A56

Project Report 18

GHA/74/013

THE DEVELOPMENT OF FOREST ENERGY RESOURCES

GHANA

# A PROVISIONAL YIELD TABLE FOR GMELINA ARBOREA PLANTATION IN SUBRI RIVER FOREST RESERVE

Report prepared for the Government of Ghana

by

the Food and Agriculture Organization of the United Nations
acting as Executing Agency for
the United Nations Development Programme

UNITED NATIONS DEVELOPMENT PROGRAMME
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Takoradi, Ghana May 1982

# DISCLAIMER

This field document is one of a series of reports prepared during the course of the UNDP/FAO Project identified on the title page. The conclusions and recommendations given in the report are those considered appropriate of the time of its preparation. They may be modified in the light of further knowledge gained at subsequent stages of the Project. The content of this report does not necessarily concur with the FAO approval and is the sole responsibility of the author.

# TABLE OF CONTENTS

# FORWARD

The author, F.K.Odoom was Ghanaian counterpart to the Inventory Expert on the Project from June 1981, and continues as Senior Assistant Conservator of Forest in charge of the Forestry Department Inventory Unit that is the successor to the Project Inventory Unit.

The work described was planned, directed and analysed by him between July 1981 and May 1982. In the analysis, some technical support was also provided by Denis Alder, the FAO Inventory Expert for the Project. Members of the Forest Inventory Unit carried out different aspects of the field work and data processing.

Project Manager

## LIST OF TABLES



## LIST OF FIGURES

# GLOSSARY OF TERMS

| | |
|---|---|
| d.b.h. or d | Diameter at 1.3 above ground level or the uphill side of the tree on a slope. |
| Lorey's height | Mean height weighted by basal area i.e. Lorey's ht. =Σ(h*d*d)/Σ(d*d). |
| n | Number of sample plots. |
| N or Stocking | Number of tree per hectare of a stand or plot. |
| Coefficient of Determination | The ratio of the portion of the variation of the observed values from their mean which is explained by the regression to the total variation. This is expressed by the square of the correlation coefficient and has a range from Ø to 1. The closer the value is to 1 the better the regression. |
| m.a.i. | Mean annual increment; the volume in m cu.m./ha at a given age divided by the number of years. |
| c.a.i | Current annual increment; the difference between the volume in cu.m./ha at a given year and that at the preceeding year. |
| EXP(x) | Exponent x; x is the exponent of the power e. |
| SQR(x) | Square root of x. |
| ↑(x) | x is the exponent of the preceeding term. |
| * | Multiplication sign. |
| sq.m or m2 | square meters. |
| cu.m or m3 | cubic meters. |
| o.b. | subscript for overbark. |
| u.b. | subscript for underbark. |
| Σ | Summation sign. |

# SUMMARY

A provisional yield table is constructed for *Gmelina arborea* in the tropical rainforest zone of Ghana. The area coverage of the Gmelina plantation is about 759 hectares. Data from 233 temporary sample plots were used. Thinning yields and stocking were not predicted. Ages 1 to 10 were covered by the data. The results were extrapolated to 15 years. The following functions were used:

- Tree volume tariff for volumes to 5cm top diameter limit.

- Plot volumes on plot basal areas.

- Ratios of tree volumes to 8cm top diameter on tree volumes to 5cm top diameter against tree diameter.

- Ratios of tree volumes to 12cm top diameter on tree volumes to 5cm top diameter against tree diameter.

- Ratios of tree volumes underbark on tree volumes overbark against tree diameter.

- Plot mean diameter on plot mean height for different spacings.

- Plot mean heights on plot ages for different site classes.

- Maximum m.a.i. on age for different stockings.

The tree volume tariff and the volume ratios were based on 30 independent felled sample plots.

The average maximum m.a.i. and stocking were found to be 22 m3/ha/yr. and 600 trees/ha. respectively. Yield tables have been presented for constant stockings from 200 to 1600 at 200 intervals within a yield class. Yield classes 10 to 34 were covered in 4 m3/ha/yr. classes.

# CHAPTER 1

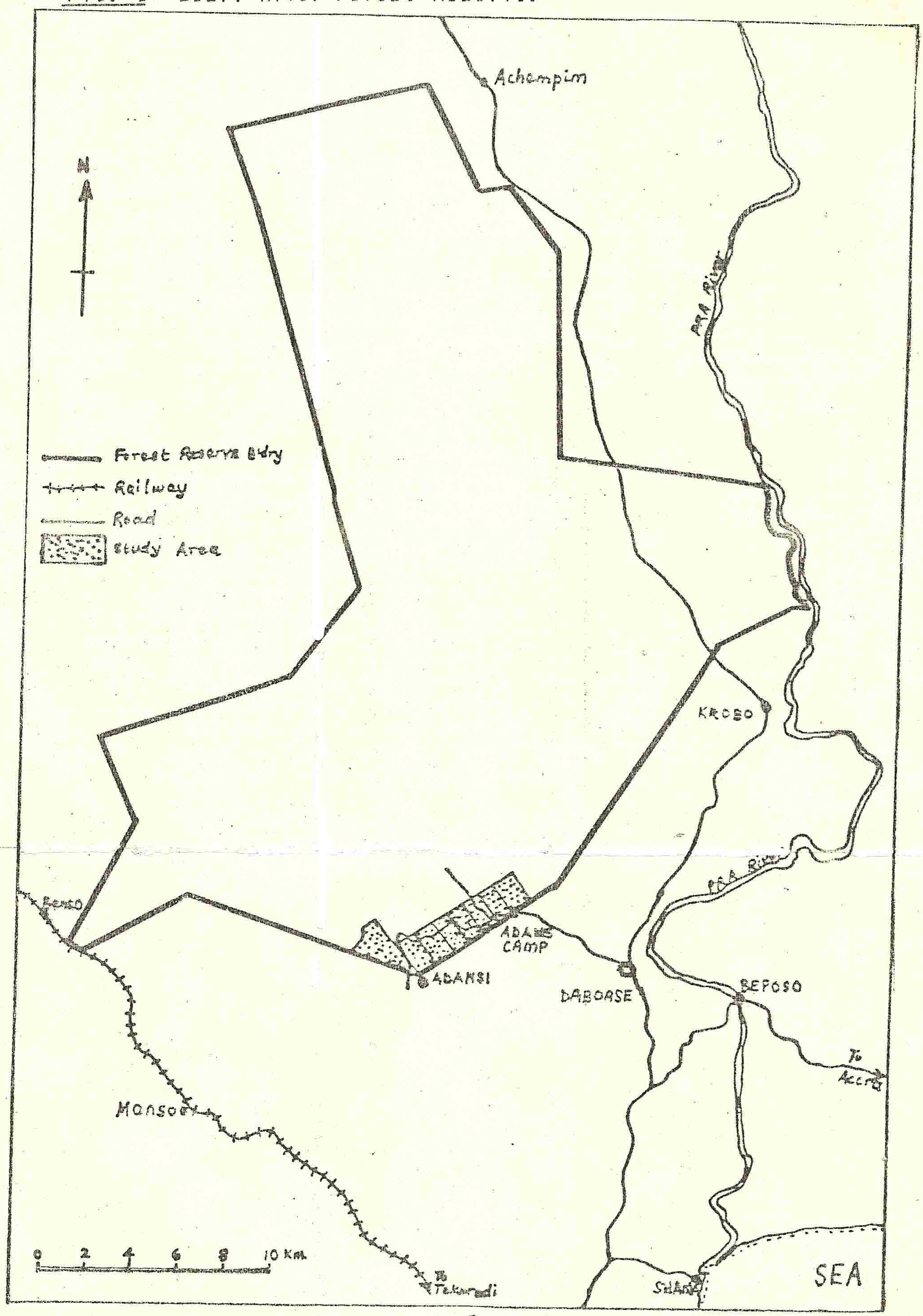
## INTRODUCTION

As part of the activities of the UNDP/FAO/Forestry Department project (the Subri Project), plantations are being established at the project site in the Subri River Forest Reserve. Studies which have so far been conducted propose a planned production of pulp and paper from an indigenous tropical mix, gradually changing to plantation species as these are established to replace the natural forest species removed.

