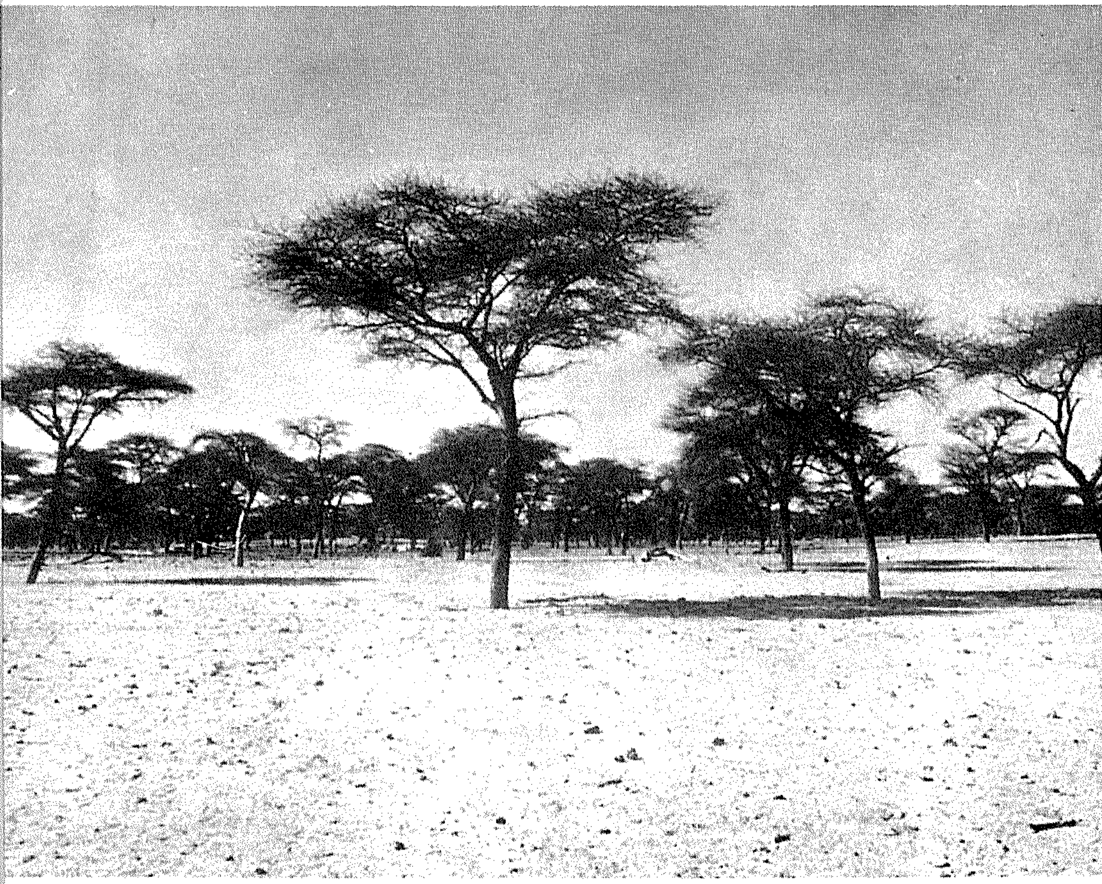
Studies on the volume and yield of tropical forest stands

1. Dry forest formations

FAO FORESTRY PAPER

51/1



FOOD
AND
AGRICULTURE
ORGANIZATION
OF THE
UNITED NATIONS

Cover photo: Natural stand of *Acacia raddiana* at M'bidi, Senegal. Photo by C. Palmberg.

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Rome, 1989

M-35
ISBN 92-5-102184-8

PREFACE

This Forestry Paper is published within the framework of FAO's programme of work on the estimation of volume and yield of tropical forest formations. It forms part of a set of three publications dealing respectively with the growth and yield of dense moist forests, of dry forest formations and of plantations.

The preparation of this document on the estimation of volume and yield for dry forest formations has been coordinated by Mr. K.D. Singh, Senior Officer in the Forestry Department of FAO, and was initiated in 1981. Four experts were then recruited in order to review the literature dealing with this subject in different parts of the world: Mssrs. J.O. Abayomi of the Forest Research Institute, Ibadan (Nigeria) for anglophone Africa, J. Clement of the Centre Technique Forestier Tropical (France) for francophone Africa, S. P. Singh of the Forest Research Institute, Dehra Dun (India) for tropical Asia and G. Lund of the United States Forest Service for Latin America. On the basis of these four studies, Mr. F. Guinaudeau, Professor of mensuration and inventory at the Ecole Nationale des Ingénieurs des Travaux des Eaux et Forêts (France), prepared this report, also incorporating his own experience. FAO thanks these five specialists for the quality of their contributions.

The translation of this paper , originally prepared in French, into English;and the additional section included on the application of remote sensing , were prepared by Mr. R. Baltaxe, formerly of FAO's Forestry Department and Remote Sensing Centre.

We hope that this Forestry Paper will be useful for forest officers and forest technicians working in areas of dry forests, whether on research or as practising foresters wishing to base the management of forests on solid foundations.

A list of currently available information is also included. When using the book, special attention should be paid to the limitations of all models like the ones presented in it, and the degree of accuracy to be expected.

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1 - PURPOSE OF THE STUDY

11 - Vegetation formations considered

In FAO's global study 'Tropical Forest Resources' the question of classifying vegetation formations is approached in a very clear manner. The choice made in the context of this global study was to favour the Unesco classification, albeit with the application of a different set of symbols.

In the system which was adopted the formations coverd by the present study are referred to in the following two ways:

- NHc/NHO "Mixed broadleaved forest-grassland formations with a continuous dense grass layer in which the tree synusia cover more than 10% of the ground surface".

This mainly includes the savanna woodlands and woodlands of the Yangambi classification. A special case is that of the dry forests of the Indian sub-continent which are difficult to place in the Yangambi classification which was designed for Africa. However, due to the presence of a dense and continuous grass layer these forests can be included in the category NHc/NHO.

- n "Formations of which the main woody element consists of shrubs and bushes ((thickets, shrub savannas)".

12 - Common features of these formations

These formations occur in the dry tropical regions (rainfall less than 1500 mm).

- Their timber production potential per hectare is low compared to other forest types.
- Their standing volume and increment is not well known, little effort having been applied to the study of these until now.
- They constitute a vital source of small timber and especially of fuelwood for the inhabitants of these regions.
- The conformation of the trees and shrubs requires an adaptation of classical dendrometric procedures, both as regards sampling and taking actual measurements.

13 - Objectives of the report

The first objective, in amplification of the basic texts and particularly FAO Forestry Studies nos. 22 and 27 (1), is to describe the difficulties encountered in the application of classical mensuration methods and how they can be modified to mitigate these difficulties. The mensuration problems dealt with are:

- sampling and stratification
- plot measurements and tree measurements
- the elaboration of growth and yield models

Photointerpretation methods are not dealt with in the present report but the application of remote sensing is covered in some detail.

The second objective is to provide a summary presentation of the results obtained from a range of studies in an attempt to show the agreement which exists between these results. Although the paucity of precise and reliable information in this field towards achieving this must be made.

14 - Readership aimed at

This report is aimed at technical and professional foresters working in countries with a low rainfall:

- whether concerned with management and wishing to base such management on the experimental data obtained by research and development institutions

- whether concerned directly with research and development

The former will find the data which is presently available and can take note of the degree of precision and limits of application of the models presented. Every manager must be closely aware of the methods used to construct the models he employs, to avoid committing serious errors.

Researchers will find a range of solutions proposed and already tested by other foresters throughout the world.

(1) - Forestry Study 22: Growth and yield estimations of forest stands; vol.1, Cailliez (1980), vol.2, Alder (1979).

- Forestry Study 27: Manual of Forest Inventory (1973).

2 - INVENTORY METHODS SUITABLE FOR THE FORMATIONS UNDER CONSIDERATION

21 - Problem formulation and definition of objectives

In the FAO Manual of Forest Inventory a general outline for the planning of a forest inventory is given. This outline can be used for inventories in those regions where fuelwood is the main product. In this case there are three points to be emphasized:

211 - What are the real needs for an inventory?

A forest inventory is a costly and time-consuming undertaking which must be justified. In the case of dense tropical forest the commercial value of the inventoried resource suffices to justify the operation. In a forest whose main product is fuelwood or poles an inventory is fully justified whenever there is the risk of an imbalance between the needs of the population and the resources available. It is absolutely essential to avoid a shortfall, since this will lead to such pressure as to bring about a deterioration of the forest environment.

To evaluate the real need for an inventory in an area it is therefore necessary to evaluate the risk of a shortfall in supply, making use of local demographic studies as well as investigating indices of overexploitation.

212 - Consumer participation in determining objectives

Such participation will consist of surveys among the consumers, who will be able to provide information on:

- customary felling intervals in space and time

- the criteria (dimensions, species, etc.) by which the different categories are distinguished (timber, poles, fuelwood)

- the methods of measurement, officially prescribed and used in practice, for stacking

The criteria applied to distinguish poles and fuelwood can also be furnished by the consumers.

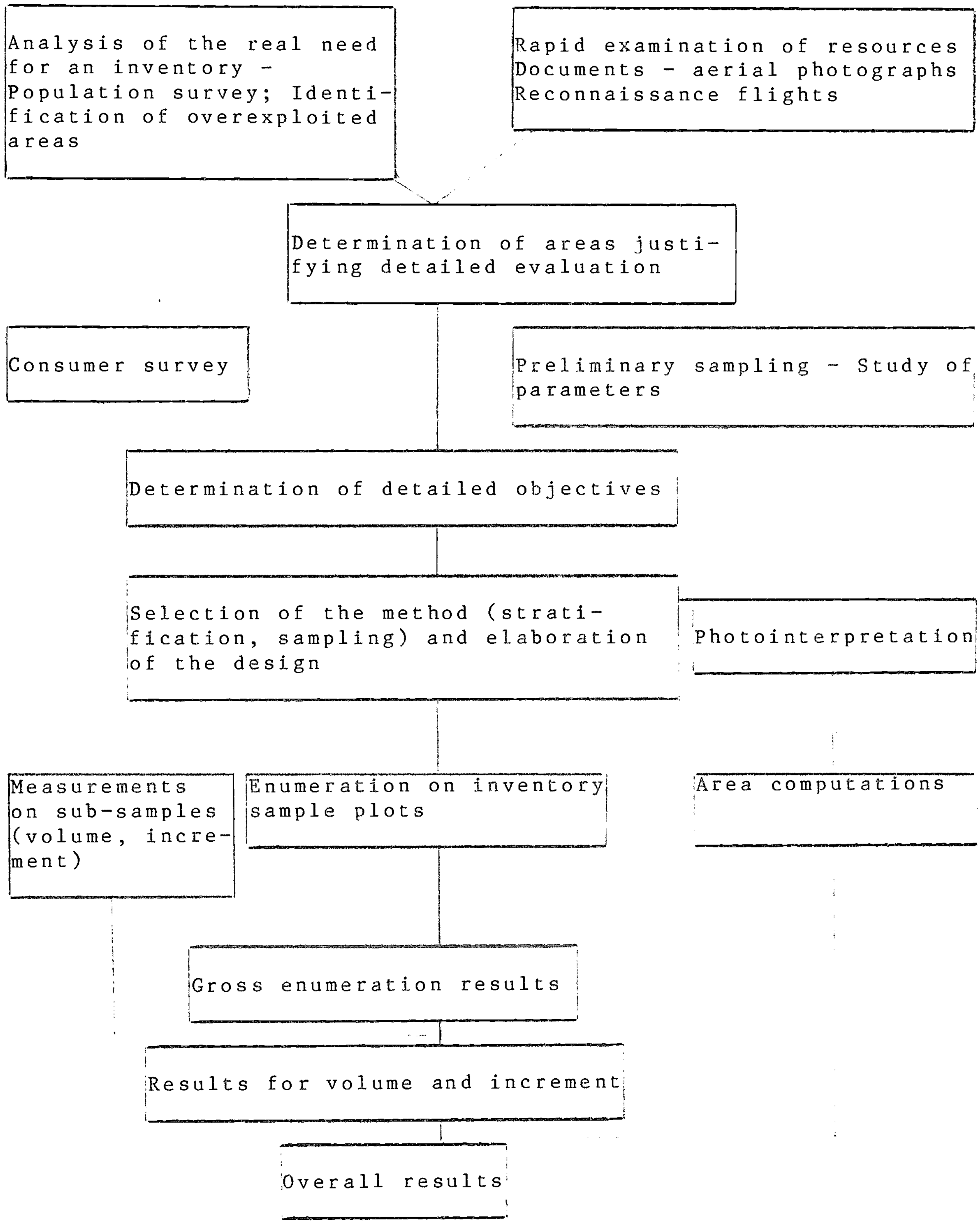
213 - Type of information to be obtained

The main purpose of any forest inventory is to provide the standing volume at a given time, if necessary according to species and size classes. However, as a basis for the management of the forest this one-time information must be supplemented by a knowledge of the forest's development.

