3 Diameter growth model

Diameter development depends on site, age and the development potential of the crown size, i.e. the stand density or canopy closure. The records of the stands' actual canopy closure ranged between 73 and 146 %, with an average of 100 % and stand densities varied between 13 to 780 trees per ha at an age of 5 to 38 years. As no time series were available, this dataset was inappropriate to identify any relation to diameter development directly.

Figure 3 shows the development of the DBH_{dom} depending on age and different sites. The different site index groups show a different level in DBH development. Figure 4 shows the DBH_{dom} depending on canopy closure. No correlation between canopy closure and DBH_{dom} could be demonstrated.

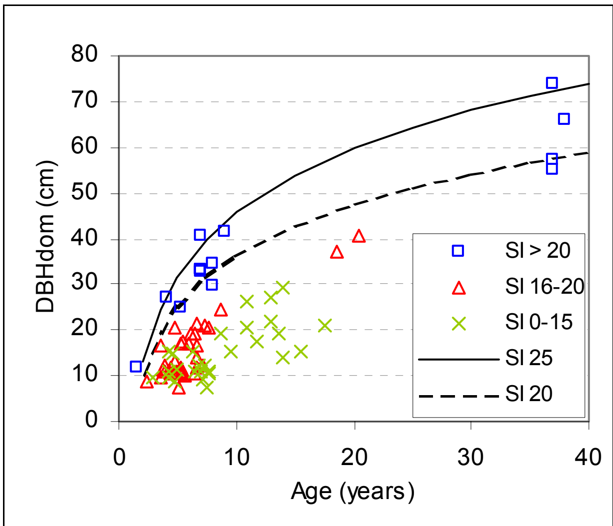

Figure 3: DBH_{dom} development depending on age and site.

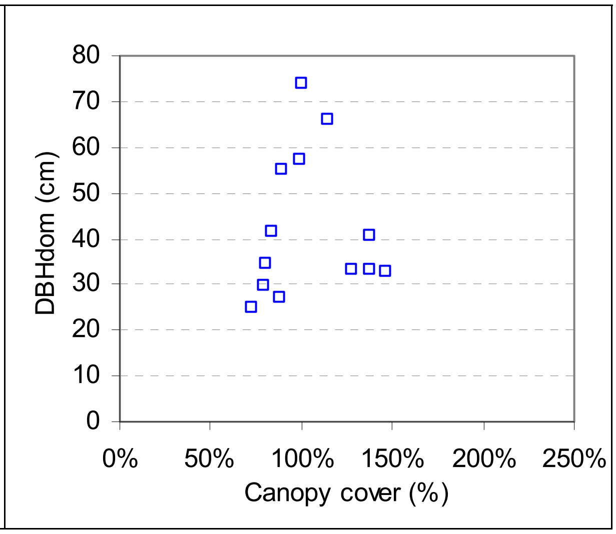

Figure 4: DBH_{dom} depending on canopy closure for a SI above 20.

The lines in Figure 3 show the range of the DBH_{dom} development for the group with a 20 to 25 SI (see Figure 3) and can be described by equation (8). According to this figure, a DBH_{dom} in the range of 48 to 60 cm can be expected at an age of 20 years for *Maesopsis eminii* stands classified with a site index above 20 SI.

Equation (8) is derived from equation (5) and describes the development of DBH_{dom} depending on age and site index.

(8) $DBH_{dom} = -1.1146 + (15.2004 * \ln(A)) * 0.0535 * SI$ (N = 13; $R^2 = 0.9232$)

where DBH_{dom} is given in cm, A is the age in years and SI is the site index.

3.4 Validation and discussion of the diameter growth model

Figure 5 shows the DBH_{dom} development according to the model developed above for a site index of 25 SI compared to the DBH_{dom} development according to KINGSTON (1974), which is represented by the dotted line. The KINGSTON model predicts a lower DBH_{dom} for all ages than the model introduced above. The difference between the curves could be explained by a difference in stand density development, which was not recorded for the dataset used by KINGSTON.

