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Determination of the Technical Rotation of *Acacia nilotica* Plantations for Production of Saw Logs and Associated Millable Wood Percentages

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Abstract: The objectives of this research were (i) to estimate the technical rotation of *Acacia nilotica* stands grown along the Blue Nile, Sudan, for the producion of saw logs that yield railway sleepers, and (ii) to estimate millable wood percentages at different crop ages for stands of site indices SI 25 and SI 28. The results revealed that mid-log diameters (over bark) of 36-47, 48-55, 56-64 and 65-68 cm were required to produce single-, double-, triple- and tetra-sleeper logs, respectively. The best stands to produce saw logs for sleeper production were those of SI 28 and SI 25, stands of SI 22 were marginal and those of SI 19 and SI 16 were not suitable. The ranges of technical rotation were estimated as 25-36 years for stands of SI 22 to produce single-sleeper logs, 29-36 years for stands of SI 25 and SI 28 to produce double and triple sleeper-logs, respectively. The results have important empirical implications in manegerial decision making of *A. nilotica* plantations. Two curves of percentages of millable wood for total sawlogs and for sleeper logs alone were constructed for stands of SI 28 and SI 25.

Key words: *Acacia nilotica*; technical rotation; saw logs; millable wood

INTRODUCTION

The total length of the growth period from stand establishment to final harvest is referred to as the rotation (Clutter *et al.* 1983), and the meaning of optimal rotation depends on objectives (Price 1989). The technical rotation is the rotation under which a species yields the most material of specified sizes and suitability for economic conversion or special use

(APFD 2008). It is used particularly by industrial companies which own forests for the purpose of supplying timber for their plants such as paper pulp companies (Osmaston 1968). It may not only specify lower limits of size but sometimes upper limit as well (Evans 1992).

Acacia nilotica stands along the Blue Nile have been managed with the objective of producing saw logs large enough to yield Sudan railways sleepers (SRS) for local consumption. Earlier studies on *A. nilotica* crop were concerned with management for saw log production, with management strategies prescribed for this objective specifically. However, there is lack of consensus on the optimum technical rotation that produces saw logs large enough to produce railway sleepers. Technical rotation has been recommended to extend to 35 years (Booth 1949; Foggie 1968), 30 years (Jackson 1959), or 25-30 years for *Gerf* slope and *Karrab* slope, and 30 -35 years for *Maya* site type (Goda 1987).

Eltayeb (1985) constructed a series of yield tables for the main crop and thinnings of *A. nilotica*. The yield tables assume a thinning regime that starts with light thinnings at the age of 6-9 years to remove wolf, suppressed, dead and dying trees. Moderate thinning follows at age 12-15 years, while heavy thinning is applied at the age of 18 years to leave the specified number of trees required per hectare. Rotation age for maximum volume production is 30 years. Initial stockings of *A. nilotica* plantations are 372, 500, 708, 1139 and 1647 stems ha^{-1} reduced to a final crop stocking of 72, 94, 125, 190 and 280 stems ha^{-1} at the age of 30 years for stands of SI 16, 19, 22, 25 and 28, respectively.

Despite the long history of management of *A. nilotica* plantations along the Blue Nile, there is lack of a precise estimate of the technical rotation of saw log production particularly in relation to site indices. Furthermore, there is lack of knowledge of the proportions of millable and non-millable wood that make up the crop at different ages and on various site indices. For final harvest specifically, Foggie (1968) reported actual exploitable volume for saw timber as 67% of the gross stem volume down to 25 cm girth for stands of quality class (Q. C.) I – II/III at a rotation of 35 years. Dafa-Alla (2004) reported millable volume of about 67% and 53% of standing volume at

Hedaibat (SI 25) and El Gezair (SI 16), respectively, at a rotation age of 25-27 years. The Inventory Directorate of the FNC (2003) reported mean millable to non-millable wood ratio in the range of 47% - 50% at a rotation age of 25-27 years.