Thus, in a forest devoted to the production of timber a knowledge of the diameter to be fixed and therefore the harvesting intensity and interval to be determined.

In a forest producing mainly fuelwood harvesting is usually done by clear felling and a knowledge of the mean annual yield by volume (or by weight) will enable the felling interval to be determined.

214 - <u>Diagrammatic presentation of inventory planning</u>



22 - Classification of the vegetation

221 - Physiognomic description of the main types

It has already been stated that the formations concerned, designated NHc/NHO and n, are formations with woody plants.

The distinction between the two types is essentially based on the height of the tallest woody plants. According to the Unesco classification a height of 5m is used to distinguish between trees and shrubs. The formation with the symbol n consists mainly of shrubs, with less than 10% of the ground being covered by trees.

Within the group NHc/NHO one can distinguish:

- productive formations NHc/NHO 1 (woodland in the Unesco classification) where the tree cover exceeds 40%.

- unproductive formations NHc/NHO 2 where the tree cover is less than 40% (grassland with tree synusia in the Unesco classification).

The Yangambi classification has the advantage of having long been used (1956) by foresters on the African continent. They have become familiar with the terminology and from the outset each term has been accompanied by a schematic profile diagram. However, it lacks precise quantitative thresholds (Figure 1).

It must be remembered that in this classification the distinction between savanna and steppe is based on the incidence or absence of burning and that there is a gradual transition from woodland to woodland savanna, to tree savanna, shrub savanna and finally grassland.

Shrub savanna (or steppe) belongs unambiguously to formation n.

Woodland belongs unambiguously to NHc/NHO 1 (open productive forest).

Tree savanna (or steppe) and woodland savanna should belong to NHc/NHO 2, but this is somewhat doubtful.

S.P. Singh (1980) proposes the following correspondence between this classification and that used in India:

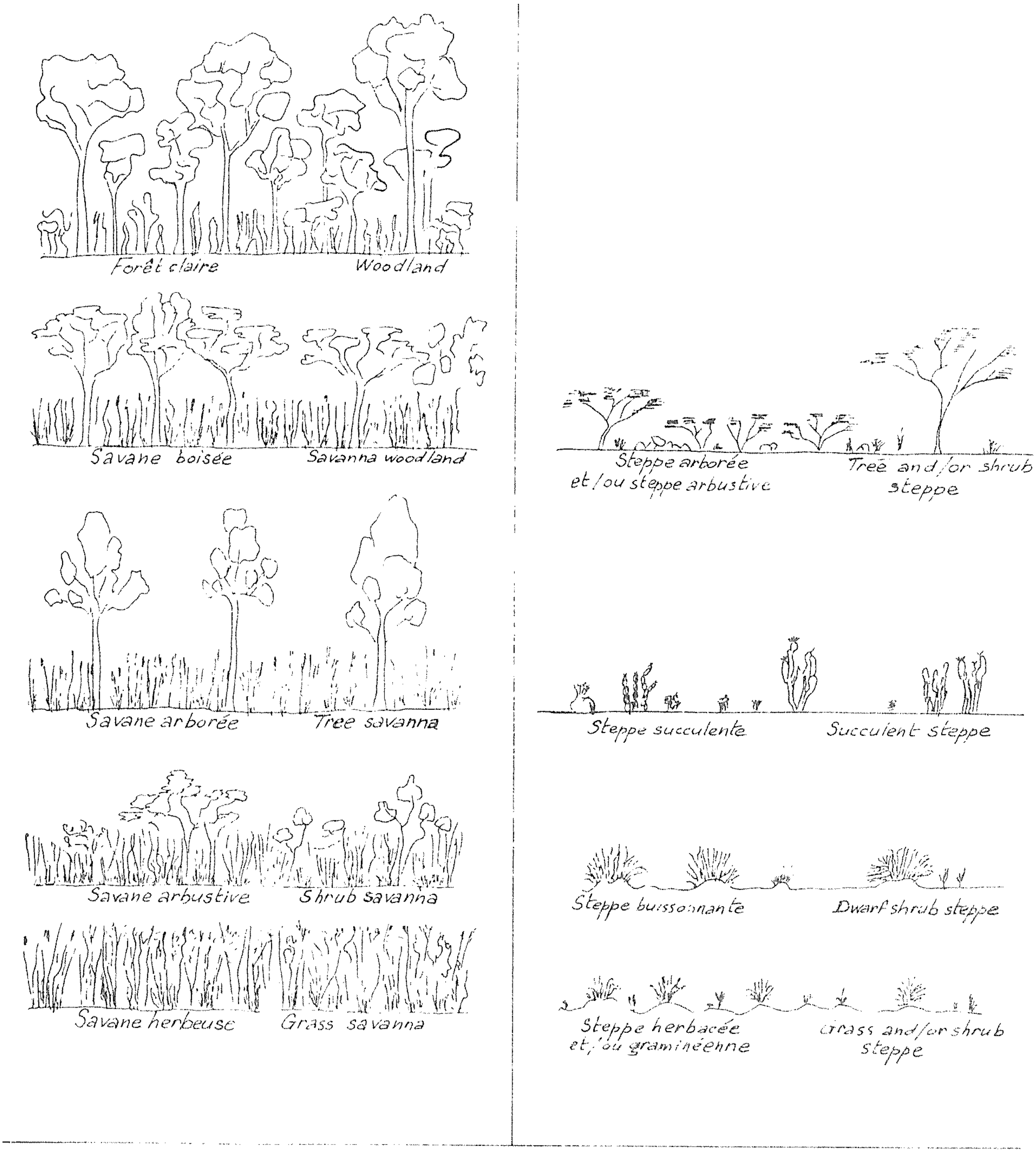
- Savanna woodland: degradation stages of dry deciduous forest

- Tree savanna: thorn forest where Acacia predominate

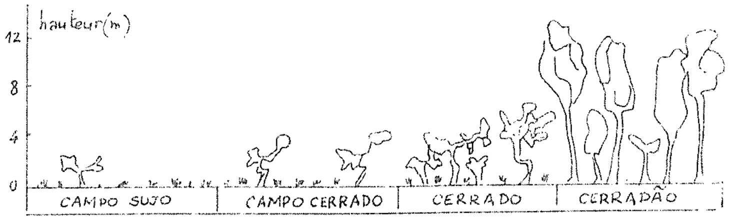
- Shrub savanna: thorn forest degraded due to biotic factors

Figure 1

Diagrams of the YANGAMBI classification



Diagrams of the different types of 'cerrado'
(after CARNEIRO)



222 - Quantitative criteria associated with these types

The various classifications have inevitably remained imprecise regarding quantitative characteristics. The only precise limits applied are:

- 5m height limit between tree and shrub
- tree cover less than 10% (non-forest); between 10 and 40% (unproductive open forest); more than 40% (productive open forest).

The inventory of a stand enables numerous characteristics to be ascertained: distribution of heights, of diameters, volume per hectare, etc. But so far too few data have been gathered to enable them to be used to define the different types. Carneiro (1982) has made an interesting attempt to define the 'cerrado' formations in Brazil. Each type named is associated with a schematic profile diagram and quantitative data. It is by increasing this type of study that the definition of vegetation types can best be achieved. At present one is confined to the application of physiognomic criteria, as is the case with the general classifications which have been adopted.

23 - Definition of the features studied

The principal aim of a forest inventory is the determination of volume. However, in the case of fuelwood this can be replaced by the determination of weight.

In the first place the raw material concerned may be defined.

231 - Biomass

Biomass corresponds to the total vegetal matter, including twigs, branches and roots. This concept is of particular interest in the context of those scientific studies aiming to compare formations of different climates or vegetation. In practice it can be applied in those regions where mechanised harvesting allows the total vegetal matter to be converted to energy.

In the case of the formations considered in the present study this approach remains theoretical and it would be better to adopt a breakdown of the raw material into categories based on its local use, as determined by a special survey forming part of the inventory operation.

232 - Criteria to distinguish categories of wood

In the case of dry forest formations utilisation criteria are used to distinguish:

1 - Wood destined for industrial uses - this concerns mainly timber to be used for wawing or peeling, pulpwood being mentioned only in passing.

2 - Wood destined for non-industrial uses, in two categories:

- poles for house building, agricultural or structural uses
- fuelwood destined directly, or indirectly, for the production of energy (as charcoal, or in a power station).

It must be underlined that in most forests several categories will normally be found and that this must therefore be foreseen in planning the inventory so that a breakdown can be made.

In India a simple distinction is made according to size, between sawtimber (overbark diameter more than 20 cm) and small wood (diameter between 5 and 20 cm).

As underlined by Singh (1980) this distinction is being applied less and less since industries increasingly tend to use wood of less than 20 cm diameter.