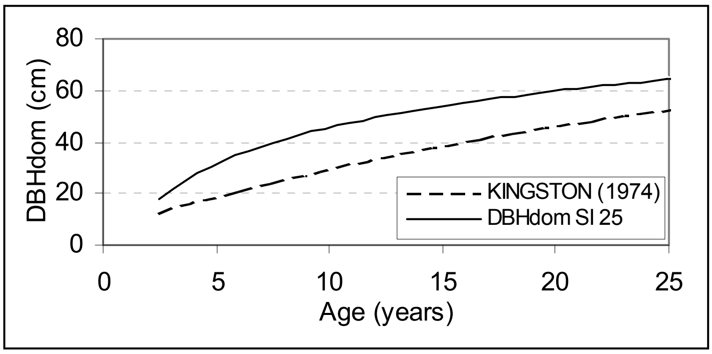

Figure 5: DBH_{dom} development models for a 25 SI in comparison.

3.5 Crown width model

The crown width model allows the calculation of crown width from DBH and, vice versa, the calculation of DBH development when the maximum growing space is given. Accordingly, a stand's maximum density can be calculated for a given DBH and canopy closure. In Figure 6 the relationship between crown width and DBH is presented for the recorded trees. Including the age in the model did not improve the predictive ability for the crown width.

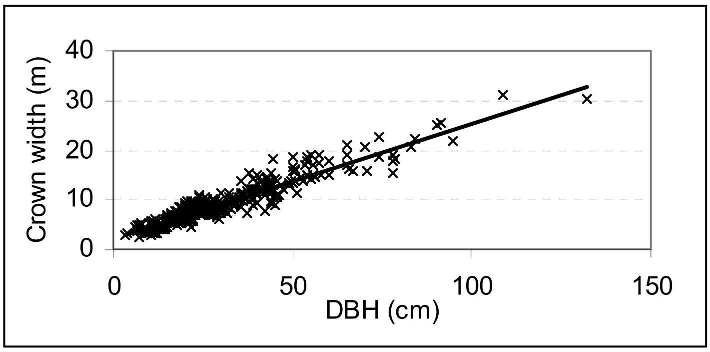

Figure 6: Relationship between the DBH and crown width of *Maesopsis eminii*.

A linear relationship between crown width and DBH, represented by the black line, can be observed. The resulting crown width model describing this relationship is the equation (9):

(9) $CW = 2.1789 + 0.2329 * DBH$ (N = 361; R^2 = 0.8882)

Where *CW* is the crown width in m and *DBH* is given in cm.

3.6 Validation and discussion of the crown width model

The crown width model developed by DAWKINS (1963a) (CW=0.85+25.15*DBH; with CW and DBH in the same units) results generally in a lower stand density for a given DBH compared to our model. Assuming a canopy closure of 80 % and a DBH of 50 cm, the crown width model presented above gives a stocking density of 53 trees/ha, while applying the model developed by DAWKINS (1963a) results in a stocking density of 57 trees/ha.

The reason for the different results may be caused by different approaches to calculate the crown projection area. However, Dawkins did not describe his method.

Concerning the influence of age on the model, SPIECKER (1991) found a strong influence of age on the predictive ability of the crown width model. However, OHLAND (1998) concluded for *Gmelina arborea* that the age only slightly improves the power of the model.

3.7 Bole length model

The development of a branch-free bole length is influenced by the tree height and the stand density (see chapter 3.7). In Figure 7 bole length data from stands with known stem density and canopy cover were plotted against tree height in order to investigate the relationship between bole length, tree height and stand density.

A multiple linear regression model was calculated with height, age and DBH as independent variables for dominant trees. The stepwise regression showed that the only significant influence on bole length of dominant trees was the tree height. Figure 7 shows the relation between tree height and bole length.

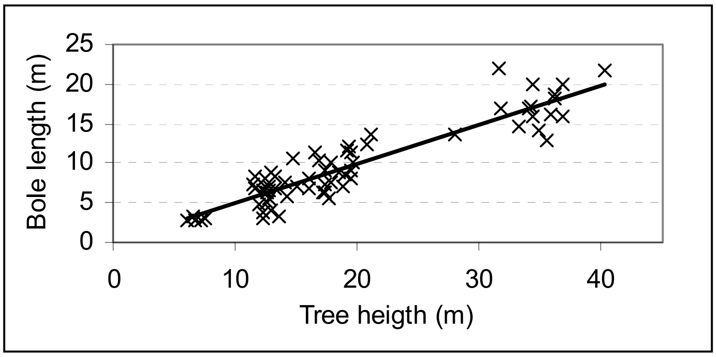

Figure 7: Relationship of bole length to tree height.