Observations in the field indicate that of the plantation species which have been tried on the project site, Gmelina arborea is the most promising with respect to its fast growth rates. In addition, it fufils the requirements for a suitable raw material for pulp.

In this paper, an attempt has been made to provide a provisional yield table for the Gmelina growing on the project site. Data from temporary sample plots were used. Apart from the use of the yield table in the preparation of a comprehensive management plan for the plantation, it will also provide figures for feasibility studies for the proposed pulp and paper mill at Daboase, about 7km from the southern boundary of the Subri River Forest Reserve (see map on page 2).

Fig. 1: Subri River Forest Reserve.



CHAPTER 2

# THE STUDY AREA

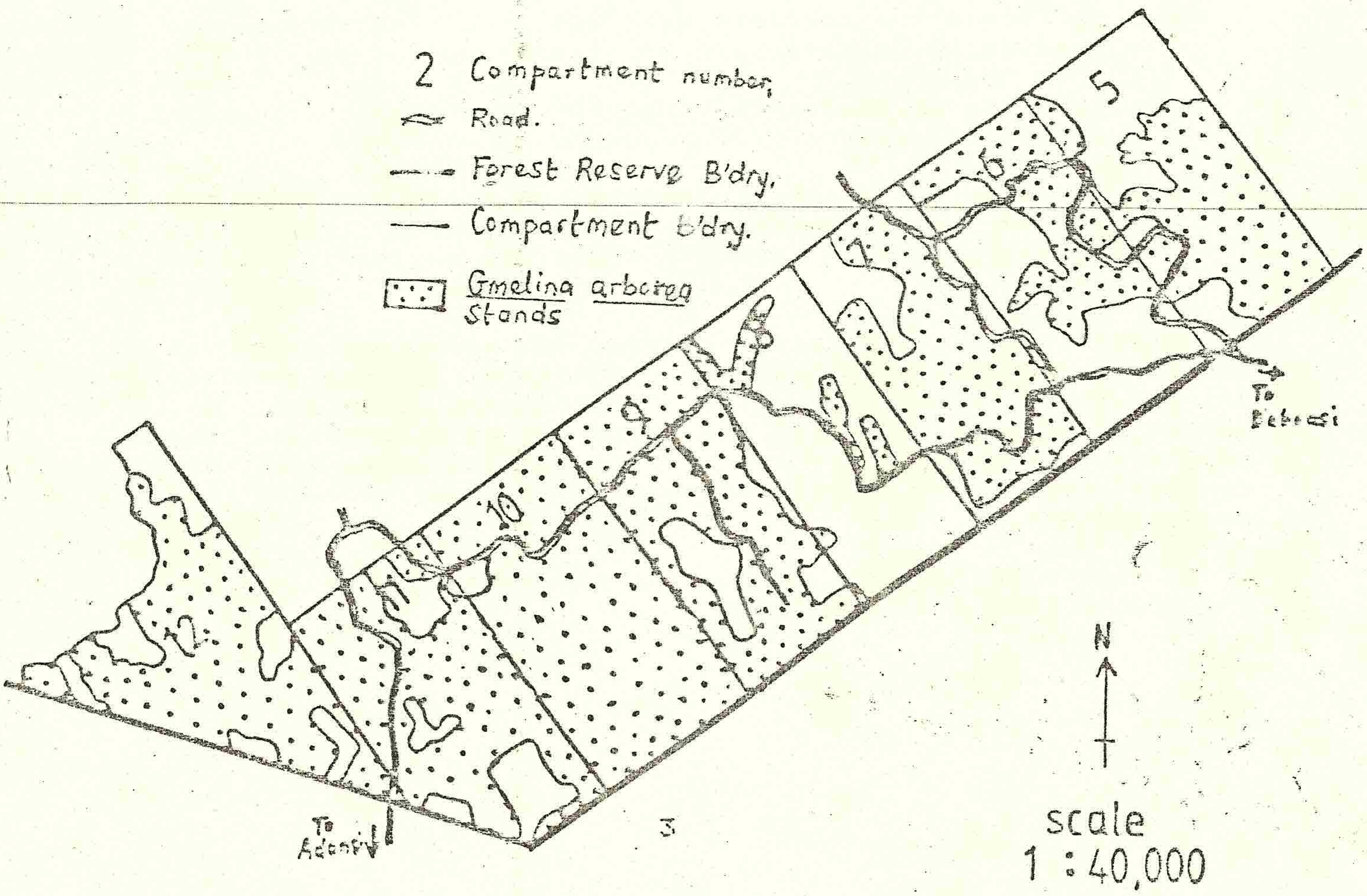
## 2.1 AREA

The Subri River Forest Reserve, in which the activities of the UNDP/FAO/Forestry Department (Subri Project) are concentrated, covers an area of about 57,000 hectares. It forms part of the catchment area of the Pra River from which most of the water supply for the cities of Sekondi and Takoradi is derived (see map on page 2). The study area consists of 8 compartments on the southern boundary of the reserve. The area of each compartment is about 150 hectares.

## 2.2 FOREST TYPES

According to the classification by Taylor (1960), which is being used by the Forestry Department, the northern and eastern portions of the Subri River Forest Reserve fall within semi-deciduous forest (Lophira-Triplochiton Association) whilst the rainforest covers the southern and eastern sectors. It is within the latter formation that the study area falls.

Fig.2: *Gmelina arborea* Plantation, Subri River Forest Reserve; Compartments 5 - 12.



## 2.3 SILVICULTURAL HISTORY

The study area is found in a timber concession which had been subjected to commercial salvage fellings before the reforestation programme was initiated by the Forestry Department in 1972.

Until 1978, the cut and burn technique was used for preparing the site for planting. The planting stock was raised in polythene pots and planted at 6.7m x 2.5m and 2.7m x 2.7m. They were often intercropped with foodstuffs. As a result of financial constraints and early failures, the cut and burn method was abandoned in 1977. The failed areas were heavily invaded by *Eupatorium odoratum* which causes the most serious weed problem in the area. Clearing and replanting of such sites were done at a relatively high costs.

In 1977, the Subri Plantation Scheme was integrated with the UNDP/FAO Project -The Development of Forest Energy Resources in Ghana. From this point, the utilisation of felling wastes, obtained from conversion operations, was incorporated into the establishment of new crops in a more effective way.

From 1978, the planting programmes have been carried out using variations of the present Subri Conversion Technique. In this method, a number of juvenille species are left as standards evenly over the plantation species. The system was adopted for the following reasons:

a. to avoid the complete destruction of indigenous tree species which have pulp and timber potential.

b. to minimise damage to the environment, and maintain ecological diversity.

c. to provide shade to reduce the rapid growth of the highly light demanding Siam Weed (*Eupatorium odoratum*) which rapidly colonises any newly cleared area.