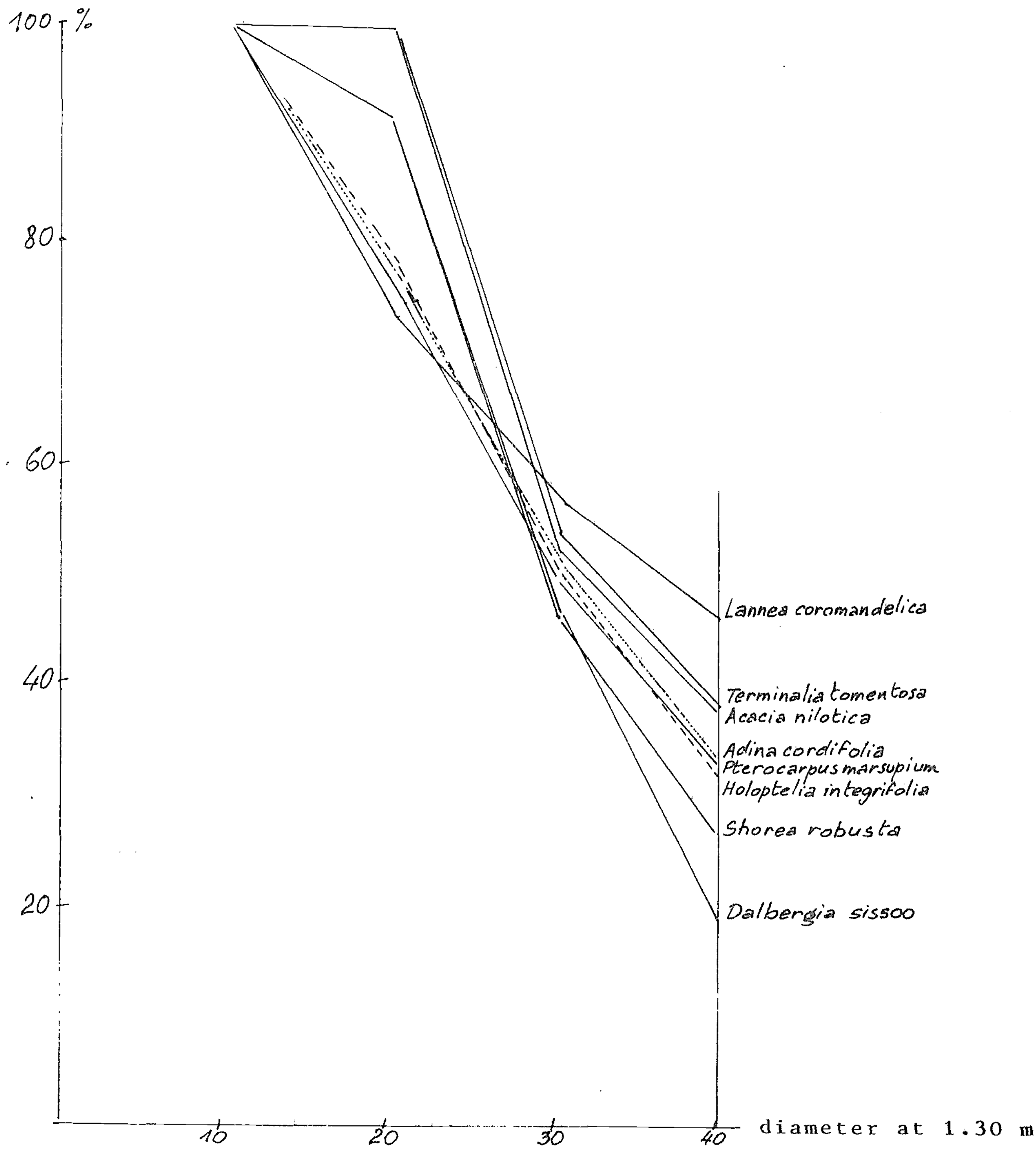
In an inventory over 3,660 ha in Cameroon (case study no.4) the species were divided into three categories according to their suitability for fuelwood. Such a distinction is equally important for fuelwood as it is among species used for sawtimber.

233 - Volume determination

2331 - Measurement units

The measurement units in use are not entirely uniform, but are tending to become so. A conversion table for the commonest units is given below.

Graph no.1



Volume of wood of less than 20 cm diameter as percentage of total volume (from Singh, 1980)

Table no.1

LENGTH

1 inch
1 m
1 foot
1 m

VOLUME

1 cu.ft = 0.0283 m^3

STACKED VOLUME

1 cord = 3.62 steres (4 feet x 4 feet ...

AREA

1 acre = 0.405 ha (66 feet x 660 feet)

WEIGHT

1 pound = 0.450 kg
1 kg = 2.222 pounds

BASAL AREA

1 sq ft/acre =
1 sq inch =
1 m^2/ha = 4.36 sq ft/acre

Table no.2

Conversion table of weight to volume (stere or m^3)

SOURCE	CONDITIONS	RESULTS
Singh (1980)		1 tonne = 2.12 steres
	Casuarina (green) stem	1 " = 1.38 "
	" branches	1 " = 2.31 "
	" roots	1 " = 2.10 "
	Eucalyptus tereticornis	1 " = 1.44 "
	Anogeissus pendula (green)	1 " = 1.07 m^3
	Felled, weighed, measured on 4 ha (34 m^3/ha)	
Morel (1981)	Green state	1 tonne = 1 m^3
in Clément	4 months later	1 " = 1.25 m^3

2332 - Design of volume measurements

Existing methods are essentially designed for solid volume and are well suited for saw timber. The direct application of these methods for the measurement of fuelwood volumes would require making a very large number of measurements on short billets. This has not proved satisfactory and consequently two types of measurement have been used:

1 - Measurement of stacked volume of billets of uniform length; determination of the stacking coefficient for calculation of the solid volume.

2 - Determination of green weight, i.e. at the time of felling, and taking samples on which to ascertain water content and dry weight.

The relationship between solid volume and dry weight requires a knowledge of the weight per unit volume for each species. Each species would therefore have to be treated separately. The two methods consequently do not yield the same results and a choice must be made between them.

In an inventory operation aimed at evaluating the amount of wood available experience shows that the first type of measurement is the most suitable. The work of stacking, after felling a sample area, requires neither special skills nor facilities. This technique had already been applied in the earliest investigations referred to (case studies no. 1 and no. 7 for example). However, one should not avoid ascertaining the stacking coefficients, which requires a higher level of technical competence. The extreme variability of the stacking coefficients actually found in the context of different inventories shows that their determination is essential.

For work of an experimental nature the scale of the operation will permit weighing to be undertaken. Stacking wood and determining the stacking coefficient are therefore optional operations but nevertheless extremely useful.

2333 - Measurement of calorific value

As for the weight per unit volume, so there are tables giving the calorific value of different species. As the calorific value varies according to the species, this enables the user to be provided with a more useful value than solid volume or dry weight. In fact, this is the only value of interest for the user.

This information can in any case be given in another manner as done in the context of an inventory over 3,600 ha in Cameroon. At the time of stacking the wood can be separated into three categories according to its quality as fuelwood: very good, medium, poor. This distinction can reasonably be made at the inventory site if the local inhabitants are involved in this. The inventory results are then provided by category and thus correspond well to the real needs of the population.

2334 - Volume tables and use of regressions

The use of volume tables calculated by simple or multiple regression methods has been well developed for forests producing timber. The model is established at the level of a tree and the resultant tables provide the individual tree volume. From this the stand volume is obtaine by summing the tree volumes.

For the formations being considered here the case is quite different, as it becomes evident that it will be much more convenient to use stand tables. The characteristics of the stand (in practice, of the sample plot) which are measured will serve to determine its volume without necessarily involving measurements of individual trees on the plot.

To establish a tree volume table the volume v and another variable, for example the basal area g, are measured on sample trees; a regression is then established for all the pairs of measurements (v, g) having the form $v = a + bg$.

To establish a stand table the total volume V (which is what is of interest) on the sample plots is measured, as well as other stand variables, for example: the number of trees more than 5 meters high; the height of the tallest trees; the number of trees less than 5 meters high... The multiple regression which can be calculated has the form $V = f(X_1\ X_2\ X_3)$ where $X_1\ X_2\ X_3$ are the stand variables.

Choice of stand variables. These variables must be:

- readily defined and measured
- well correlated with volume V so that the best possible model is obtained.

The experiment made in the inventories in Cameroon and in the Central African Republic has shown which variables can usefully be measured:

X_1 number of trees of all species: height between 1 and 2 m
X_2 number of trees of all species: height between 2 and 3 m
X_3 number of trees of all species: height between 3 and 4 m
X_4 number of trees of all species: height between 4 and 5 m
X_5 number of trees of all species: height greater than 5 m

The form of the regression $V = a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 + a_5X_5$ permits the coefficients a_1 to be interpreted as the mean volume of a tree of the corresponding height class, though this is not strictly necessary.

Another characteristic of interest is the mean diameter of the trees over 5 m high, or else their basal area.

In this regard it has to be recognised that much remains to be done, since up to now the tendency has been to rely on the application of tree volume tables.

2335 - Types of volume tables

2335.1 - Single entry tree volume tables

In order to verify a single entry volume table it is useful to draw the corresponding curve and to superimpose this on several existing volume curves. In graph no.2 the curves of two volume tables cited in case study no.7 (Burkina Faso inventory) and two from Singh (1980) have been drawn. If the volume model is of the type $v = a + bd^2$ then d^2 can be used for the scale on the abscissa. This is not the case for these volume tables, which have the form $v = a + bd + cd^2$.

2335.2 - Stand volume tables

2335.21 - Model V = bG

The commonest model is that where the independent variable is the stand basal area and the simplest of these has the form $V = bG$. In this form the stand table is identical to the tree volume table $v = bg (v = \underline{4}\ bd^2)$.

2335.22 - Model V = a + bG

This represents a slightly more elaborate model. It should be noted that V and G are values measured on sample plots which do not necessarily have an area of 1 ha. For convenience the above model should give V converted to the value per hectare according to G converted to the value per hectare. The constant a is a function of the volume per hectare.

Example (compare case study no.3) - on 50 sample plots with an area of 0.2 ha the volume V' and the basal area G' have been measured. The model derived from the regression of these values is:

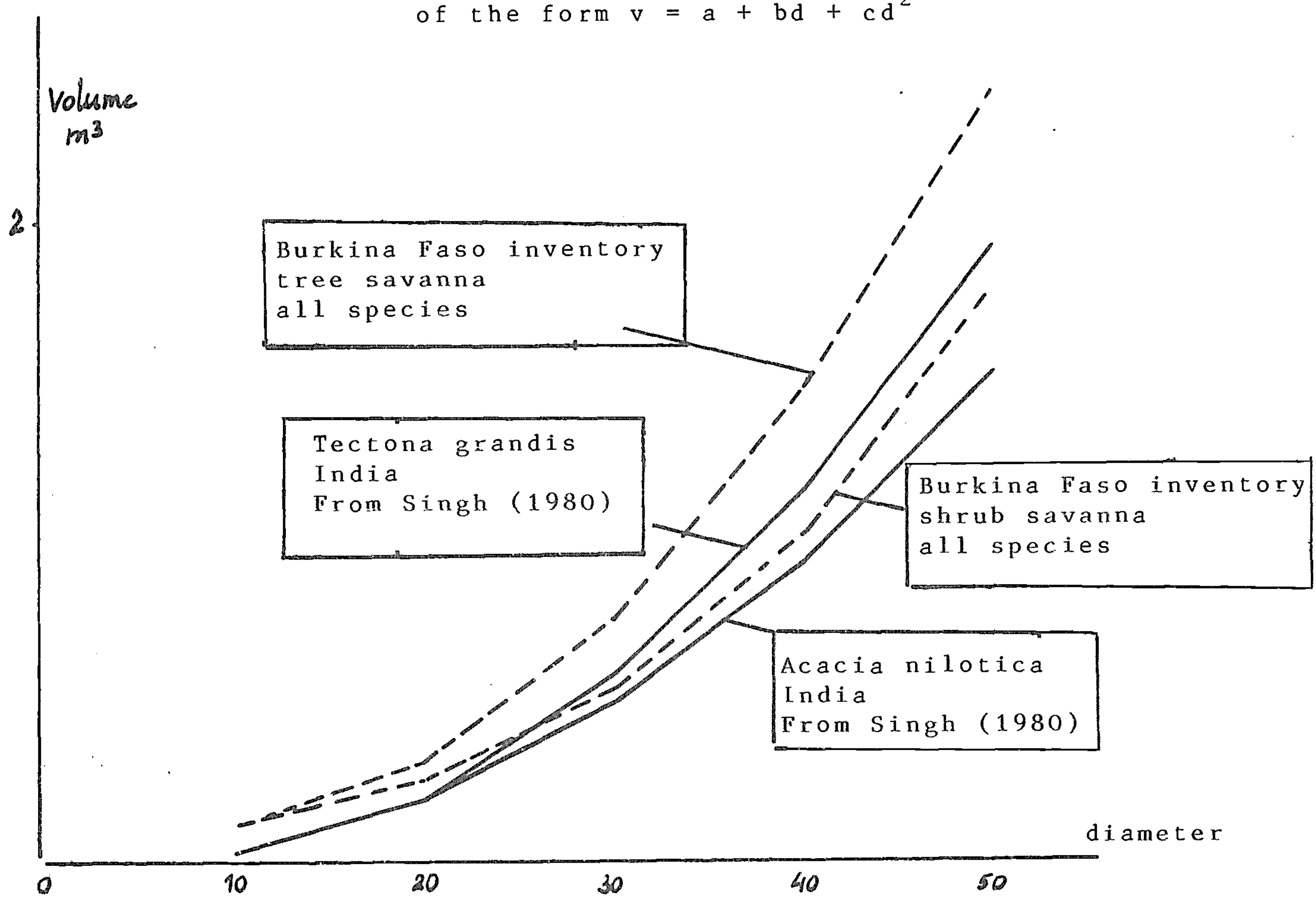
$$V' = 5.9\ G' - 1.1$$

The corresponding model converted to the value per hectare is:

$$V = 5.9\ G - 5.5 \quad V \text{ in } m^3/ha,\ G \text{ in } m^3/ha$$

Graph no.2

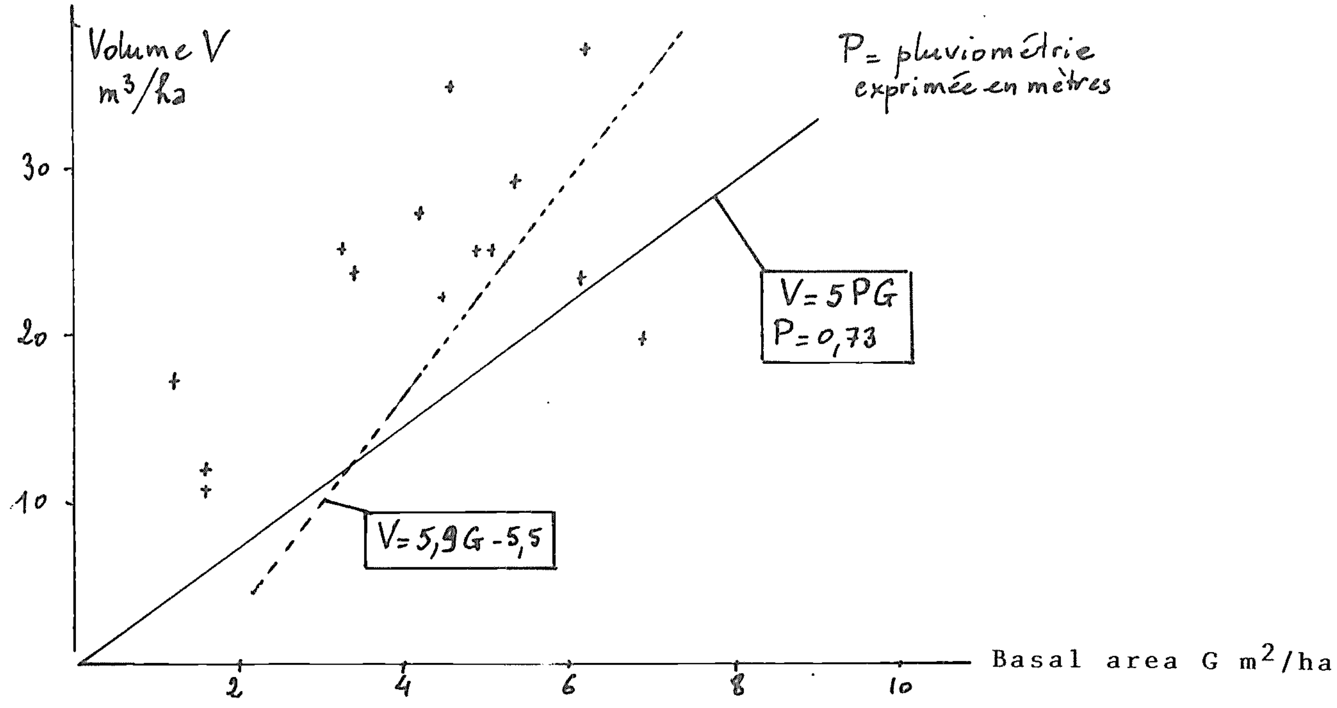
Examples of single entry tree volume tariffs of the form $v = a + bd + cd^2$



Graph no.3

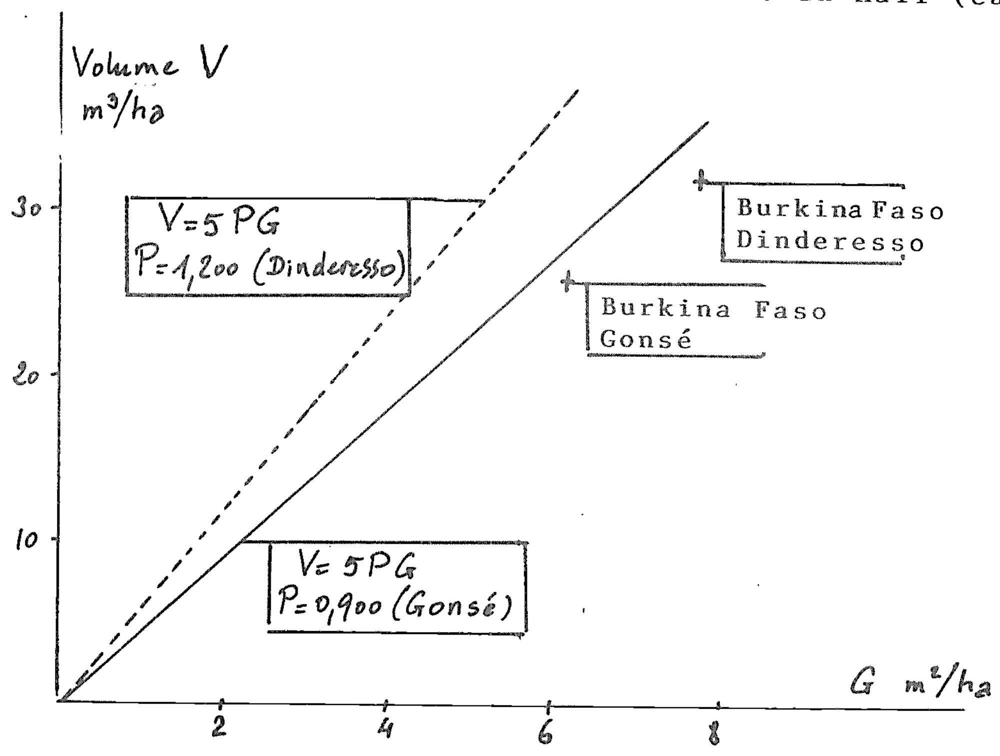
Comparison of the data from the Bakura-Tureta experiment (case study no.1) with the models established in Mali (case study no.3)

1.1 ha plots. Stacking coefficient 0.31



Graph no.4

Comparison of the data from the Burkina Faso experiments (case study no.8) with the models established in Mali (case study no.3)



2335.23 - Other models

For the work done in Mali other models were tried (see case study no.3):

- 2 models using Dg, the diameter of the mean tree:

$$V = aDg + bG + c$$
$$V = G\ (aDg + b)$$

It must be stressed that for the first of these models it should be indicated whether V and G have been converted to units per hectare.

- a model including rainfall:

$$V = 5\ P\ G$$

where P is rainfall in meters.

Originally the formula was V = 10 P G, V being expressed in steres. The measured stacking coefficient was 0.5.

2335.3 - Verification of a stand table

As for a tree volume table, the measured values should be plotted for judging the validity of a stand table. This is the purpose of graph no.3 which shows the values from the experiment at Bakura-Tureta in Nigeria (case study no.1) and the models established in Mali (case study no.3) namely:

$$V = 5.9\ G - 5.5$$
$$V = 5\ P\ G \text{ which becomes } V = 3.65 \text{ since } P = 0.73\ m$$

An examination of the graphs shows that the model established in Mali is not applicable in Nigeria, nor is it exactly the same as that obtained in Burkina Faso. This emphasizes the necessity for constructing models adapted to each individual situation.

Table no.3

	Volume Table Models	
Source	Conditions	Models (1)
Morel, in Clément	Felling and stacking on a 10 ha block, divided into 50 plots of 0.20 ha each. Stand table	$V = 5.9\ G - 5.5$ $V = 262\ D + 4.59\ G - 21.6$ $V = (38\ D + 1.44)\ G$
	Felling and stacking on a 4 ha block divided into 40 plots. Stand table	$V = 5\ G$ (equivalent tree table $v = 6.36\ d^2$)
Singh (1980)	Tree volume tables giving total volume (branches - stems) of fellings over 5 cm ciameter. Acacia nilotica Tectona grandis	 $v = (2.699\ d - 0.104)^2$ $v = (3.168\ d - 0.182)^2$

(1) Explanation of symbols
Stand volume tables

V = volume converted to per hectare basis expressed as m^3/ha

G = basal area converted to per hectare basis expressed as m^2/ha

D = diameter of the stand mean tree expressed in m
Tree volume tables

v = tree volume (m^3). d = diameter at 1.3 m (m). h = total height (h)

2336 - Accuracy of volume table estimates

For an inventory based on sample measurements the error due to the application of a volume table can be considered similar to that due to the use of a measuring instrument. If the instrument is free of bias, and if the volume table gives an estimate without bias, then the error due to these is included in the sampling error. Under such conditions they can be ignored.

For the estimation of volume on a single plot (e.g. an experimental plot, or the 100% inventory of a forest) weighted volume tables must be used to obtain a correct error estimate. A simplified, albeit more approximate, method consists of using the residual standard deviation of the regression as the standard deviation of the regression.

24 - Inventory design - Sampling

Important points:

- relatively good accessibility and visibility
- low standing volume per unit area
- high degree of variability

241 - Use of remote sensing

2411 - General

Aerial photography and satellite images are by now used routinely at various stages of the survey, mapping and inventory of most types of forest because experience has shown that:

- the overview of the forests, of their location, extent and variability which is obtained, permits a useful appreciation of the various aspects of an inventory operation
- information on the exact location and extent of all formations can be obtained more efficiently than from ground surveys alone
- information about the nature of the different forest formations can be obtained more efficiently by a combination of remote sensing and ground survey than from the latter alone
- the degree of prior stratification of the forest cover which this permits and the possibility of sampling on remote sensing images facilitate optimisation of the sampling design when remote sensing images are used for their planning and to guide their execution.

Satellite data

Three main types of satellite data applicable to forest surveys are now available:

- Landsat multispectral scanner (MSS) data, with a nominal ground resolution of about 80 m
- Landsat Thematic Mapper (TM) data, with a nominal ground resolution of 30 m
- data from the French SPOT satellite, with a nominal ground resolution of 20 m and 10 m.

The SPOT satellite started producing data early in 1986, but at the time of writing (April 1986) its processing was not yet fully operational. TM data is so far not yet available over all tropical regions and its application is still rather more experimental than operational. Consideration will therefore be confined to Landsat MSS data which has been in use since 1972 and is routinely available on a world wide basis.

Consideration will further be confined to the use of photographic images, since the computer aided classification of digital landsat data is generally too unreliable and costly for routine application to inventory operations, nor will the required facilities always be available.

Some characteristic features of Landsat MSS images relevant to their use for forest survey and for comparison with aerial photographs may be listed as:

- relatively low cost per unit area
- relatively ready availability of new cover
- potentially available for a range of seasons
- area covered by one scene is 34,225 sq km
- standard scene formats at 1:1 million, 1:500,000 and 1:250,000
- virtual absence of image displacement due to differences in ground elevation
- low resolution, individual crowns not visible
- photographically processed digital data; many ground objects not directly recognisable.

Aerial photographs

Aerial photography can be obtained at a wide range of scales of the order of 1:5,000 to 1:120,000 and on various films, including black and white (panchromatic), false colour (colour infrared) and natural colour. For forest inventory purposes in tropical dry forests of relatively low commercial value, black and white photography at 1:20,00 to 1:40,000 scale would commonly be used. Recognition of species and certain other features may be better on colour infrared photography, but this is also considerably more costly and, due to its greater sensitivity to high temperatures and haze, can also be more difficult to acquire in the tropics.