Therefore, bole length for stands can be modelled by the following linear equation (10) describing the trend line in Figure 7:

(10) $bl = 0.4983 * th$ (N = 66; R^2 = 0.8462)

Where *bl* is the bole length in m and *th* the tree height in m.

This model implicates that a dominant tree's bole length is of approximately 50 %, which is nearly independent of stand density.

3.8 Validation and discussion of the bole length model

The data set used for developing the model was taken from BUCHHOLZ (2003). To develop the model, mean values of stands were used. To validate this model, data recorded from solitary trees in this original data set were used. These trees had a mean relative bole length of 40 %, indicating the distinctive self-pruning habit of *Maesopsis eminii*. Consequently, even slight competition can lead to a mean relative bole length of 50 % derived from the model. The so-called rule cited in KINGSTON (1974), that bole length is independent of height when exceeding an age of 10, could not be supported.

4 OUTPUT OF THE SINGLE-TREE MANAGEMENT MODEL

4.1 Management strategy

Compiling the preliminary models described above led to the consolidation of all relevant tree growth data required for the development of a single-tree management model. Additionally, this model is based on the following strategic objectives in order to be in line with the aims mentioned in chapter 1.2, i.e. optimising the single-tree growth in order to maximize the economic value of a plantation by reducing the rotation period and improving timber quality.

Objectives:

- The model is restricted to sites classified with an site index between 20 and 25 SI;
- The rotation period is 20 years;
- Stand density is managed in a way as such to avoid the canopy cover to exceed 80 %. Only at the end of the rotation is canopy cover allowed to close to approximately 100%;
- Establishment follows a kind of “twin-planting” system. For each future tree, two trees are planted with a distance of 2 m in between. After 1 to 2 years a sapling selection (quality and height) is executed and the weaker individual of the twins is removed. When choosing the initial square spacing, it has to be considered that the final square spacing must allow unrestricted growing space within the planned rotation period;
- The thinning is executed when a crown cover of 80 % is reached the first time. It removes every second diagonal row, or 50 % of the trees. This will lead to a final square spacing, which is chosen to give trees an optimal regular growing space with minimum chance of heliotropic stem bending. Both results in fast growth of straight, cylindrical boles (BUCHHOLZ, 2003).

4.2 Yield table

With the above-mentioned models and strategic objectives, the tree management model was developed. Table 2 presents figures of this single-tree management model for a site index of 25 SI.

Table 2: Single-tree management model for *Maesopsis eminii* for 25 SI.

ACTIVITY	AGE	HEIGHT	DBH	BOLE LENGTH	STAND DENSITY	SQUARE SPACING	LARGE LOG [a]	SMALL LOG [b]	IND. WOOD [c]	FUEL WOOD [d]	MAI
	(years)	(m)	(cm)	(m)	(N/ha)	(m)	(m^3)	(m^3)	(m^3)	(m^3)	m^3/ha/a
Establishment	0	-	-	-	200	10	-	-	-	-	-
Thinning	5	17.1	34	8.5	100	10	0	27	6	1	13.4
-	10	25	46	12.5	50	14	-	-	-	-	13.6
-	15	31.1	54	15.5	50	14	-	-	-	-	14.1
Harvest	20	34.6	59	17.3	50	14	184	0	50	9	13.9

[a]) Top diameter min. 35 cm; min. length 4 m; branch-free bole log; 20 % sawlogs, 80 % veneerlogs
[b]) Top diameter min. 20 cm; min. length 4 m; branch-free bole log
[c]) Top diameter min. 10 cm; min. length 2 m; industrial wood
[d]) Top diameter min. 5 cm

The stand is established in a square spacing of 10 x 10 m, leading to a final spacing of 14 x 14 m. The final spacing is established after the thinning.

The example presented in Table 2 leads to a mean annual increment (MAI) of 13.9 m^3/ha/a at an age of 20 years. Reducing the rotation period to 12 years would result in a mean DBH of 50 cm and a MAI of 14 m^3/ha/a at the end of the rotation period. A minimum rotation period of 8 years results in trees with a mean DBH of 41 cm and a MAI of 17 m^3/ha/a. For stands classified 20 SI, a DBH of 48 cm and a MAI of 11 m^3/ha/a would be reached at an age of 20 years.