The planting stock was also raised in polythene pots as before and planted at spacings of 5m x 2m, 5m x 3m and 4m x 3m. The young trees were also intercropped with cocoyam, maize and plantain, with the latter being predominant. The food crops, particularly the plantain, are used to help control the growth of weed as well as to supply food for the project staff.

About 759 hectares of *Gmelina* had been planted by the end of the 1980 planting season.

## 2.4 CLIMATE

No meteorological station has been established within the forest reserve, but figures from the Daboase and Inchaban Waterworks indicate the mean monthly precipitation and temperature to be about 100cm and 25°C respectively.

There are two rainy seasons with peaks in May/June and September/October.

The prevailing winds are south-westerly to southerly and are generally light. Strong gusting winds of short duration can however occur and are usually accompained by very heavy rain.

## 2.5 SOILS AND TREE GROWTH

A fairly general and simplified catena for the study area can be described as follows:

- red, gravely well-drained sedentary clay soils on the uplands.

- well-drained red concretionary clay soils on steep slopes with similarly drained yellow, brown/orange gravely soils on the lesser slopes.

- light yellow colluvial soils on the lower slopes over a mottled subsoil sometimes found close to the surface.

- badly drained yellow to grey reduced sandy or silty clay alluvial soils (Granite or Phyllite) in the valley bottoms.

Field observations confirm that plantation productivity is highest on the middle slopes and poorest on the upper slopes or summits.

## 2.6 TOPOGRAPHY

The topography is mostly flat to gently undulating with a moderate range of elevation which rarely exceeds 150 metres. A considerable network of smaller rivers and streams is present and swampy areas are frequent in the valley bottoms and near streams.

## CHAPTER 3

## DATA COLLECTION

The inventory of the plantations on the Subri Project area was undertaken between July and October, 1981. Eight compartments were covered (i.e. compartments 5-12). These extended over an area of about 1200 hectares. Approximately 40 men including 6 Technical Officers carried out the inventory.

The plantation area was stratified by species and age classes using the existing stock map. A systemtatic line-plot sampling design was employed on a grid of 100m x 100m. The size of the fixed circular plot used was 0.03 ha. (radius = 9.77m). The sampling intensity was thus 3%. In all 1222 plots were laid of which 233 plots contained 100% Gmelina. The other plots contained other plantation species or indigenous species or a variable mixture of Gmelina and other species.

On each plot the following data was collected:

i. Species and the corresponding diameters for trees with diameters of 5cm and above.

ii. Total height of 3 trees whose crowns appeared in the canopy. (measurement by clinometer).

iii. Age class (from stock map).

iv. Extent of regeneration of Gmelina.

v. Site characteristics (ie. slope, aspect, position on slope, and drainage conditions).

CHAPTER 4

# ANALYSIS OF RESULTS

## 4.1 DATA PROCESSING

An electronic data processing system at the Takoradi Office of the Inventory Unit was used in the analysis of the data.

The system hardware consists of Research Machines 380Z's, operating as two independent units. Each unit has a keyboard, display, 56k bytes memory, a twin 8-inch IBM 3740-type floppy discette with approximately 1.1 megabytes of storage, and a Microline-80 printer connected via a 7-bit parallel interface.

The main software packages used were as follow:

-Disc FORTRAN IV, BASIC and MACRO assemblers, CP/M operating system and file manager.

-CGMP(Conversational Graphics and Multiple Regression Program). This is a comprehensive computer package for multiple regression analysis. It was provided by the Commonwealth Forestry Institute, Oxford.

-SNIFTA (Small Nonlinear Fitting Algorithm). This program also allows the user to input functions, fit them to data, and then plot the data and function on the printer. This was developed by Denis Alder, the Inventory Officer (FAO).

Other small BASIC programs were also written to edit the raw data, which were stored on the magnetic discs, and also to prepare files for processing by the above packages.

## 4.2 VOLUME PREDICTIONS

### 4.2.1 Tree Volume Tariff

The tree volume tariff data was collected about a year before the plantation inventory. ( ie. between September and December, 1980).

Point sampling, using the Spiegel Relascope with a basal area factor of 4 sq m/ha., was the method of tree selection on each plot. This ensured that the probability of the selection of a tree for felling was proportional to its

CHAPTER 4

ANALYSIS OF RESULTS

## 4.1 DATA PROCESSING

An electronic data processing system at the Takoradi Office of the Inventory Unit was used in the analysis of the data.

The system hardware consists of Research Machines 380Z's, operating as two independent units. Each unit has a keyboard, display, 56k bytes memory, a twin 8-inch IBM 3740-type floppy discette with approximately 1.1 megabytes of storage, and a Microline-80 printer connected via a 7-bit parallel interface.

The main software packages used were as follow:

-Disc FORTRAN IV, BASIC and MACRO assemblers, CP/M operating system and file manager.

-CGMP(Conversational Graphics and Multiple Regression Program). This is a comprehensive computer package for multiple regression analysis. It was provided by the Commonwealth Forestry Institute, Oxford.

-SNIFTA (Small Nonlinear Fitting Algorithm). This program also allows the user to input functions, fit them to data, and then plot the data and function on the printer. This was developed by Denis Alder, the Inventory Officer (FAO).

Other small BASIC programs were also written to edit the raw data, which were stored on the magnetic discs, and also to prepare files for processing by the above packages.

## 4.2 VOLUME PREDICTIONS

### 4.2.1 Tree Volume Tariff

The tree volume tariff data was collected about a year before the plantation inventory. ( ie. between September and December, 1980).

Point sampling, using the Spiegel Relascope with a basal area factor of 4 sq m/ha., was the method of tree selection on each plot. This ensured that the probability of the selection of a tree for felling was proportional to its basal area. An efficient sample was thereby obtained for the tree volume regression analysis as the residual variances are approximately proportional to the diameter squared.

Five plots were distributed subjectively in each of the areas planted during the years 1972-1977. A total of 30 plots were laid with 164 trees in all being felled and measured. The felled trees were cross-cut into one metre lengths and the top diameter of each section was measured over and underbark with a tape. Before cross-cutting, the total height of each tree was recorded. The following tree volume tariff was consquently obtained after the regression analysis:

$$V = -0.0540189 + 0.000622587D*D$$

where, V = volume overbark to 5cm top diameter above 5cm d.b.h. (cu.m.)

and D = d.b.h. (cm)

(n = 164, Coefficient of determination = 0.92)

#### 4.2.2 Stand Volume Equation

A regression of the individual inventory plot volumes on the respective basal areas was used to predict the stand volumes used in the Yield Table. The following equation was obtained:

$$V = -6.5578 + 8.02965*G$$

where, V = plot volume above 5cm d.b.h. to 5cm top diameter. (cu.m/ha.)

and G = plot basal area above 5cm d.b.h. (sq.m/ha.)

( n= 233, Coefficient of determination = 0.99)

Stand volumes were taken as zero when predicted as negative.