Some characteristic features of medium scale aerial photography relevant to its use for forest inventory and for comparison with Landsat MSS images are:

- relatively costly per unit area
- new cover may not be readily obtainable
- limited to a single season
- effective area of single photograph at 1:40,000 covers ca. 50 sq km, requiring ca 680 photographs to cover a single Landsat scene
- acquisition scale can be specified according to requirements
- image displacement proportional to differences in ground elevation
- high resolution; individual crowns may be visible
- photographic image recording size, shape, tone and texture of ground objects, facilitating recognition.

The application of Landsat MSS images (supported by limited aerial photointerpretation and ground checking) is therefore most appropriate for reconnaissance inventories of an entire country or other large area, concerned with the overall distribution and availability of wood resources and for the production of maps at 1:200,000 or smaller scales.

Detailed management inventories of smaller areas (possibly selected by a Landsat-based survey) producing sample estimates of known precision and/or maps at 1:50,000 or larger scales will require the use of aerial photography.

2412 - Application of Landsat MSS images

Detailed descriptions of the characteristics, production and interpretation of Landsat images can be found in various texts, e.g. Colwell (1983), Lillesand and Kieffer (1979), Sabins (1979). The treatment of these topics with special reference to tropical forest surveys can be found in Baltaxe (1980, 1985).

Only the application of such images will be considered here, except to point out that under most circumstances considerably more information on forest types can be obtained if false colour composite as well as black and white (single spectral band) images are interpreted. For most applications the information content can be significantly improved by enhancing the digital data prior to the production of Landsat images. When there is no access to the facilities required for this, such enhancements can be carried out by specialist companies and institutes on a commercial basis.

2412.1 - Detection of forest formations

There is considerable experience which demonstrates that formations consisting of trees, or having a tree and/or shrub component, can normally be differentiated from other land cover types on multispectral images. However, exerience has also shown that if the data has been recorded when the grass layer of mixed formations is fully green, or blackened due to burning, then the presence of a relatively open cover of trees and shrubs can generally not be detected. Selection of data of the appropriate season therefore plays an important role in the use of Landsat images.

2412.2 - Identification and stratification of forest formations

Since objects on multispectral images are displayed as a function of their numerically scaled spectral response, transformed to levels of grey on black and white images, or to a range of colours on colour composite images, their identification is a separate process from their detection. Especially on colour images the density of forest formations and to some extent their relative height is readily apparent. But more detailed identification must be based on matching the specific appearance on an image with the feature on the ground giving rise to this.

Consequently the first step for the identification and classification of forest types is the praparation of an interpretation key. This can be based on the interpretation of aerial photographs of selected areas, reconnaissance flights, ground survey, or any combination of these. Such direct observation of small type-areas can often be extrapolated to identify extensive areas of forest on Landsat images and is one of the main advantages of their use.

Identification of forest types over a large survey area covered by several scenes can be aided by a preliminary stratification according to the incidence of bioclimatic factors such as altitude and rainfall. These will influence characteristics such as heiglht and species composition, and therefore standing volume, which may therefore be significantly different among formations at different locations but with the same appearance on the images.

A classification will be required for the forest types which it is possible and of interest to distinguish. The primary classes, within a given bioclimatic zone, are best based on characteristics which are most readily and consistently interpretable, for ease and consistency of classification. These will be physiognomic characteristics such as life form (trees or shrubs), density (forest, woodland, mixed tree and/or shrub aions) and phenology (evergreen, deciduous).

Formations along streams, on periodically inundated areas, on rocky sites, etc. can generally be distinguished. The employment of such edaphic sub-classes therefore provides a useful amplification of the identifiable forest types.

The presence of particular species is normally not observable in dry forest formations, but may at times be readily inferred from their phenology (comparison of wet and dry season images), or association with recognisable site types.

The denser tree formations - dry forests, woodland, savanna woodland - are most readily distinguished, by virtue of their relative density, than the more open formations - tree/or shrub savanna. With the former there is less spectral interference from the ground layer, but also stronger contrast at the boundaries so that these can be mapped with reasonable accuracy. The more open formations may not be readily distinguishable from each other and their boundaries not easily determined when there is a gradual transition between density classes.

This general outline may be illustrated by two examples of classifications used for dry forest surveys with Landsat images.

For a survey of vegetation types, their location and area, over the whole of Burkina Faso, Cameratti (1982) used false colour composi images at a scale of 1:200,000 (to conform to the available base maps). Dry season images were interpreted to avoid confusion between the appearance of the green foliage of woody vegetation and the background of green grass, which was apparent on rainy season images. The classes mapped were:

- Shrub savanna

- Tree savanna. Crown cover ca 20 - 25 %; height not exceeding 12 m. Some denser clumps of taller trees also identified.

- Gallery forest. Canopy denser than tree savanna; height 10 - 25 m.

- Dense thickets of thorny shrubs (separable from shrub savanna on rainy season images).

- Plantations.

For a fuelwood survey in the Blue Nile Province of Sudan Poulin, Theriault (1984) used an enhanced Landsat image (colour composite of first three principal components). On this it was possible to interpret:

- Woodland and woodland savanna. Crown cover of trees and shrubs more than 30 %

- Tree savanna. Crown cover of trees and shrubs less than 30%.

- Shrub savanna

- Grass savanna.

While the number of classes which can be identified on Landsat MSS images will vary according to circumstances, there is ample evidence that such images permit a useful stratification of extensive forest areas at a relatively low cost and in a relatively short time. Satellite remote sensing can therefore be an efficient method of obtaining a first level of information on which to base more intensive inventory operations.

2412.3 - Mapping

Landsat images recorded at ca 700 km above the earth's surface exhibit no significant displacement of objects due to difference in terrain elevation. The interpretation film of an image can therefore be laid over a map of the same scale for the direct transfer of forest type boundaries. Usually the match will not be perfect because:

- the scale of a Landsat image is usually slightly different from its nominal scale

- a certain amount of displacement and distortion is introduced by the satellite and sensor systems.

The latter can be removed by correction of the digital data if an accurate planimetric map is available as reference. Images conforming to 1:250,000 planimetric map accuracy standards can be produced in this way. However, the cost of this procedure is rarely justified in relation to the accuracy with which boundaries of open forest types can be located.

The discrepancies between map and image can usually be overcome by dividing the map into a number of sub-areas within which a good match with the image is obtainable. The displacement is thus locally minimised and distributed over a whole sheet.

When the available base map is not at the same scale as the interpreted image, one of the many possible optical or photographic methods for changing the scale of one or other of the documents must be resorted to.

2412.4. Area determination

When forest type boundaries have been transferred to a map the areas the areas can be measured by any of the usual methods. Among these the use of a dot grid is preferable, both for its ease of application and because it constitutes a sampling procedure whose error can be approximately estimated (FAO Manual 1973, p.83)

Area determination in the present context will mainly be subject to interpretation errors, i.e. due to the location of class boundaries, particularly for the more open formations. Such errors can to some extent be self-compensating, in terms of area, as when separating savanna woodland and tree savanna on the basis of percentage crown cover.

Interpretation errors can be quantitatively assessed by checking on an appropriately designed sample of aerial hotographs and/or ground locations. For the extensive survey areas being considered this will often not be practicable, nor justified in terms of the time and cost involved. However, a systematic check of the interpretation of doubtful areas can be undertaken, with subsequent control and adjustment, if the application of the results justifies this.

Point estimates of areas

When only area estimates are required (and no map), these can be obtained by point sampling the presence of the different forest type strata. In this case:

- decisions about the placement of class boundaries are eliminated

- interpretation is confined to small, relatively homogeneous areas (circles of a few millimeters diameter around the sample point on the image)

- the sampling error of the area estimate for each class can be calculated

After an interpretation key and classification have been established the relative extent and variability of each class can be estimated. These can then be applied to calculate class sampling intensities.

The area of a class as a percentage of the total area will be:

$$\frac{\text{Number of points in the class}}{\text{Total number of sample points}} \times 100.$$

The absolute area of a class will be given by:

$$\frac{\text{Number of points in the class}}{\text{Total number of sample points}} \times \text{Total area being surveyed (ha or sq km)}$$

2412.5 - Application to sampling

The main advantage of invorporating Landsat images in a sampling design is that this permits the results obtained from sampling relatively small areas on aerial photographs and on the ground to be extrapolated to very large areas.

The reliability of such extrapolation will depend on the accuracy of the stratification carried out on the Landsat images and the homogeneity of the resultant strata.

Because sample units located on Landsat images can rarely be accurately identified on the ground their application is usually confined to multistage sampling designs incorporating the use of aerial photographs.

The initial stage of such a sampling procedure will consist of the random selection of areas on Landsat images to serve as primary sampling units. This can be done by selecting squares from a transpararent grid laid over the images.

The secondary sample units can consist of the effective area of aerial photographs selected within each primary unit (e.g. from a plot of photo centre points). A third sampling stage will be obtained by selecting a number of plots within each effective area and a further stage by selecting some of these plots to be measured on the ground. The results from the ground plots are then extrapolated to the total area of the successive sub-samples to obtain an estimate for the entire area sampled.

For the calculation of the sample estimate from the various sub-samples the sampe units at each stage are selected with a probability proportional to size (PPS), i.e. to the predicted magnitude of the variate being sampled. In this respect standing volume, for example, could be equated with the area of forest, or of different forest types, over different portions of the sub-population being sampled at each stage.

Thus, the selected primary sampling units can be grouped into classes according to the percentage area occupied by forest (e.g. < 30, 30-60 %). To account for the presence of different forest types a weighting factor, based on the relative magnitude in each forest type of the variate being sampled, could be applied to the area of each type in a primary unit.

Details of the application of such a sampling design, which can be highly efficient, and of the relevant statistics, can be found in Langley et al. (1974).

2413 - Application of aerial photographs (1)

For detailed inventories and/or the preparation of stand maps at scales of the order of 1:50,000 or larger, the remote sensing

(1) See also Case study no.5, Tanzania, 2nd stage.

input cannot be obtained from Landsat images and must be provided by using aerial photographs at a somewhat smaller than, that of the mapping scale.

The principles of their application will basically be the same as described in the previous section. Some differences in practice will arise due to the different characteristics of Landsat images and aerial photographs in certain respects, as indicated in section 2411 above.

The main application of aerial photographs will be to distinguish classes of forest, map their location, determine their area and optimize their sampling. Comprehensive treatments of these topics can be foun in spurr (1960), Husch et al. (1972) and the FAO Manual of Forest Inventory (1973).

2413.1 - Stratification

Even when a detailed management inventory is to be carried out entirely on the ground, or when an area is coverd by a more or less uniform forest types, aerial photographs can be effectively used for an elementary stratification of forest and non-forest. The latter can be equated with gaps in the canopy of more than a specified extent, according to the type of formation concerned. This can result in a significant reduction variability of the forest population to be sampled.

Aerial photographs may also permit stratification of a single physiognomic class into a number of broad condition classes, for subsequent correlation with standing volume and other parameters. This can arise, for example, when topographic variations cause slight differences in moisture availability, reflected in the height and density of the tree cover. Different degrees of degradation of the forest cover due to human intervention may also be observable, especially in relation to distance from settlements.

Under favourable circumstances stand heights can be measured directly on aerial photographs, although this will be more relevant to denser tree formations than to open mixed formations with low trees of poor form.

The stratification criteria considered above in relation to Landsat images will also be applicable to earial photographs, on which the features concerned will usually be more readily recognisable and in more detail. While direct recognition of species will rarely be possible, the shape and relative size of crowns can be observed at the larger photo scales.

Stratification can proceed by complete interpretation, or point sampling, of all or of a sample of the aerial photographs covering the area being inventoried. The accuracy of photo-interpretation can be assessed by ckecking an appropriately selected sample of ground plots in each forest type and the results used to adjust the boundaries or estimated areas (FAO Manual of Forest Inventory, 1973, p.171).