4.3 Validation and discussion of the single-tree management model

The only comparable yield tables for *Maesopsis eminii* were developed by KINGSTON (1974). The output of his yield table for a 25 SI at an age of 20 years was compared with the output of the single-tree management model for the corresponding site index. Coming up with a basal area close to our findings, he recommended a high stand density (73 vs. 50 trees/ha), consequently resulting in a lower DBH_{dom} than computed by our model (46 vs. 60 cm).

The single-tree management model presented in this study was calculated based on a regular square spacing throughout the whole rotation period. This is based on the insight that *Maesopsis eminii* develops bent boles under irregular light competition. However, the intensity of a bole bending reaction in relation to increasing competition, i.e. crown cover or irregularity of competition, could not yet be modelled (BUCHHOLZ, 2003). In case that a strictly regular spacing is not necessary to grow straight boles, it could be recommended to thin twice, allowing the harvest of more stems with a chance to harvest more valuable products at the second thinning.

Additionally, the application of the model is restricted, as it is based on false time series due to the lack of growth monitoring plots.

4.4 Economic competitiveness of the *Maesopsis eminii* single-tree management model

The study objective was to prove the economic competitiveness of *Maesopsis eminii*. Therefore, an economic analysis was conducted comparing the output of the single-tree management model of *Maesopsis eminii* introduced above with a production model for *Pinus caribaea* developed by ALDER et al. (2003). This production model is characterized by a high stand density compared to the *Maesopsis eminii* model and two thinnings, each removing 33 % of the trees.

In order to estimate the product output, taper functions as mentioned in chapter 2.3.5 were applied. In order to get comparable results, optimal site conditions for both tree species were assumed, leading to a 25 SI for *Maesopsis eminii* and 20 SI for *Pinus caribaea*, respectively. Timber prices were based on the roadside market price in Uganda in 2004.

Table 3: Economic analysis of input and output for a 1 ha plantation of *Maesopsis eminii* vs. *Pinus caribaea*; rotation period 20 years.

Column	Input Parameter	Unit	*Maesopsis eminii*		*Pinus caribaea*	
1	Interest rate	%	10		10	
2	Land lease	€/ha	5		5	
3	Management costs [a]	€/ha	25		25	
4	Price per seedling	€/seedling	0.10		0.10	
5	Labour establishment/early tending [b]	days/ha	45		55	
6	Labour pruning	days/ha	-		30	
7	Harvest costs thinnings [c]	€/m^3	10		10	
8	Harvest costs final clearcut [c]	€/m^3	7		7	
9	Harvest losses	%	20		20	
10	Labour costs	€/day	1.5		1.5	
11	Total volume	m^3/ha	277		760	
12	Mean annual increment	m^3/ha/20yrs.	14		38	
Product volumes and price assumptions			**m^3/ha**	**€/m^3**	**m^3/ha**	**€/m^3**
13	Veneer		147	30 [d]	43	30 [d]
14	Large sawlog		37	22 [d]	173	22 [d]
15	Small sawlog		27	20 d	341	20 d
16	Industrial wood		55	3 [d]	40	3 [d]
17	Fuelwood		10	2 [d]	142	2 [d]
Investment analysis						
18	Net present value	€	27		-36	
19	Internal rate of return	%	11		10	
20	Investment costs (first 2 yrs)	€	209		548	
21	Total revenue	€	4,184		11,494	
22	Total costs	€	2,413		7,087	
23	Revenues per m^3 timber	€/m^3	24.7		22.0	
24	Costs per m^3 timber [e]	€/m^3	14.3		13.5	

[a]) Including fire control, inventories, etc.
[b]) Including site preparation, planting, weeding and selection in the sapling stage
[c]) Including logging trail construction, machinery and labour

[d]) Price including harvest (at road side)
[e]) Considering total volume of veneer and sawlogs

The lower volume output of the *Maesopsis eminii* model compared to the *Pinus caribaea* model (column 11) was balanced by a higher production of high-quality timber , e.g. veneer (column 13), thus resulting in a higher revenue.

The analysis of the cost allocation produced comparable results for both examples. In both cases, harvest activities claimed around 55 % of total expenditures, establishment/early tending activities around 6 %. Remarkable differences occurred only in the fixed expenditures like land lease and management thinning activities.