Application of the management strategy, prescribed by Jackson (1959) or Foggie (1968), for the management of riverine *A. nilotica* stands for saw log production, involves the production of sizeable quantities of non-millable wood from both intermediate and final cuts. The share of millable and non-millable wood in the quantity harvested from thinnings or final harvest is of great importance for the analysis of volume and value flows along the rotation.

Development of a set of curves, representing the millable percentages of wood for stands of different site indices and at different crop ages, helps to achieve a number of objectives. First, they tell the approximated quantities of millable and non-millable wood per unit area. Secondly, they help in establishing prices per unit area that reflect variable diameters; and finally they are vital for financial/economic anaylses of timber growing projects when both millable and non-millable wood components are involved.

The objectives of this research were (i) to estimate the technical rotation of *Acacia nilotica* stands grown along the Blue Nile, Sudan, with the objective of producing saw logs that yield railway sleepers, and (ii) to estimate millable wood percentages at different crop ages for stands of SI 25 and 28..

MATERIALS AND METHODS

This research was concerned with the even-aged forest stands of *A. nilotica* grown along the Blue Nile, south of Sennar dam. These plantations are managed mainly for production of saw logs capable of yielding railway sleepers (El Houri 1976) as the main sawn wood product. The major part of sawn wood production from small-sized logs (25 cm diameter at small end) is the responsibility of private sawmill (El-Siddig and Hetherington 1985).

Determination of technical rotation for log production

Data were collected in 2002 from Hedaibat, Zumurka and El Gezair forest reserves in the Blue Nile State, Sudan. These forests were under final felling, which was performed using power-chain saws. Mean stump heights were measured for 37 felled trees in order to relate stump height to the mid-log diameter of the first log.

Production records of Es Suki sawmill during a period of 507 working days were examined and analyzed to estimate minimum mid-log diameters required to produce varying numbers of SRS (2.1 m* 25 cm*12.5 cm). The corresponding ranges of crop ages that produce commercial logs or sleeper logs with diameters large enough to yield single, double, triple or tetra SRS were identified, using *A. nilotica* yield tables constructed by Eltayeb (1985).

Estimation of potential millable wood percentage

Mid-log and small-end diameters over bark (DOB) of 111 logs, randomly selected from final felling, were measured and recorded. They ranged from 27 to 70 cm and from 25 to 67 cm, respectively. Regression of small-end on mid-log diameters was established. Taking the dbh as the mid diameter of the first log, the regression relationship of small-end on mid-log diameters was then used to estimate mid diameters of the second and subsequent logs up to the limit of bole height.

To determine the potential numbers of logs to be produced, each tree was assumed as consisting of a series of successive log-long sections. It was also assumed that saw logs are produced only from the main stem. Potential numbers of logs to be produced from single trees at various ages and for the five site indices were estimated up to a minimum of 25 cm mid diameter when commercial logs were considered, and up to a minimum of 35 cm mid diameter when only logs for state sawmills were considered. Log-long sections were grouped into diameter classes commencing at 25 cm at an interval of 5 cm, and their respective volumes were calculated applying Huber's formula (Thomson and Jerram 1948) as presented in equation 1. Volumes of logs were added together to give the total millable volume of a single tree

$$V_l = \frac{d^2}{4*10^4} * \Pi * L \qquad (1)$$

where:

V_l = log volume (m^3)
d = mid-log diameter (cm)
L = log length (m)

The ratio of bole height: total height was used as an indicator of the level of application of the prescribed management regime where 0.3, 0.5 and 0.75 bole height: total tree height ratios were treated as low, intermediate and high level adherence to prescribed management regime, respectively. Seven ratios of bole height: total tree heights were tested (0.3, 0.4, 0.5, 0.6, 0.7, 0.75 and 0.8). The two ratios of 0.6 and 0.75, being considerd as targets of forest management for sawlog production, were used for estimation of millable wood percentages reported in this study. The choice of these two ratios was guided by earlier estimates at final cut reported by Dafa-Alla (2004), Goda (1985) and Foggie (1968).