#### 4.2.3 Volumes to 8cm and 12cm Top Diameter Limits

For each of the trees used in the construction of the tree volume tariff ( see section 4.2), the ratio of the volume to 8cm top diameter (V8) on that to 5cm top diameter (V5) in addition to the volume to 12cm to diameter (V12) on V5 were calculated.

i.e. R = VI/V

where, VI = V8 or V12

and V = V5

A model was consequently fitted giving the ratio as a function of the tree diameter. The model is given by

$$R = a + bD + cD*D$$

where, R = V8/V5 or V12/V5

a, b, c = coefficients of the model

D = d.b.h. (cm)

All data points with zero ratios were excluded before the model was fitted. The following coefficients were obtained. The respective models are also shown in figs 3 and 4.

| | a | b | c | trees | Coeff.of Det. |
|---|---|---|---|---|---|
| V12/V5 | -0.427486 | 0.0.7718335 | -0.001113831 | (164 | 0.75) |
| V8/V5 | 0.305227 | 0.03966719 | -0.0006179106 | (164 | 0.56) |

Fig. 3: Ratio Curve - Tree volume to 8cm top diameter.

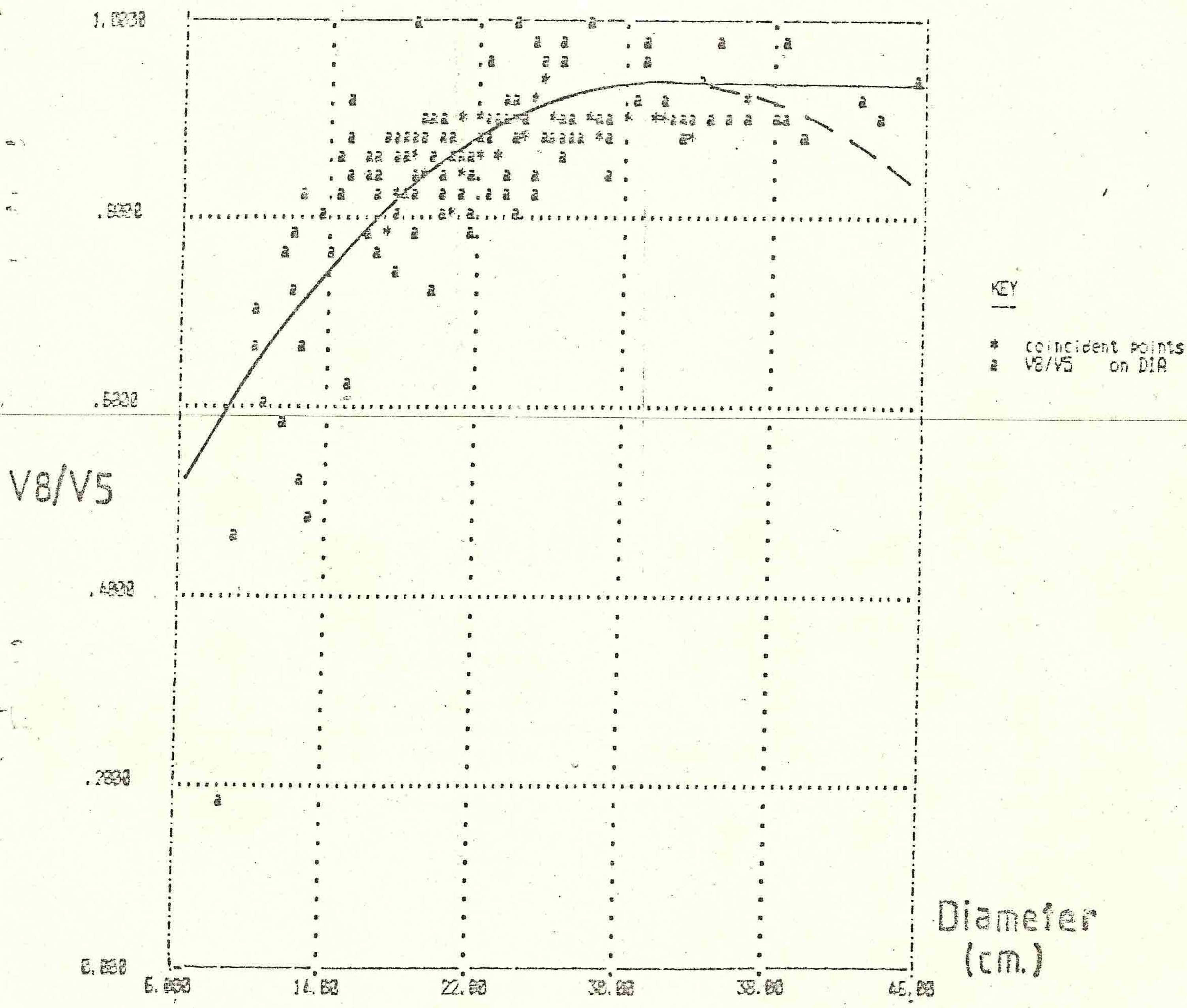
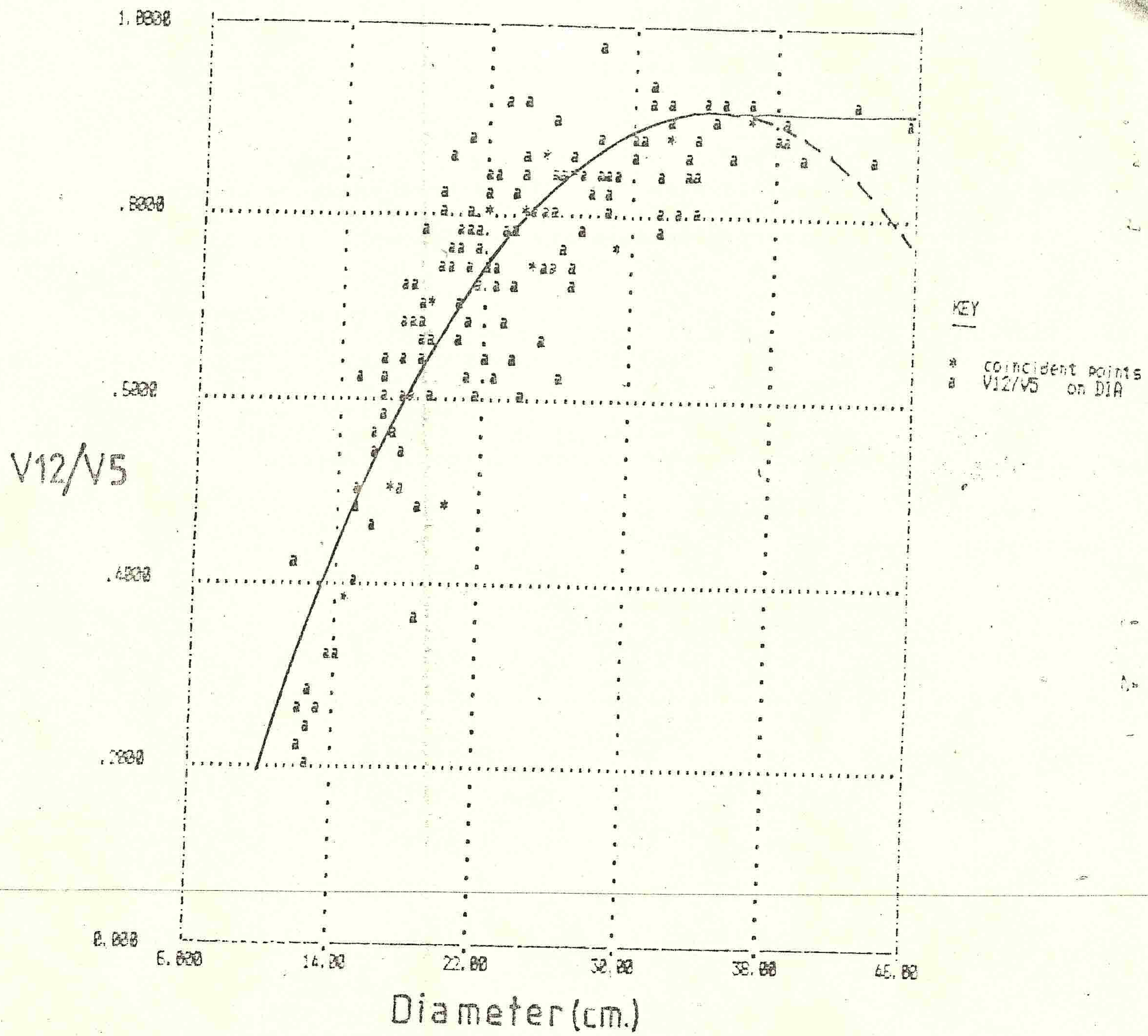


Fig. 4: Ratio Curve - Tree volume to 12cm top diameter.