Considering financial aspects, the first and only thinning had a positive cash flow in the case of *Maesopsis eminii* while the cash flow of the first *Pinus caribaea* thinning was negative. The internal rate of return was slightly higher in the case of *Maesopsis eminii* than in the case of *Pinus caribaea* (column 19; 11 and 10 %, respectively). Additionally, the investment costs for a one hectare *Maesopsis eminii* plantation were less than 50 % of the investment costs required for the establishment of one hectare according to the *Pinus caribaea* plantation model (column 20). Production costs per cubic meter timber were slightly higher in the *Maesopsis eminii* model than in the *Pinus caribaea* model (6 %; column 23). However, compared to the *Pinus caribaea* model, *Maesopsis eminii* generated a 12 % higher revenue per cubic meter timber sold (column 24) due to its high ratio of better-prized products.

4.5 Validation and discussion of the economic analysis

The comparison was only calculated for plantations established on optimal sites, as it is difficult to predict relative growth difference of the both species on poorer sites, i.e. which site index should be applied. Another restriction was that taper functions were unavailable for either of the two species.

Considering financial aspects, the information on the harvest costs as well as on product prices is difficult to validate. For both species, same product prices and relatively high harvest costs were assumed, although the total volume production is different and influences these figures as well. Additionally, increasing timber dimensions tend to correspond to reduced harvest costs per m³ timber harvested. However, for both models the same harvest costs were assumed, although the *Maesopsis eminii* model predicted bigger timber dimensions than the *Pinus caribaea* model for all cutting activities. Therefore, the harvest costs for the Maesopsis eminii model might be overestimated.

There are additional considerations that make *Maesopsis eminii* especially attractive for small holders. These aspects are not considered in the economic analysis and favour the *Maesopsis eminii* model over *Pinus caribaea*:

- The high risks (e.g. fire and health hazards) and resulting cost for a *Pinus caribaea* plantation are relatively low for a wide-spaced *Maesopsis eminii* plantation. Fire lines reducing the total area productivity are not necessary with the *Maesopsis eminii* model;
- In case of the *Maesopsis eminii* model, the rotation period can be decreased to 12 to 15 years while still producing harvestable timber dimensions (app. DBH 50 cm). This might be an interesting option as it results in an earlier cash flow;
- Intercropping (agroforestry) or combined cattle use options may improve the economics of a *Maesopsis eminii* plantation;
- The thinning itself generates a remarkable cash flow for *Maesopsis eminii*.

With regard to environmental issues, negative impact on biodiversity, soil and water is assumed to be less in the case of *Maesopsis eminii*.

5 CONCLUSION

The study objective was to develop a single-tree management model for *Maesopsis eminii* aiming at high-quality timber production in a short period and to prove its competitiveness compared to exotic timber species.

It could be proved that *Maesopsis eminii* has a high potential to produce high-quality timber in short rotation periods. In this context, it is competitive with exotic timber species, i.e. *Pinus caribaea*. When aiming at high-quality timber and a high rate of return, *Maesopsis eminii* should be favoured over *Pinus caribaea,* at least on good forest sites.

Under volume production aspects, *Maesopsis eminii* has an exceptional high tree productivity, although the area productivity is low even when grown on optimal sites.

The single-tree management model for *Maesopsis eminii* is highly recommendable to small holders as it is characterized by a) low investment costs, b) the potential for a multiple land use form (e.g. agroforestry) and c) a revenue in the foreseeable future with minimum rotation periods of less than 10 years on good sites.

For commercial forestry, the single-tree management model for *Maesopsis eminii* is an interesting option: a) on good sites, b) if area productivity is not a objective, i.e. land is not the limiting factor, c) high-quality timber is priced adequately on the market and d) a high internal rate of return is desired. If the low area productivity of Maesopsis eminii is seen as a constraint in a pure plantation concept, it might be compensated with a two-storey/mixed species model.

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7 REFERENCES

ALDER, D. DRICHI, P., ELUNGAT, E., 2003. Yields of Eucalyptus and Caribbean Pine in Uganda. Consultancy report. http://www.bio-met.co.uk/pdf/uymdoc.pdf [26.08.04]

BINGELLI, P. 1999. *Maesopsis eminii* Engler (Rhamnaceae) http://members.lycos.co.uk/WoodyPlantEcology/toc.htm [15.06.2003]

BUCHHOLZ, T., 2003. Silvicultural potential of *Maesopsis eminii* – a study on tree quality. Waldbau Institut Albert-Ludwigs Universität, Freiburg. http://www.uni-freiburg.de/waldbau/I-TOO [20.04.2004].