Counting of logs started from the stump of the tree upwards. Logs that could potentially be produced at heights beyond the bole height in each alternative ratio were ignored. Total solid volume (m^3) of single trees was calculated using equation 2 as reported by Taylor (1962).

$$V_t = s \times h \times f.....(2)$$

where:

V_t = tree total volume (m^3)
s = the breast height sectional area (m^2)
h = total height (m)
f = form factor

The bole form factor (f) used is presented in equation 3 according to El-Siddig and Hetherington (1985):

$$f = 0.931 + 0.0022D - 0.0232hb \qquad (3)$$

where:

f = form factor

D = diameter at breast height (cm)

hb = bole height (m)

Relating the saw logs volume to total volume of each single tree and multiplying the result by 100 provided the percentage of millable wood volume to total wood volume for various ages and site indices, based on single tree statistics. Similar percentages were made for trees used for sleeper-logs alone. The source of dbh and total tree heights was *A. nilotica* yield tables according to Eltayeb (1985).

RESULTS AND DISCUSSION

Determination of technical rotation for log production

The mean stump height was 25.3 cm above ground level, and accordingly, the diameter at breast height (dbh) of a tree was close to the mid of first log. Following the current sawing pattern at Es Suki sawmill, mid-log DOB required to produce single, double, triple and tetra SRS were within the ranges of 36-47, 48-55, 56-64, and 65-68 cm, respectively. Table 1 displays the range of mid-log DOB required to produce the indicated product categories and the ages that correspond to technical rotation limits for *A. nilotica* stands of site indices 16, 19, 22, 25 and 28.

These results are in agreement with those presented by Khan (1964) and supported by Foggie (1968) who indicated that Sunt (*A. nilotica)* stands, which were capable of producing SRS logs on a short rotation were between quality class (Q.C.) 1 and Q.C. 11/111. The results further support that of Foggie (1968) who affirmed that mediocre crops, which were capable of producing SRS logs eventually on a longer rotation, were largely of Q. C. 111/1V, and poor crops, which were most unlikely ever to yield sleeper size logs, comprise the rest of the 111/1V and 1V quality classes. Based on tree height, comparable analysis revealed that stands of site indices 25 and 22 closely relate to stands of Q.C. 1 and I/II-II, respectively, while stands of SI 19 match those of Q. C. II-II/III, stands of SI 16 go with stands of Q. C. III and III/IV.

Table 1. Technical rotations for the production of saw logs on the basis of site index

Product category	Mid-log DOB[1] (cm)	Stands of site index				
		28	25	22	19	16
		Age[2] (year) to attain minimum mid-log diameter (cm) necessary to yield each product category				
Commercial log	25-35	9-13	11-17	16-24	21-36	28-36
Single-sleeper log	36-47	14-20	18-28	25-36		
Double-sleeper log	48-55	21-28	29-36			
Triple-sleeper log	56-64	29-36				
Tetra-sleeper log	65-68	>36				

[1]DOB = diameter over bark
[2]Based on Eltayeb (1985)

The determination of the technical rotation has several policy and practical implications. Management objectives and strategies could be based on site potentiality and limit the process of saw log production to sites of high quality, i.e., SI 28 and SI 25. Accordingly, stands of SI 16 and SI 19, which are potentially not capable of producing sleeper-logs, may be managed for the production of fuel wood under shorter rotations of twenty years or less.

The process of re-organization of compartments seems indispensable. This is supported by the recommendation made by Hetherington and El-Siddig (1984) who indicated that the compartmentation system may be one of the major factors resulting in the alarming deviation of the structure and failure to attain sustainable production. The Inventory Directorate of the FNC (1998) came to the same conclusion.