2413.2 - Mapping

Forest type boundaries delineated on aerial photographs can be transferred to topographic maps using third order photogrammetric instruments, or simpler optical transfer devices (sketch-masters, transferscopes, variable scale plotters) when variations in terrain elevation are relatively small and the photography is not greatly affected by tilt.

The former instruments are more accurate and versatile, but require specialized personnel to operate. Under facourable circumstances of low relief, when the aerial photographs and maps are of the same scale and display an adequate amount of common planimetric or topographic detail, transfer of boundaries from photographs to maps can be done by eye.

2413.3 - Area determination

Spurr (1960) states "In areas of low relief, the sum of errors due to scale, tilt, and slope should not affect area estimates on aerial photographs by more than 5 percent, provided the total variation in elevation does not exceed 3 percent of the flying height. Under such circumstances, areas may generally be measured directly on the photographs."

When these conditions are not present then the area of types within delineated boundaries should be measured on maps, after transfer from the interpreted photographs as indicated in the previous section, and preferably by using dot grids as discussed in section 2412.4.

When stratification has been carried out by point sampling, the determination of the area of each stratum is made by the method of proportion as described in section 2412.4.

2413.4 - Application to sampling

The main applications of aerial photographs to inventory operations will consist of optimizing the sampling design and guiding its execution and will include:

- the stratification, with a minimum of ground survey, of the area to be inventoried into sub-populations of known area, whose variability will be less than that of the total population

- the execution of sampling designs with two or more stages

- the correlation of estimates made on aerial photographs (e.g. stand height, condition class) with measurements made on the ground

- the estimation of variability within strata, for the determination of sampling intensity
- avoiding that the distribution of sample units coincides with a regular pattern of topographic or other features, to avoid introducing a bias to the sample estimates
- the planning of field operations in relation to conditions on the ground
- guiding the execution of inventory operations on the ground.

In most of these respects the use of aerial photographs contributes to reducing the amount of field work required, or to reducing the sampling error for a given level of ground sampling, or both. Thus the cost and time required for an inventory will also be reduced.

242 - Sampling design

2421 - Multistage sampling

The main advantage of multistage sampling, for a given sampling intensity and for a given size and shape of the sample plots measured on the ground, is the considerable reduction in the cost of the latter. This is particularly so for dense tropical forest with difficult access; for dry forest formations it is less significant. Furthermore, the sample concentration resulting from a multistage sampling design increases the variance of the estimates and the greater the variability between primary sampling units the more significant this increase in variance becomes. Finally, a two-stage sampling design should not be applied unless a comparative cost analysis clearly shows this to be advantageous.

2422 - Single - stage systematic sampling

This is the sampling design most recommended, when undertaken with the appropriate stratification. The number of sample units n, the percentage error of the mean (at the 66% probability level), and the coefficient of variation cv of a parameter measured on the sample units are linked by the relationship:

$$e = \frac{cv}{n}$$

This allows the number of sample units for a given error to be determined, assuming a value for the coefficient of variation. Values for the latter are given in para. 244. The distribution of the sample units is based on the fact that, in comparison to dense forest formations, there is much greater freedom of movement.

243 - The sample units

2431 - Units with a given area (plots)

2431.1 - Strip plots

The narrow strips (e.g. 10 m) commonly used for the inventory of dense forest are not as appropriate in formations where movement is much easier. The main disadvantage of these plots is that, for the same area, their boundary is considerably longer than that of circular or square plots. The longer the boundary the greater the risk of error over boundary trees.

This disadvantage can be reduced by increasing the width to approach the shape of a square plot. But this can then increase the difficulty of laying out the plots, also resulting in the risk of error in the determination of boundary trees.

2431.2 - Circular plots

This is incontestably the easiest form to lay out on the ground. The various techniques for doing this are:

- using a chain or 20 m tape
- using a Pardè target and a Suunto or Blume-Leiss dendrometer fitted with a prism
- using an instrument like the Bitterlich relascoe or angle gauge.

It would seem useful to develop the last two methods as they are eminently suitable for laying out large plots in open formations.

The Pardè target (Figure 2)

The Pardè target resembles a surveying pole with one fixed and one moveable sighting target so that the distance e between these two can be adjusted. The pole to e established. Using a wedge prism of known angle (3/100 of a radian in the case of a Suunto or Blume-Leiss dendrometer) the observer can readily place himself at a distance equal to $\frac{100e}{3}$ from the rangefinder and consequently describe the boundary of a plot of surface area $R^2 = \left(\frac{100e}{3}\right)^2$.

The required distance e for a given plot area can be obtained from a set of tables. The distance e can be readjusted and so compensate for slope, enabling plots of constant area to be established even when the terrain is not level.

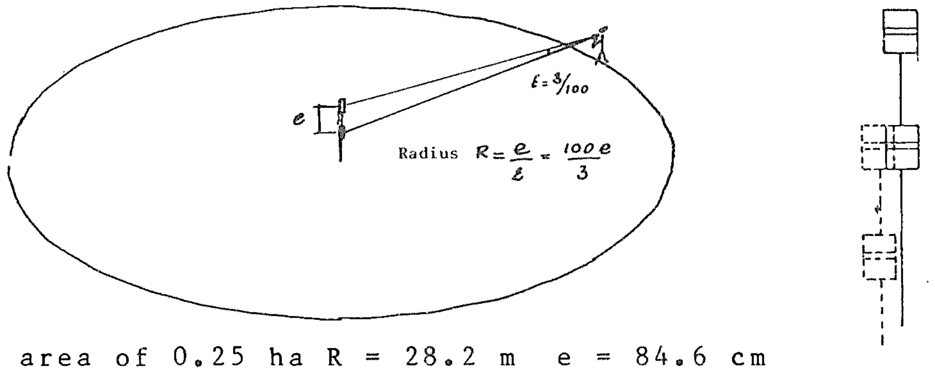
Bitterlich Relascope or angle gauge (Figure 3)

Another method is to place a cylindrical target with a vertical axis and of diameter d at the centre of the plot and range on this with the angle gauge using an angle ε. The distance R between the observer and the target is $R = \frac{d}{\varepsilon}$.

Thus, with $\varepsilon = 1/100$ and a target diameter of 20 cm the distance R will be 20 m. The observer can therefore readily describe a circle with a 20 m radius (0.125 ha).

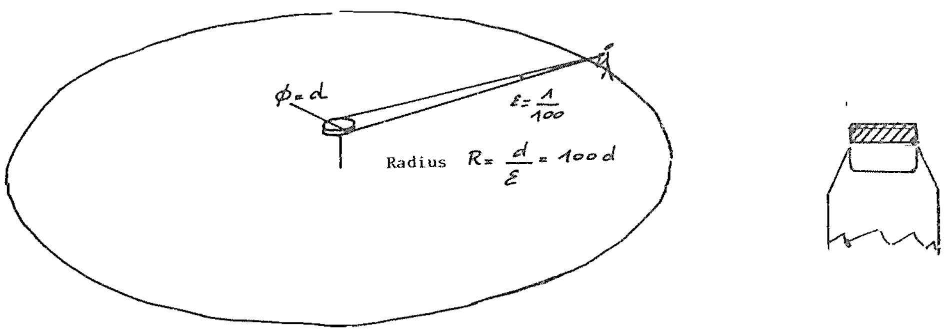
Figure 2

Circular plot laid out with the Pardé target and a 3/100 angle prism (Suunto or Blume-Leiss dendrometer)



For an area of 0.25 ha R = 28.2 m e = 84.6 cm

Circular plot laid out with a cylindrical target and a 1/100 angle gauge (Bitterlich relascope or simpler angle gauge)



For an area of 0.25 ha R = 28.2 m d = 28.2 cm

2431.3 - Plot clusters

Another type of sampling unit can be obtained by establishing a systematically designed group or cluster of small plots (recording units), which together comprise the sampling unit. This can have two advantages:

- for a given size of sampling unit it may be easier to lay out several smaller plots than one larger one.

- when there is competition between trees at a distance similar to, or greater than, the dimension of a plot then the information obtained from the plot will be a function of its size. This problem is avoided with a cluster of plots placed at a sufficient distance from each other.

Plot clusters also have a serious disadvantage in that the total circumference is considerable increased. Thus, when a circular or square plot is replaced by n smaller plots the total length of the boundary length is multiplied by $\sqrt{n}$.

For example, if a 0.25 ha circular plot (radius 12.6 m) the total boundary length is multiplied by 2.2, so that the greater ease of laying out the plots represents little gain.

2432 - Dimensionless (angle count) plots

For the formations being considered here this type of plot will only be of interest when there are large but widely dispersed trees which, to be counted, would require excessively large sample plots (larger than 1/8 ha). On such dimensionless plots the tree count should be accompanied by the measurement of the diameters.

An angle count provides:

- basal area per hectare if only the number of trees is counted without measuring their diameters.

- the number of trees per hectare by diameter class when the diameter of the counted trees is also measured.

The n_i trees counted in diameter class d_i will all be within a circle of radius $R_i = \frac{d_i}{E}$ where E is the angle of the angle gauge used. This circle having an area $\pi R_i^2 = \frac{\pi d_i^2}{E^2}$ the number of trees per hectare N_i of the n_i trees in diameter class d_i is:

$N_i = n_i \frac{E^2}{\pi d_i^2}$ and the number per hectare is $N_i = n_i \frac{10.000\, E^2}{d_i^2}$

When the stocking is low (less than 10 m^2/ha) an angle gauge with a low factor (1 or 0.5) should be used. The table below shows the area of the circles on which trees of different diameter classes are counted.

Table no.4

Factor	Angle E (radians)	Area (ha) of the circle on which trees are counted with a diameter of:		
		Diameter 0,20 m	Diameter 0,40 m	Diameter 0,60 m
2	1/35,3	0,016	0,063	0,141
1	1/50	0,031	0,125	0,283
0,5	1/70,7	0,063	0,251	0,565

The disadvantage of this procedure is that it is difficult to use with stems of small diameter. Stems of less than 15 cm diameter tend to be crooked, which reduces the accuracy with which angle gauge readings can be taken. This method should therefore be confined to situations where there are both large and small trees present and where the advantage for the measurement of the larger trees will be preponderant.

Singh (1980) underline the time gained by using dimensionless plots instead of plots of fixed area. He advocates counting the trees of less than 10 cm diameter on a plot of 5 m radius. It may be noted that for an angle count using a factor of 1, a radius of 5 m corresponds exactly to trees of 10 cm diameter.

244 - Coefficients of variation

To determine the number of sampling units required for a predetermined level of error, the coefficient of variation of the parameter/s being investigated must be known. An idea of the order of magnitude involved can be obtained from the results of two inventories.

The first is the inventory carried out in Burkina Faso (case study no.7) which provides information on the coefficients of variation of the volume measured on 0.25 ha plots.

- the coefficient is very high for bush fallow types formations (90-110%) which corresponds well to their considerable heterogeneity.

- it is lowest (40-70%) for woodland and tree savanna formations, which are the best stocked and most homogeneous.

- it is intermediate (50-90%) for shrub savanna type formations which are also the poorest.

It is therefore evident that the coefficient of variation of the volume on 0.25 ha plots, after stratification, ranges from 50% to 100%.

The second is the inventory done by complete enumeration in Mali (cae study no.3) on square sub-plots of 0.20 ha. A coefficient of variation of 37% was found, somewhat below that of the previous inventory. However, since the subplots were adjacent and the area of limited extent, the figure of 37% must be considered as somewhat optimistic.

For plots of 0.125 ha a coefficient of variation of at least 70% must be expected and for plots of 0.25 ha of at least 50%.

Table no.5

Number of plots required for a specified sampling error at a 95% probability level

Error (%)	0.125 ha plots	0.25 ha plots
2 %	4,900	2,500
5 %	784	400
10 %	196	100

3 - MEASUREMENTS

31 - Measurements to determine the volume (or weight) on a sample plot

For the establishment of stand volume tables the total volume (or weight) on a sample plot of known area must be measured. Experience has shown that the most suitable method is first to fell and stack the wood present on a sample plot and then to take measurements.