After the parabola has reached the point of inflexion, the descending part of the curve is replaced by a horizontal line. Thus when using the model for the mean basal area tree, if mean diameter exceeds that at the point of inflexion, the latter diameter is used for calculating the volume ratio. Also, a predicted negative volume to a particular diameter limit was taken as zero.

4.2.4 Volume Underbark

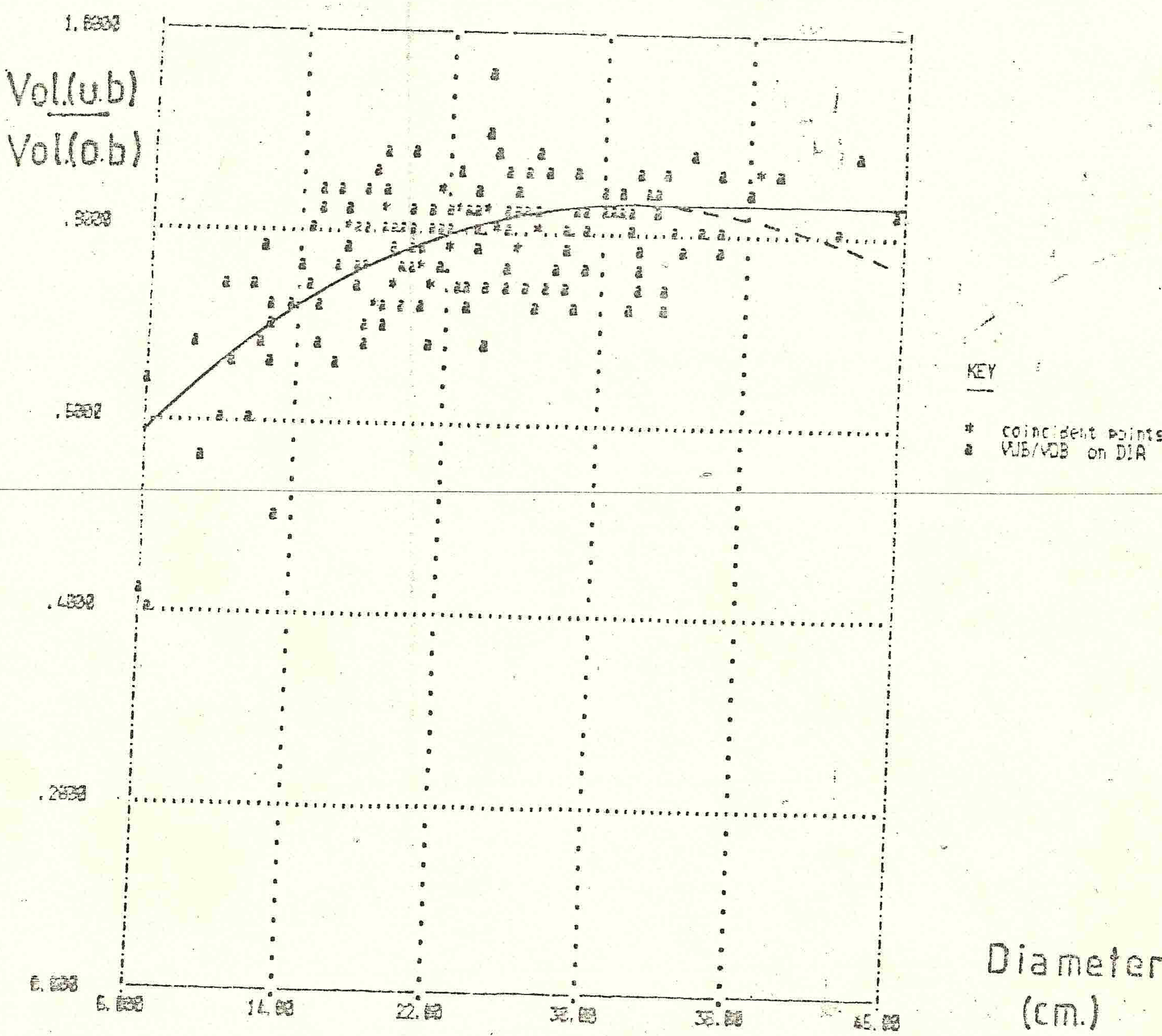
In this case, a similar procedure as was applied in section 4.4 was used. The ratio in the model then becomes volume under-bark (VUB) on volume over-bark (VOB).

i.e. R = VUB/VOB

The coefficients obtained were as follows:

a = 0.46932
b = 0.02271861
c = -0.0003526147
(n = 164, Coefficient of determination = 0.43)

Fig. 5: Ratio Curve - Tree underbark volume.



## 4.3 STAND MEAN DIAMETER

The data for the 233 inventory plots was fitted via the multiple regression analysis to the following model:

$$DG = (B0 + B1*HT + B2*HT*HT)(1+A+(B*100)/SQR(STOCKING))$$

where, DG = Plot mean diameter (cm). [i.e SQR(Σd²/t)]