The minimum diameters required to produce railway sleepers are determined with due consideration to the current sawmill technology. Therefore, any improvement of mill environment, in terms of machine efficiency and log characteristics that leads to the utilization of smaller diameters will affect the range of the technical rotation. According to Osmaston (1968), as even-aged stands always contain a big range of tree sizes around the mean size, the technical rotation should probably be longer or shorter than that corresponding to a mean dbh in the stand. This supports the findings of the present study and encourages adoption of a range of years rather than a technical rotation based on a single year.

The use of mid-log DOB, as currently adopted, is not justified and resort to the use of small-end log diameter under bark (DUB) is indispensable. To produce a single railway sleeper from a straight, defect-free log, its small end diameter should at least be 28 cm under bark or 31 cm over bark. Similarly, the minimum small end diameter required for the production of two sleepers per log is 35.3 cm under bark or about 36 cm to allow for the saw kerf (Abdelgadir and Nile 1998a). Logs are generally of better quality if they are straight and have a round cross-section, a larger diameter and small branches and are free from defects such as rots, insect damage and internal defects, and have not been damaged in the processes of felling, extraction and cross cutting (James 2001). Classification of logs according to size is an indicator of the number of sleepers produced but not an appropriate one unless log defects are taken into consideration (Abdelgadir and Nile 1998b).

Estimation of potential millable wood percentage

The regression anlysis revealed that the relationship between DOB at mids and small-ends of logs produced from final felling can be described by equation 4.

$$Y = -1.18 + 0.987 * X \quad (4)$$

$$(r^2 = 0.94)$$

where:

Y = small-end diameter (cm)

X= mid-log diameter (cm)

Figures 1 and 2 display millable wood percentages of all (commercial and sleeper) logs and sleeper logs only produced from stands of site indices 25 and 28 for bole/ height ratios of 0.75 and 0.6, respectively. The limits of the bole: total tree height are consistent with those estimated by Dafa-Alla (2004), Foggie (1968) and Goda (1985) who stated that timber height is taken as 44.6% and 37.4% of total height for site types Gs-Ks and M, respectively, in young crops, while in old crops the ratios are 82.4% and 82% for site type Gs-Ks and M, respectively. As expected, the millable wood percentage increased with site index and management level. This is also reflected in the relationship between number of sleeper-logs produced, age and site index.

This result is of practical importance in that inference about quantity of final products such as commercial logs and railway sleepers can be made by knowing measurable parameters in the forest. This has implications for value estimates particularly for concessions and other management decisions.

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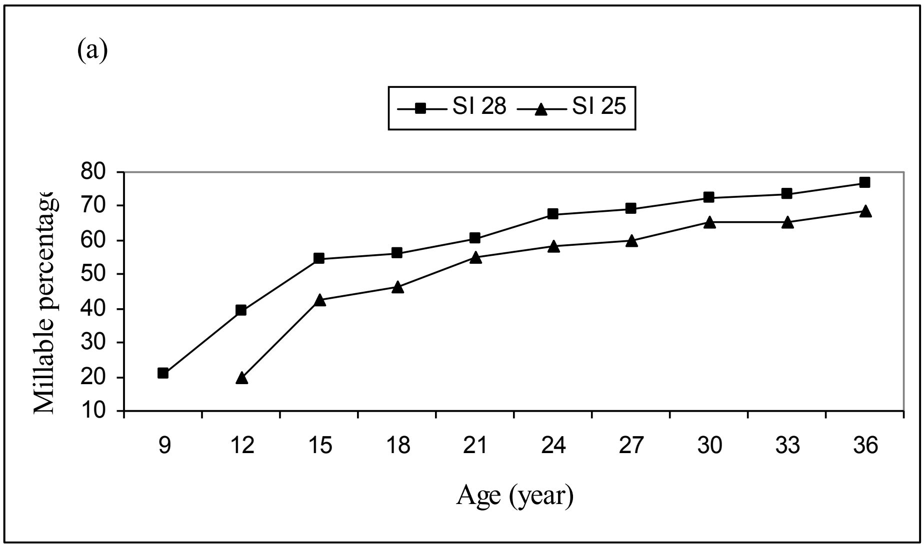