311 - Before felling the plot has to be laid out and its area and other dendrometric characteristics determined, so that subsequently the correlation between these characteristics and the volume (or weight) of all the plots can be studied and the volume equation can be established.

312 - At the time of felling and stacking, whenever possible the wood should be sorted according to quality criteria (various fuelwood categories and possibly building poles) so that a breakdown of the total volume (or weight) into different quality classes may be obtained.

Stacking should be done with wood of uniform length. A length of one meter can be considered satisfactory from a practical point of view.

313 - Measurements after stacking

Once stacking has been done the stacked volume on each plot can be measured directly. This will be facilitated if the wood is of constant length and the stacks are made with care.

The stacked volume may be the final result of interest. In so far as the needs of the local consumers have been taken into account in the stacking and quality breakdown of the wood, the resultant stacked volume can constitute a perfectly satisfactory result for the consumers.

However, when working on a larger scale and the results obtained are to be applied to the prediction of the wood supply over regions where this is little known, then inventory results expressed in terms of stacked volume become difficult to use.

314 - A first approach could be to measure directly:

- either the solid volume
- or the dry weight

without first measuring the stacked volume. This is perfectly practicable in the context of exerimental operations. The method is in fact used for the exact determination of biomass to serve as reference data. Its application is essential to obtain the reference data which is largely still lacking for mixed forest/grass formations.

However, this is not justified for inventories where the aim should rather be to convert the stacked volume measured on the plots:

- either to solid volume
- or to dry weight

both being provided in certain cases.

315 - First case: conversion of stacked volume to solid volume

The problem consists of determining the stacking coefficient = (solid volue)/(stacked volume).

In the publications cited the figures vary to such an extent that it is not possible to accept volume estimates based on stacking coefficients other than those obtained in the course of an inventory. The following table gives some of the coefficients quoted in the literature consulted.

Table no.6

SOURCE	CONDITIONS	COEFFICIENT (Conversion factor)
Caillez (1980)	Small branches of poor form	0.45
	Quarered lengths	0.80
Gravsholt,S. and Abayomi,J.O.	Azadirachta indica, northern Nigeria	0.31
Singh (1980)	Anogeissus pendula, Bharatpur forest	0.44
Bergonzini	Inventory in northern Cameroon	
	Small sizes (diam.<5 cm)	0.24
	Large sizes (diam.>5 cm)	0.43
Morel and Clement,J.	Clear cut on 4 ha;measurement of all sizes;area of Bamako (Mali)	0.50
Nouvellet (1983)	clear cut on 4.6 ha of savanna; all diameter classes; area of Bambari (C.A.R.)	0.56

The method employed for measuring must take the shape of the pieces of wood into account. With pieces of irregular shape the only method applicable is that described by Cailliez (1980). More rapid methods can be used if the stacking is very regular, but this will rarely be the case with fuelwood in the type of formations being considered.

If the pieces of wood are not too small they can be measured individually:

Diameters at each end and the mid-diameter D_1, D_2 and Dm
Length L

the volume by Newton's formula is then given by

$$V = \frac{\pi}{24} (D_1^2 + D_2^2 + 4\ Dm^2)\ L$$

This operation takes long and requires the stack to be dismantled. It will be simpler to measure the diameter of each piece at each face of the stack (without relating these two measurements to the piece of wood concerned). The application of Smalian's formula then gives:

$$\text{Solid stack volume} = \frac{\pi}{8} L \left[\Sigma\ D^2 \text{face } 1 + \Sigma\ D^2 \text{face } 2 \right.$$

After doing this for several stacks the stacking coefficient can be taken as:

$$\frac{\text{Sum of solid volume of the stacks}}{\text{Sum of their stacked volume}}$$

It is possible to calculate the confidence level of this estimate (estimate by quotient - FAO Manual of Forest Inventory (1973)).

If the wood is of small diameter then weighing is the only practicable method, but requires establishing the weight per unit volume for the total volume to be calculated.

Proposals for improving the measurement of the stacking coefficient (case study no.4)

It has been possible to verify that the variations of this coefficient are due to the differences in the diameters and the shapes of the stacked wood, leading to the idea of making stacks with wood of uniform size to obtain a more reliable coefficient. By separating large sizes (wood with a diameter of more than 5 cm at the larger end) and small sizes (the rest) for an inventory in Cameroon two different stcking coefficients were obtained (0.43 for the large and 0.24 for the small sizes) using only three stacks of each category.

A priori it is not possible to stipulate the number of stacks to be measured, but the question can be treated in the same way as the precision of a sample inventory, measuring as many stacks as the variation in the value of the coefficients obtained indicates.

Measuring the solid volume of wood of small diameter requires a large number of measurements, for which reason weighing has been advocated. It is assumed that the weight per unit volume v is the same for the large and the small sizes in their condition at the time of weighing. The weight per unit volume can be obtained by weighing stacks of large size wood whose solid volume has been measured. For a stack of small wood it will then suffice to obtain the weight, from which the solid volume can be calculated. For this method to be valid it will be necessary to carry it out at the stacking site and before the wood begins to dry.

316 - Second case: conversion of stacked volume to weight

Both weighing and determination of the degree of humidity have to be carried out, because one cannot give a weight for wood without specifying the moisture content. Green wood can weigh twice as much as dry wood. Weighing is carried out with apparatus suitable for field conditions (scales or balance).

Measurement of the moisture content is done on samples which must be weighed immediately in the green state and then taken to the laboratory, oven-dried and weighed in the dry state. If the samples cannot be weighed immediately they must be wrapped in waterproof bags and weighed in the laoratory. This method therefore requires both adequate equipment and organisation.

Moisture content can be defined as:

$$\frac{\text{weight of water content}}{\text{dry weight of wood}} \quad \text{expressed in percent}$$

- Dry weight can be considered as the weight after oven-drying
- The weight of the water content is the difference between the initial weight (before drying) and the final weight.

When the moisture content is determined in the laboratory it will also be possible to establish the weight per unit dry volume; but to convert weight to volume it must be borne in mind that the weight per unit volume varies between species and that the distribution of the wood by species will not be known.

If the species distribution of the samples used to measure moisture content is the same as for the population being sampled then the relationship weight/volume of the sample can be taken as the weight per unit volume.

32 - <u>Measurements to determine the volume of sample trees</u>

To establish individual tree volume tables it is necessary to use other measurement procedures. These are of more general application since they are habitually used for all forests producing timber. Cailliez (1980) justly underlines the importance of defining the volume which is of interest.

321 - Felling diameter

The lower limit should be fixed in agreement with the users, although an absolute lower limit of 3 cm diameter may be considered which, according to circumstances, can be raised to 5 or 7 cm. The latter is too large to be recommended for general application in the case of fuelwood.

In this respect some interesting figures were obtained in C.A.R. (Nouvellet, 1983) in the course of cutting 4.6 ha of savanna. The total volume was low (9.4 m^3/ha). The wood was cut into 1 m lengths which were all measured and grouped by circumference classes. In total there were 10,385 logs with a volume of 43.6 m^3.

Table no.7

Circumference class (in cm)	0-10	10-20	20-30	30-40	40-50	50-60	60 et +
Frequency (%)	12	58	18	6	2	2	2
Volume (%)	1	26	22	14	8	12	17

This table shows that the wood with a diameter of from 3 to 6 cm represents:

- more than half the number of logs

- a quarter of the volume

This was consequently an importent class in this instance, not to be neglected. On the contrary, wood with a diameter below 3 cm represented only a very small part of the volume. Furthermore, it must be admitted that taking into account all the wood of less than 3 cm diameter poses practical problems and that the statistics concerning this are very probably biased. But even if the volume of this category were doubled to compensate for its under-estimation, it still remains negligible.

Another value of some interest was found in the course of an inventory in Cameroon (Bibemi region) in higly firedegraded tree savanna with a total volume of 20 m^3/ha; 20 % of this volume was made up of wood of less than 5 cm diameter (Meurillon, 1980).

322 - Bark

Volume measurement of fuelwood should be made overbark.

323 - Measurement procedure

The principle consists of dividing up the tree - stem and branches or billets measure - in accordance with one of the classic formulae (those of Huber or Smalian being the best known). The more nearly the billets are of cylindrical form and the formulae produce the same results, the greater the accuracy of the latter. The stems are therefore best divided into billets with little taper, which generally means into short lengths.

On a felled tree such measurements pose no problem. On a standing tree diameter measurements can be made with various instruments:

- Bitterlich relascope
- Wheeler pentaprism caliper
- Finnish caliper mounted on a pole

Such measurements on a standing tree are always difficult. They should be restricted to trees which are large or of high value which could not be felled and stacked. Among the three instruments mentioned only the third merits detailed consideration. It has the advantage that it can be made very simply: a pole which can be assembled from a set of lengths and a wooden shape.

To enable the caliper to be read at a distance without difficulty it is useful to employ a system of compensated graduations in three colours (white, black and red) as shown in figure 3. Such graduations can be discerned at 0 or 15 m even when the figures themselves are no longer readable. Measurements can be taken to the nearest centimeter.

33 - Measurements for the indirect determination of volume

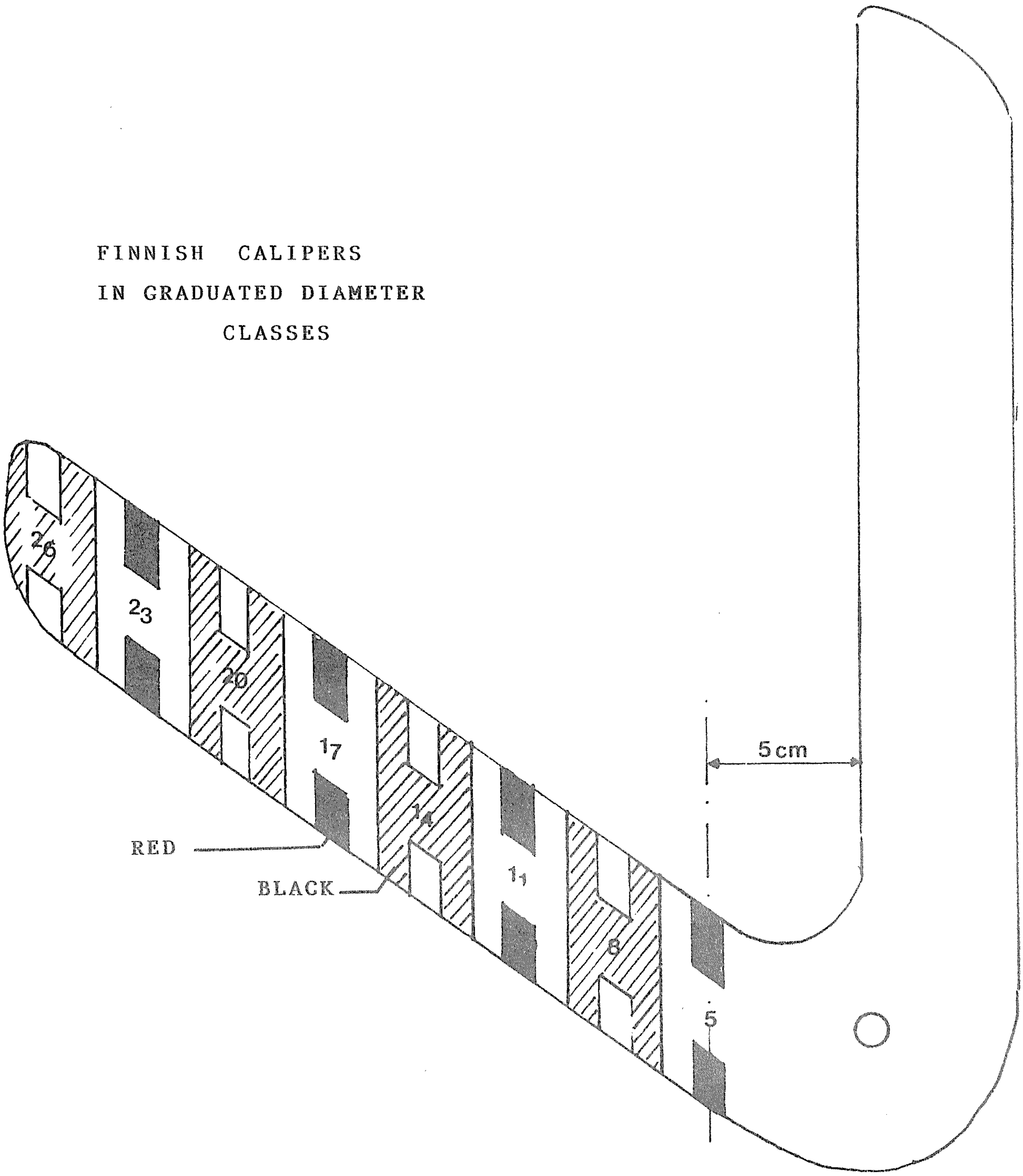
As mentioned above (para.31), the variables required to determine volume by means of a stand or tree volume table are measured on the sample plots.