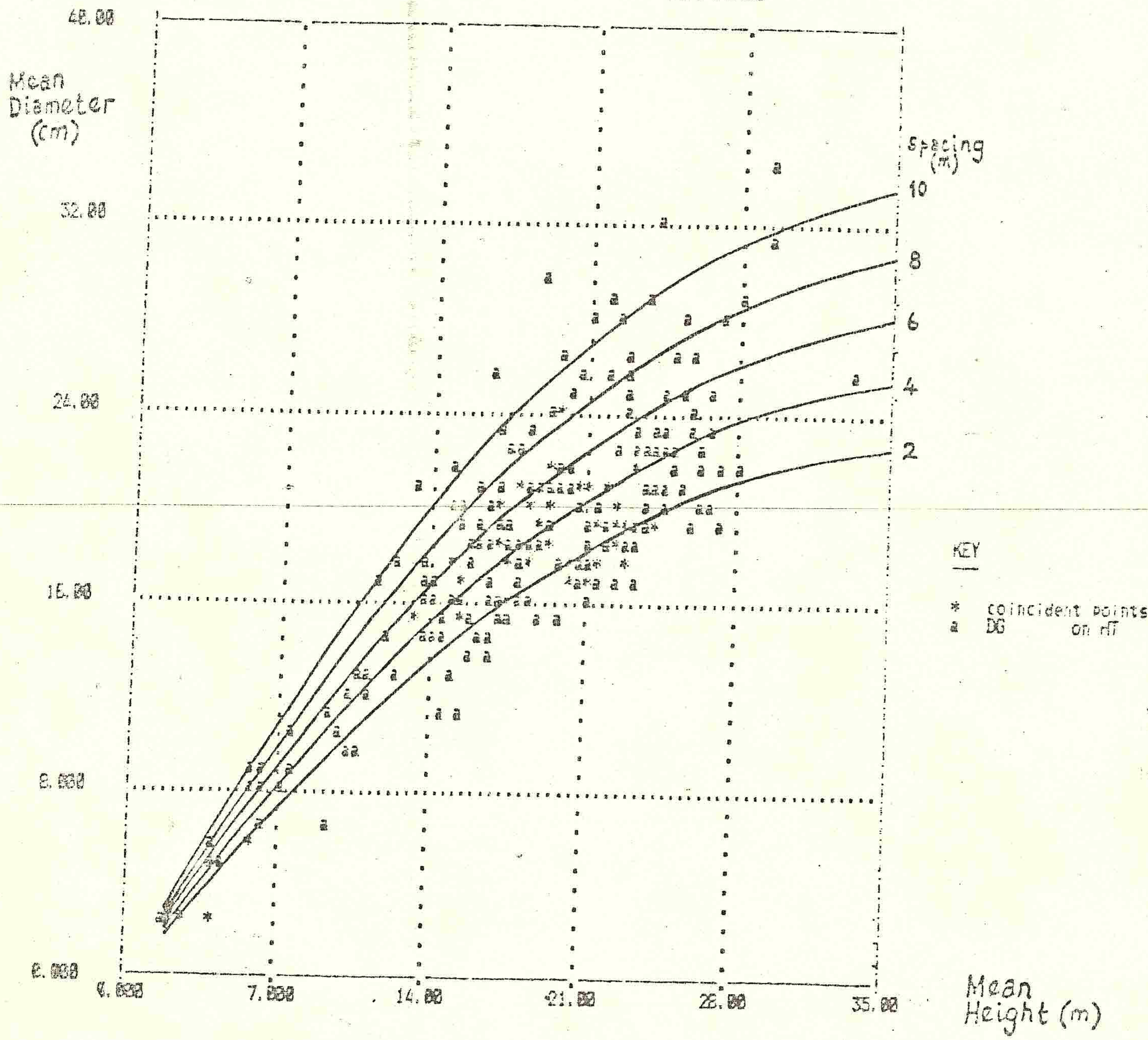
d = diameter of sample tree on plot (cm).

t = no. of trees on sample plot.

HT = Lorey's height (m).

N = stocking of sample plot.

Fig. 6: Stand mean diameter - height curves.



For the first part of the above equation the following were obtained:

B0 = -0.481785
B1 = 1.41607
B2 = -0.01875511
Coefficient of determination = 0.74, n = 233

For the second part also, we have:

A = -0.227735
B = 0.05115085
Coefficient of determination = 0.12, n=233

## 4.4 YIELD TABLE

### 4.4.1 Site Index Curves

The mathematical method which was used in fitting the site index curves is a variation of the maximum-minimum method which can be applied when there are large amounts of temporary plot data in each age-class (see ref. 2, page 48).

The height observations in each age-class were sorted in order, from maximum to minimum and each point was assigned a site class S from:

S = ( i - 0.5)/n

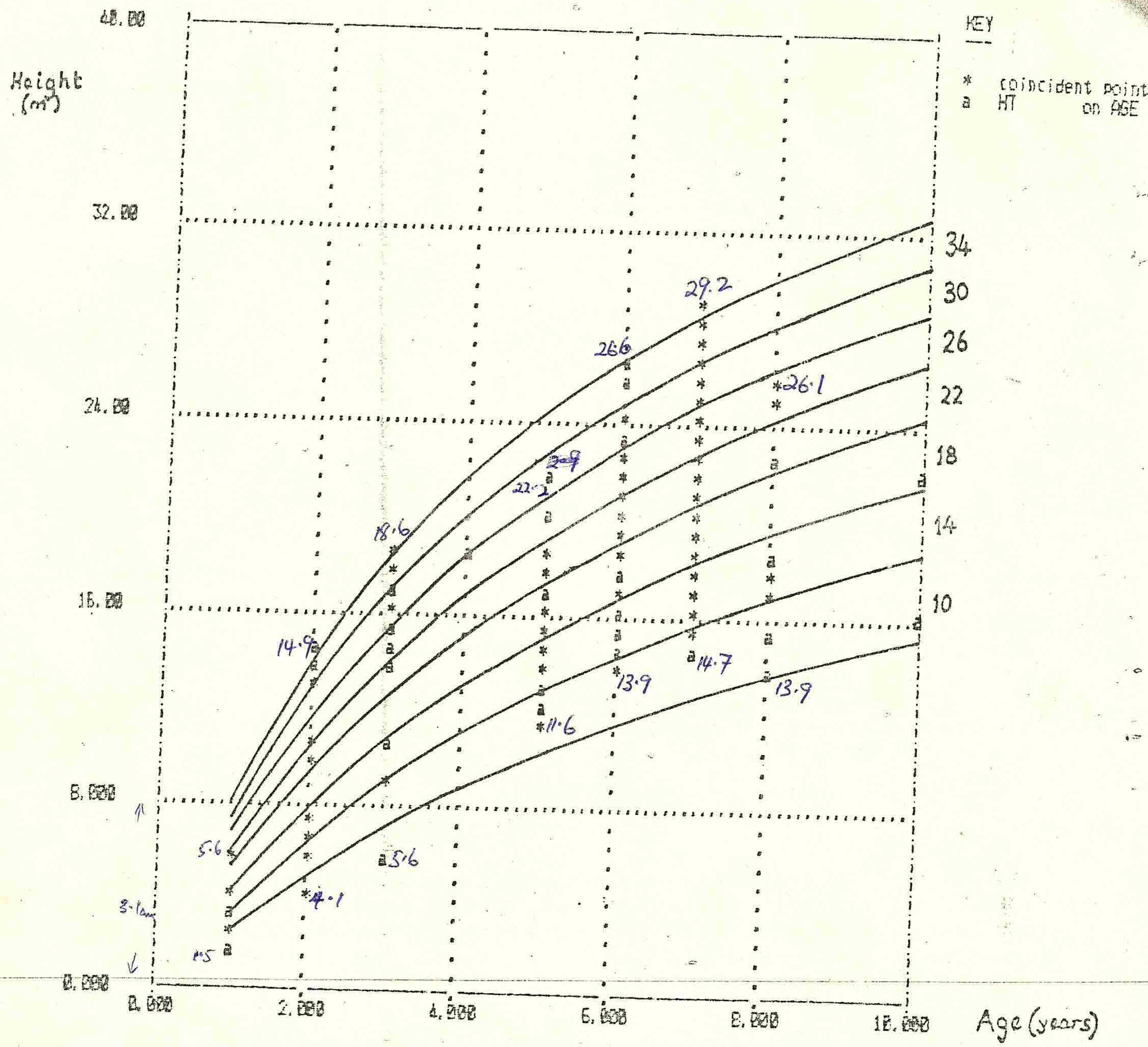
where 'i' is the plots position after sorting and 'n' is the number of plots in the age-class. Once each plot has been assigned a site class, the multiple regression analysis was used to fit the data to an expression of the Schumacher equation as shown below:

log(HT) = B0+B1*(1/AGE)+K)+B2*S+B3*S*(1/AGE)+K)

K = constant
HT = Lorey's Height (m)
B0 = 1.91708
B1 = -1.02066
B2 =-0.198367
B3 =-0.426386
Coefficient of determination = 0.96, n=233

K-values between 0 and 1 were tried with the above model. The value of K which gave the least residual standard deviation (ie. 0.4) was then used for the model.