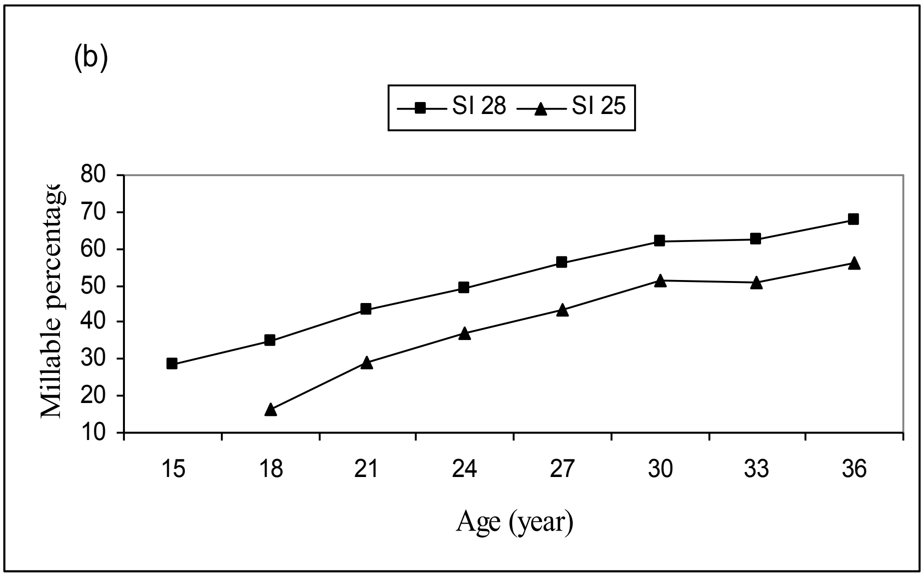

Fig. 1. Percentages of millable wood of (a) all logs and (b) sleeper logs in stands of site indices 25 and 28 (0.75 bole/total height ratio)