DAWKINS, H.C., 1963a: Observations on crown-diameter, stocking, silvicultural requirements and possible yield of Maesopsis. Technical Note No.114/63, Uganda Forest Department.

DAWKINS, H.C., 1963b. Crown diameters: Their relation to bole diameter in tropical forest trees. The Commonwealth Forestry Review 42 (2), 318-333.

FENTON, R., ROPER, R.E., WATT, G.R., 1977. Lowland tropical hardwoods – *Maesopsis eminii*. External Aid Division; Ministry of foreign Affairs, Wellington, New Zealand.

FRANCIS, J.K., 1997. *Maesopsis eminii* Engl. Musizi. USDA. http://www.fs.fed.us/global/iitf/Maesopsiseminii.pdf [20.04.2004].

HALL, J. B., 1995. *Maesopsis eminii* and its status in the East Usambara Mountains, technical paper 13. Ministry of Tourism, Natural Resources and Environment, Tanzania.

HEIN, S. 2003. Zur Steuerung von Astreinigung und Dickenwachstum bei Esche (*Fraxinus excelsior* L.) und Bergahorn (*Acer pseudoplatanus* L.). Dissertation, Albert-Ludwigs-Universität Freiburg.

KAZOORA, C.; TYLER, G. 2001. Financing Private Sector Forestry development in Uganda. Consultant report to the Forest Sector Co-ordination Office.

KINGSTON, B. 1974. Growth and yield of *Maesopsis eminii* in Uganda. Technical Note No. 200/74, Uganda Forest Department.

KRAMER, H., AKÇA, A., 1995. Leitfaden zur Waldmeßlehre. J.D. Sauerländer's Verlag, Frankfurt am Main.

KRIEK, W. 1970. Report to the government of Uganda on performance of indigenous and exotic trees in species trials. FAO, Rome.

MORTON, K.D. 1975. A summary of the performance of various species in departmental trial plots. Res. Rep. 5/ 11/75. Solomon Islands: Forestry Department. [n.p.].

MUGASHA, A.G. 1980. Growth of *Maesopsis eminii* Engl. in pure stands and under different forms of competition. Tanzania Silviculture Note (new series) No. 48. Ministry of Natural Resources & Animal production, Forest Division, Tanzania.

NAGEL, J., DÖBBELER, H., ALBERT, M., SCHMIDT, M., 2003. BwinPro Programm zur Bestandesanalyse und Prognose. Niedersächsische Forstliche Versuchsanstalt, Göttingen. http://www.nfl.gwdg.de/A/BwinPro/bwinpro.php [26.08.04]

NUTTO, L. 1999. Neue Perspektiven für die Begründung und Pflege von jungen Eichenbeständen. Schriftenreihe Freiburger Forstliche Forschung, Band 5, Freiburg.

OHLAND, C. 1998. Entscheidungshilfen zur Bewirtschaftung von *Gmelina arborea* in der Zona Norte Costa-Ricas: Ergebnisse einer Untersuchung zum Dickenwachstum, zur Kronenentwicklung und zur Astreinigung. Msc. thesis Albert-Ludwigs University. Freiburg

SPIECKER, H., 1991. Zur Steuerung des Dickenwachstums und der Astreinigung von Trauben- und Stieleichen. Schriftenreihe der Landesforstverwaltung Baden-Württemberg, Band 72.

TENNIGKEIT, T.; WEINREICH, A. 2001. Tree density dependent yield development of *Araucaria hunsteinii* and *A. cunninghamii* at Kifu Forest Reserve, Mukono District, Uganda. Consultant report to the EC Natural Forest Management and Conservation Project.

VAN LAAR, A., AKÇA, A.,1997. Forest mensuration. Cuvillier Verlag, Göttingen.

WARSOPRANOTO, R.S.; SOER JONO, R.; ARDIKUSUMA, R.I., 1966. Results of an investigation of *Maesopsis eminii* plantations in the S. Bandung forest management unit. Rimba Indonesia 11 (1/4).