Fig. 7: Yield class curves.




#### 4.4.2 Yield Class

For simplicity sake, site index classes were expressed in terms of maximum mean annual increment (to 5cm top diameter underbark). This is a common approach in Europe.

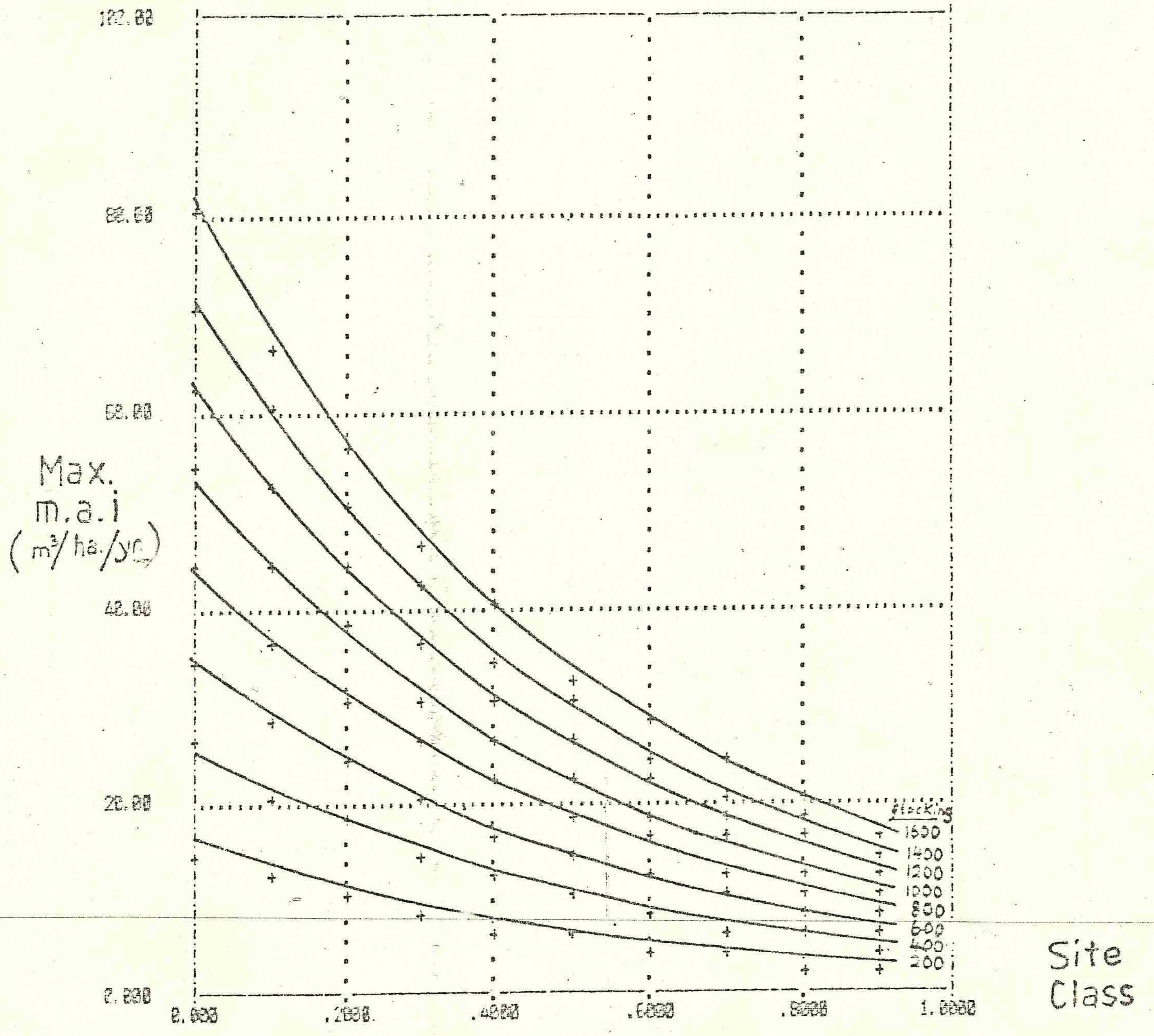
The following good relationship was found between max. m.a.i. from the yield equations and site class S in equation 4.4.1 for various stockings:

Max. M.A.I.= (B0+B1*STOCKING)*EXP(B2*S)

B0 = 7.40586
B1 = 0.04597298
B2 =-1.71401

Coefficient of determination = 0.99, n=80

Fig. 8: Max. m.a.i. - site class curves for different stockings.