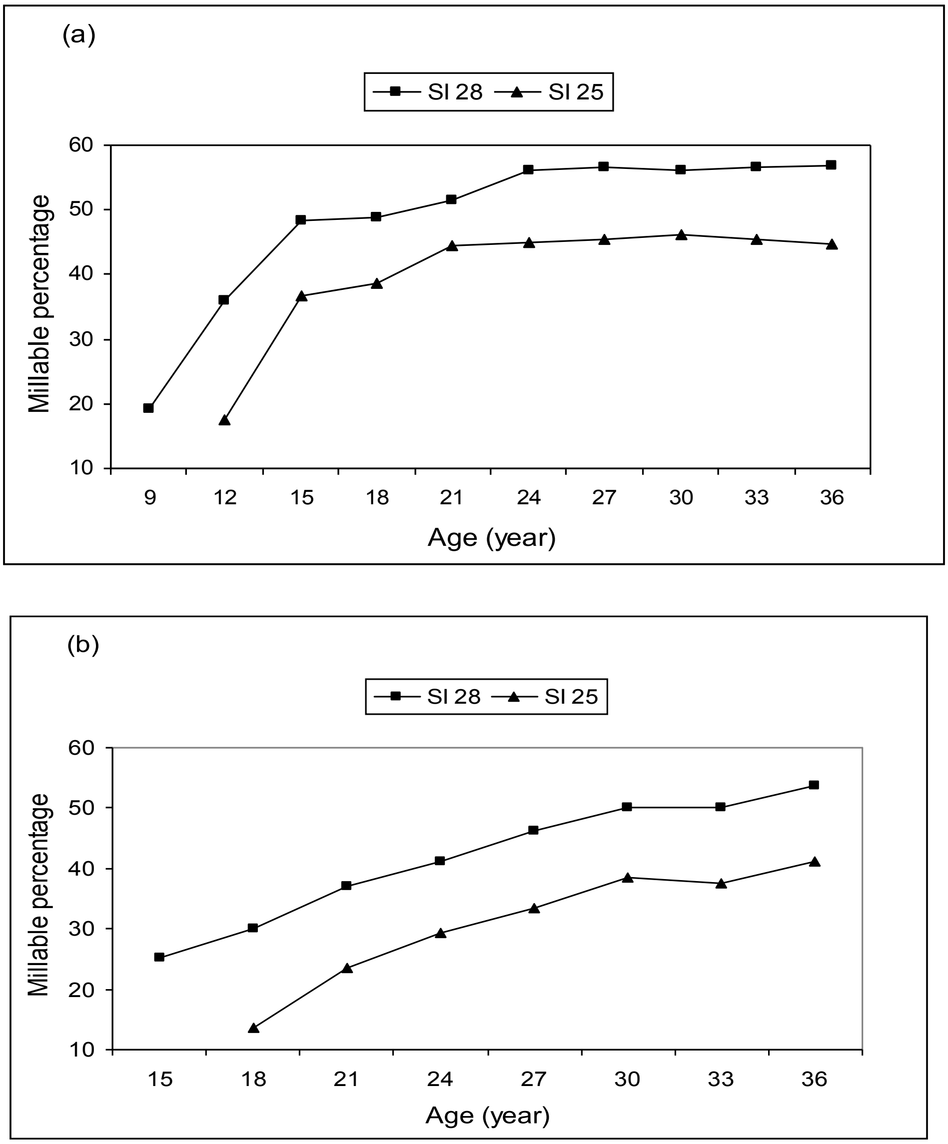

Fig. 2. Percentages of millable wood of (a) all logs and (b) sleeper logs in stands of site indices 25 and 28 (0.6 bole/total height ratio)

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تحديد الدورة الفنية لغابات السنط المزروعة لإنتاج كتل النشر و نسب خام النشر الملازمة لها

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موجز البحث: هدف هذا البحث بصورة رئيسة لتقدير مفهومين فنيين مرتبطين بقرارات الادارة الفنية هما طول الدورة الفنية لغابات السنط المزروعة على ضفتي النيل الأزرق (السودان) اللازمة لانتاج كتل النشر المنتجة لو سادات سكك الحديد، وتحديد نسب خام النشر مقارنة بالحجم الكلي عند أعمار مختلفة للمحصول. أوضحت النتائج أن قطر منتصف الكتلة (فوق اللحاء) بمدى 36-47 و48-55 و56-64 و65-68 سم مطلوب لإنتاج وسادة أو وسادتين أو ثلاث أو أربع وسادات سكة حديد، على التوالي. كما اوضحت النتائج ايضا ان غابات السنط ذات مؤشري الموقع 28 و25 هي الأفضل للحصول علي كتل النشر المناسبة لإنتاج الوسادات، بينما تعد غابات السنط ذات مؤشر الموقع 22 هامشية وغابات السنط ذات مؤشر الموقع 19 و16 لا تحقق هذا الهدف. دلت النتائج ايضا علي أن الدورة الفنية تمتد من 25 الي 36 عاما لغابات ذات مؤشر الموقع 22 لإنتاج كتل نشر قابلة لإنتاج وسادة سكة حديد واحدة، و29-36 عاما لغابات ذات مؤشر الموقع 25 و28 لإنتاج كتل نشر قابلة لإنتاج وسادتين وثلاث وسادات سكة حديد، على التوالي. لهذه النتائج اهمية في اتخاذ قرارات الادارة الفنية لغابات السنط المزروعة. تم رسم منحني نسب خام النشر لكل كتل النشر ولكتل النشر المنتجة لوسادات سكك الحديد فقط وذلك لغابات ذات مؤشر الموقع 28 و25.