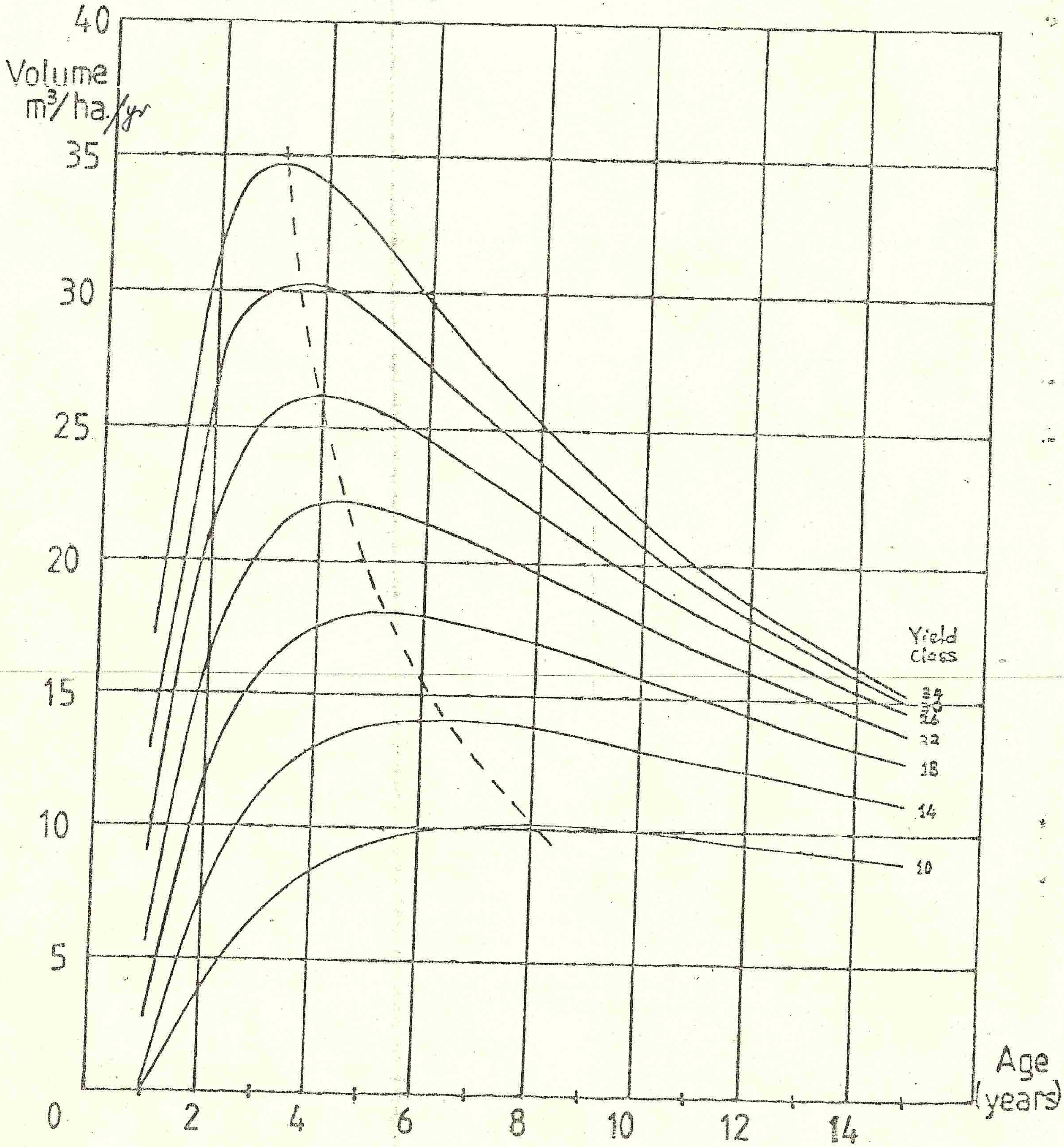

The range of max. m.a.i. encountered on the study area, as indicated in Fig.9, lies between 8cu.m./ha/yr and 36cu.m./ha/yr.This range was then divided into 4 cu. m. classes and each class termed a YIELD CLASS.

Thus a stand with a yield class of 14, has a max. m.a.i. of 14 cu.m/ha/yr. The model above was then incorporated into the height-age (site index) curves to give yield class directly instead of site index. A mean stocking of 600 for the area was used (see Table 1).

To find the yield class of a stand, one enters the Yield Class Curves (Fig.A1) with the average height and age of the respective stand and reads off the yield class directly. This is then used to enter the Appendix at the appropriate Yield Table. Within a yield class, yield tables have been presented for constant stockings from 200 to 1600 at intervals of 200. Variables for intermediate stockings may be obtained by interpolation.

The frequency distribution of the stocking and the yield classes with respect to the 233 Gmelina sample plots are as indicated in tables 1 and 2.

Fig.9: M.a.i. curves.



4.4.3 Compilation of the yield table

The index of site for a particular yield class and stocking was obtained by using the model in 4.4.2. It is this site index which when incorporated into the model for the site class curves (see 4.4.1.) results in the predicted height for a particular age class.

The obtained height in turn was used to predict the stand mean diameter via the model in 4.3. The predetermined stocking was used. The stand basal area per hectare is consequently determined from the stand mean diameter and stocking as follows:

$$BA = 0.00007854 * DG * DG * N$$

where, BA = stand basal area per hectare (sq.m/ha.).

DG = stand mean diameter (cm).

and N = stocking.

With the obtained stand basal area, the stand volume per hectare was realised by the use of the stand volume equation in 4.2.2. The ratios for the volumes to the 8cm and 12cm top diameters (see 4.2.3.) in addition to that for the underbark volume (see 4.2.4.) were used to convert the stand volume to the respective volume categories.

## TABLE 1

### NUMBER OF PLOTS BY STOCKING

| STOCKING | MEAN | PLOTS | % | CUM. % |
|---|---|---|---|---|
| 0-200 | 156 | 6 | 2.6 | 2.6 |
| 200-400 | 300 | 40 | 17.2 | 19.8 |
| 400-600 | 494 | 78 | 33.5 | 53.3 |
| 600-800 | 674 | 61 | 26.2 | 79.5 |
| 800-1000 | 875 | 29 | 12.4 | 91.9 |
| 1000-1200 | 1038 | 13 | 5.6 | 97.5 |
| 1200-1400 | 1233 | 1 | 0.4 | 97.9 |
| 1400-1600 | 1433 | 5 | 2.1 | 100.0 |
| TOTAL | - | 233 | 100.0 | - |

Mean Stocking = 600

## TABLE 2

### NUMBER OF PLOTS BY YIELD CLASSES

| YIELD CLASS | PLOTS | % | CUM. % |
|---|---|---|---|
| 10 | 18 | 7.7 | 7.7 |
| 14 | 50 | 21.4 | 29.1 |
| 18 | 40 | 17.2 | 46.3 |
| 22 | 50 | 21.4 | 67.7 |
| 26 | 44 | 18.9 | 86.6 |
| 30 | 19 | 8.2 | 95.8 |
| 34 | 12 | 5.2 | 100.0 |
| TOTAL | 233 | 100.0 | - |

Mean Yield Class ≃ 22

CHAPTER 5

CONCLUSION

The results obtained from the yield table should be regarded as being of provisional usefulness. They depend to some extent upon the assumption that all sites have an equal chance of being represented in each age-class. This is rarely the case in practise with temporary plots.

Though there were more than 233 plots with Gmelina, those plots which contained Gmelina mixtures were not used. This was done to eliminate any possible effect of interaction between species on the results.

The results have been extrapolated to 15 years so that the tables may still be used for managing the older stands should the decision on the establishment of the pulpmill at Daboase be delayed. Tables have also been deliberately provided for stockings which are not typical to the study area. This is meant to demonstrate the possiblities with planting at close spacings without intercropping with foodstuffs.

At the time of the plantation inventory, the compartment registers were not up to date. Instead, a stockmap which had been compiled a year before was used. One result of this is that areas which may have been beaten-up would have been difficult to distinguish from poor sites, especially if they occured in the older stands. The respective ages would also have been wrongly assessed. Due to the existence of two planting seasons in the year (i.e.May/June and September/October), the actual ages of the stands may differ from those used by about 3 months. Hence the assessment of age, which is a key independent variable in any yield table, contains some uncertainty which may affect the validity of the tables. Better record keeping would have eliminated this.

The production target for the proposed pulpmill at Daboase according to one study is estimated to be 60,000 cubic metres of paper per year. This is also calculated to be equivalent to 150,000 cubic metres of underbark solid wood volume for Gmelina. With a mean maximum m.a.i. of 22 m3/ha/yr. on a 5-year rotation, therefore, the annual planting program will have to extend over 1,400 hectares.

Adequate data must be collected from permanent sample plots to produce a more realistic yield table in the future. Until then, the yield table may be used for the study area, as well as for Gmelina growing on similar sites with similar climatic conditions. The yield table or its functions may also be used in analysing future inventories, as for example in producing projections for production from the whole forest area, or for producing yield class maps.

The yield tables will be revised as better volume functions become available.

## LITERATURE CITED


1. Afanyedey E.K./ D.E. Earl, 1977. A short review of the Subri Project.

2. Alder D, 1980. Forest Volume Estimation and Yield Prediction. Volume 2 - Yield Prediction. FAO Forestry Paper 22/2, Food and Agriculture Organisation of the United Nations, Rome.

3. Banyard S.G., 1980. Fundamentals of Forest Mensuration. International Institute for Aerial Survey and Earth Sciences (ITC) Enschede, The Netherlands. Lecture Notes.

4. Cailliez F., 1980.Forest volume Estimation and Yield Prediction. Volume 1 - Volume Estimation. FAO Forestry Paper 22/1, Food and Agriculture Organisation of the United Nations, Rome.

5. Earl D.E., 1981. The Development of Forest Energy Resources in Ghana - Progress to date and proposal for the future. UNDP/FAO/GHANA/74/013. Revised Draft.

6. Masson J.L., 1981. Subri Conversion Technique. UNDP/FAO/GHANA/74/013. Project Working Document No.7.