331 - Measurement of reference diameters

This is the measurement, made with a caliper (or tape), of the diameter (or circumference) at 1.30 m with the considerations concerning trees on slopes, forked trees, etc. given in the FAO Manual of Forest Inventory (1973, p.94).

To facilitate the analysis of the results these measurements are recorded by diameter classes. The class limits are selected according to the range of values present and so that there are at least ten classes. For the type of stands being considered diameter classes with a range of 3 cm (centred on multiples of 3), or circumference classes with a range of 10 cm (centred on multiple values of 10) are recommended. The main problem consists in selecting a lower diameter limit for the stems to be measured. The results of several complete or quasi-complete enumerations, i.e. using a lower limit close to 0, showed that even for poorly stocked stands this resulted in the enumeration of several thousand stems or shoots per hectare. Generally speaking, this results in a frequency curve concave towards the origin of the x and y axes.

Figure n° 3



Taking stems and shoots, of 4 cm or more generally results in a count of several hundred. These orders of magnitude being known, the influence of the selected diameter limit on the basal area can be considered. For this purpose volume and basal area may be considered as directly proportional.

Stems and shoots of less than 4 cm diameter represent 5 to 10% of the total basal area for tree savanna (NHc/NHO) with 6 m^2/ha. Stems and shoots of less than 8 cm diameter represent half of the basal area under the same conditions. For these conditions a diameter limit of 4.5 cm (or 15 cm circumference) can be adopted. This choice is favoured by the fact that for 3 cm diameter classes a value of 4.5 will be the lower limit of the class centred on 6 cm and for 10 cm circumference classes a value of 15 will be the lower limit of the class centred on 20 cm.

$\pi \times 4.5 = 14.14$ $\qquad\qquad$ $\pi \times 4.8 = 15.0$

The Finnish calipers described above can be used for assessing these diameters. They can be operated more quickly than the classic sliding calipers and are just as accurate. However, the user must be careful to read them at the correct angle.

332 - <u>Classifying bushy shrubs</u>

It becomes clear that the lower limit for taking stems into account for the determination of diameter can be difficult, as this can lead to neglecting small dimensions (sampling, shoots) which may be very numerous and represent a significant proportion of the volume. Under these conditions a procedure used in practice may be proposed (C.T.F.T., Burkina Faso - Annual Report, 1981), i.e. tallying the bushy plants in a matrix which is established at the beginning of the inventory. An example of such a matrix is given below.

Table no.8

Height	Number of shoots	Mean circumference
Bushes more than 2 m high	less than 5 shoots	< 10 cm A1
		> 10 cm A2
	from 5 to 10 shoots	< 10 cm B1
		> 10 cm B2
	more than 10 shoots	< 10 cm C1
		> 10 cm C2
Bushes less than 2 m high	very numerous	D
	numerous	E
	few	F
	very few	G

Once such a matrix has been established the volume for each category of bush must be calculated. This should be done by the inventory workers themselves to ensure good agreement with the true volume, taking a representative bushy shrub in each category for the reference measurements.

333 - <u>Other methods of classifying small-diameter stems</u>

Another method which has been used consists of measuring only those shoots which exceed a certain height (5 m is a good height). The advantage of such a height limit is that it is fairly readily distinguished by eye, whereas for a diameter limit a stem has to be measured to be classed.

Stems below the height limit are enumerated and may be grouped by height categories. Such a method has the advantage of considerably reducing the number of stems to be measured for diameter.

For a breakdown into height classes of stems below 5 m a measuring pole marked at 2 m intervals can be used - for example:

Class 4: from 3 to 5 m

Class 2: from 1 to 3 m

Class 0: from 0 to 1 m

The result of tallying by this method will be:

- number, by height class, of stems below 5 m

- number, by diameter class, of stems above 5 m

To specify the conditions for the application of this method the figures obtained by Hopkins (1962) are given in Case study no.14. This was for a fire-degraded tree savanna (NHc/NHO 2) in Olokemeji reserve (Nigeria) where all stems were measured for height and then broken down into classes.

This method is of interest for the fact that from such figures the mean tree (dg) can be calculated for the taller portion of the stand (equivalent to the dominant trees of an even-aged stand). It appears that this diameter dg plays an important role for the indication of the site potential.

4 - STUDY OF YIELD

For those regions where supplying the population with fuelwood becomes a serious problem it is important to know the yield, i.e. the amount of wood which can be harvested annually while maintaining the condition of a stand.

These studies are more important than in the case of dense tropical forests because the population pressure is greater and because the production potential can be considerably degraded by human intervention when the quantities which can be harvested are inadequately known. The planning of demand and supply at a regional scale must of course be based on the standing volume of wood at a given time, but even more so on the rate of regrowth of such wood.

41 - Determination of stand age

For yield studies priority must be given to obtaining information on stand age. The system frequently adopted for harvesting wood in the formations being considered is that of periodic clear felling. It is the size of the regenerating shoots considered adequate for exploitation which regulates the felling cycle and this is consequently determined empirically. It is therefore difficult to know the age of stand unless a precise record of successive interventions has been kept.

The use of permanent sample plots is therefore the best and probably the only effective means for the evaluation of stand yield. In practice there are very few such sample plots and this is worth emphasizing as this represents an urgent need for all the dry forest areas concerned with the problems of fuelwood supply. The methods of establishing such sample plots have largely been developed by Alder (1979) and the importance of continuity in this field cannot be overemphasized.

Apart from permanent sample plots stand age can still be ascertained if the following conditions are met:

1. that the recent history of the stand, even if not known exactly, can be derived from a clear cut.

2. that the date of such a clear cut can be determined from an examination of the annual ring.

42 - Reading of annual rings

The study by Mariaux (1979) in this field shows that for a good number of tropical species of dry regions the reading of annual rings is possible. Postulating the clear cut of a sample plot at an unknown date, the examination of a number of well-chosen stumps of average size should enable the date of the cut to be unambiguously determined.

In the absence of permanent sample plots already established for several years this is in fact the only way to determine the age of a stand and consequently to give the yield of a formation.

43 - Development of yield over time

For any forest formation periodically subjected to complete replacement by clear cutting and natural or artificial (planting) regeneration the curves of development over time can be defined as: (A = Age):

1. the standing volume of wood V

2. the productivity or mean annual production p = V/A

These two curves are deducible one from the other. For the formations concerned it is not production still developing over a short period of time which is of interest and further more there is a strong possiblity that such short term increment does not correspond to yield.

At present there is insufficient data and conditions are too diverse to allow examples of such curves of production development to be given.

Nevertheless two hypotheses can be based on available results:

431 - Production is at its highest during the first years, therefore requiring short rotations. This is what emerges from the analysis of Park et al. (1982). In the region of Las Maderas, Nicaragua, with annual rainfall varying from 850 to 1150mm, it was observed that the rate of increment fell very rapidly around an age of 10 years and even earlier, so that the rotation applied is of less than 6 years.

432 - Yield is at its highest at around 20-25 years and this is the age which is considered favourable for felling.

It is presently difficult to confirm or deny these hypotheses and the fact that they can be advanced shows that there is still much that remains unknown in this field. It should nevertheless be said that although the second is the one most commonly accepted, there are a certain number of cases where felling at 25 years is too late to ensure maximum yield. It is the incidence of fire and the degree of damage to which the vegetation is subjected during the first years which can significantly affect growth during the first years. In the absence of fire-damage yield should reach a maximum during the earliest years after felling.

In favour of this hypothesis, clearly stated by Park et al. (1982), the different measures of basal area cited in Abayomi (1982) can also be taken into consideration. The increment given is very broadly a current increment. Comparison with basal area shows that this was measured at a late stage in the life of the stand, the relationship G/ΔG for most of the time being greater than the likely age of the stand, where

G = basal area (m^2/ha)

Δ G = basal area increment (m^2/ha/year)

Table no.9

Figures for basal area increment cited by Abayomi (1982)

Locality	Vegetation type	G Basal Area (m^2/ha/yr)	Δ G Basal Area (m^2/ha/yr)	$\frac{G}{\Delta G}$ (years)	Source
Afaka, Nigeria	Northern Guinea savanna	7.1	0.24	30	Kemp, 1963
IBP Research site, Zaire	Miombo woodland	13.3	0.30	34	Malaisse, 1978
Ndola, Zambia	Miombo woodland	16.1	0.15	107	Endean, 1968
Mua Livulezi	Bamboo savanna	15.9	0.20	79	Edwards,
Malawi	Shrub savanna with bamboo	11.2	0.25	45	unpubl.
	Woodland savanna	15.0	0.21	71	
	Tree savanna	4.3	0.47	9	
Bunda, Malawi	Cut-over savanna	11.9	0.57	21	Edwards, as above

44 - Indices of yield

A yield index is defined starting from the assumption that there exists an intrinsic potential level of yield for each site when occupied by a given forest type.

As presented in Alder (1979), for homogeneous, even-aged stands the dominant height attained at a given age constitues a good index of (or indicator of fertility).

441 - Dominant height

The dominant height is particularly unsuitable for heterogeneous stands among those which have been studied and in no case has it been used as index. This is due as much to the form of the trees as to the difficulty there would be to define the number of dominants. Two studies, on the other hand, seem to reach a conclusion on the usefulness of a 'dominant diameter'.

442 - Dominant diameter

The mean diameter, without any limit as to its lower threshold, would not be significant because, for the formations being considered, the curve of diameter distribution is concave in a positive sense. If only the trees over a certain diameter are considered, then their mean diameter will reflect the diameter increment of individuals subjected to a low degree of competition. In practice it is much easier to fix a height threshold rather than a diameter threshold to facilitate measurements; this corresponds more closely to the definition of trees subjected to little competition.

443 - Diameter expressed as a function of age

The individual value for diameter x age collected by Mariaux (1964, 1967) enabled Lillelund (1981) to obtain the following equation:

$$\frac{D}{A} = 0.728 + 0.0059\ P \qquad (1)$$

D = diameter in mm

A = age in years

P = precipitation in mm

This constitutes a good model of the relationship which should be found between: the dominant diameter of stands (D_0), their age and the precipitation. It is probably not necessary, initially, to seek a more complex model because the main lack at present is one of available measurements.

One can therefore adopt the principle of a set of curves such as that obained from equation (1)

$$D = 0.728\ A + 0.0059\ AP$$

or from some closely similar equation.

444 - Yield expressed as a function of precipitation

Following the examination of a number of experimental results Clement proposes the following expresion for yield p in m^3/ha/year:

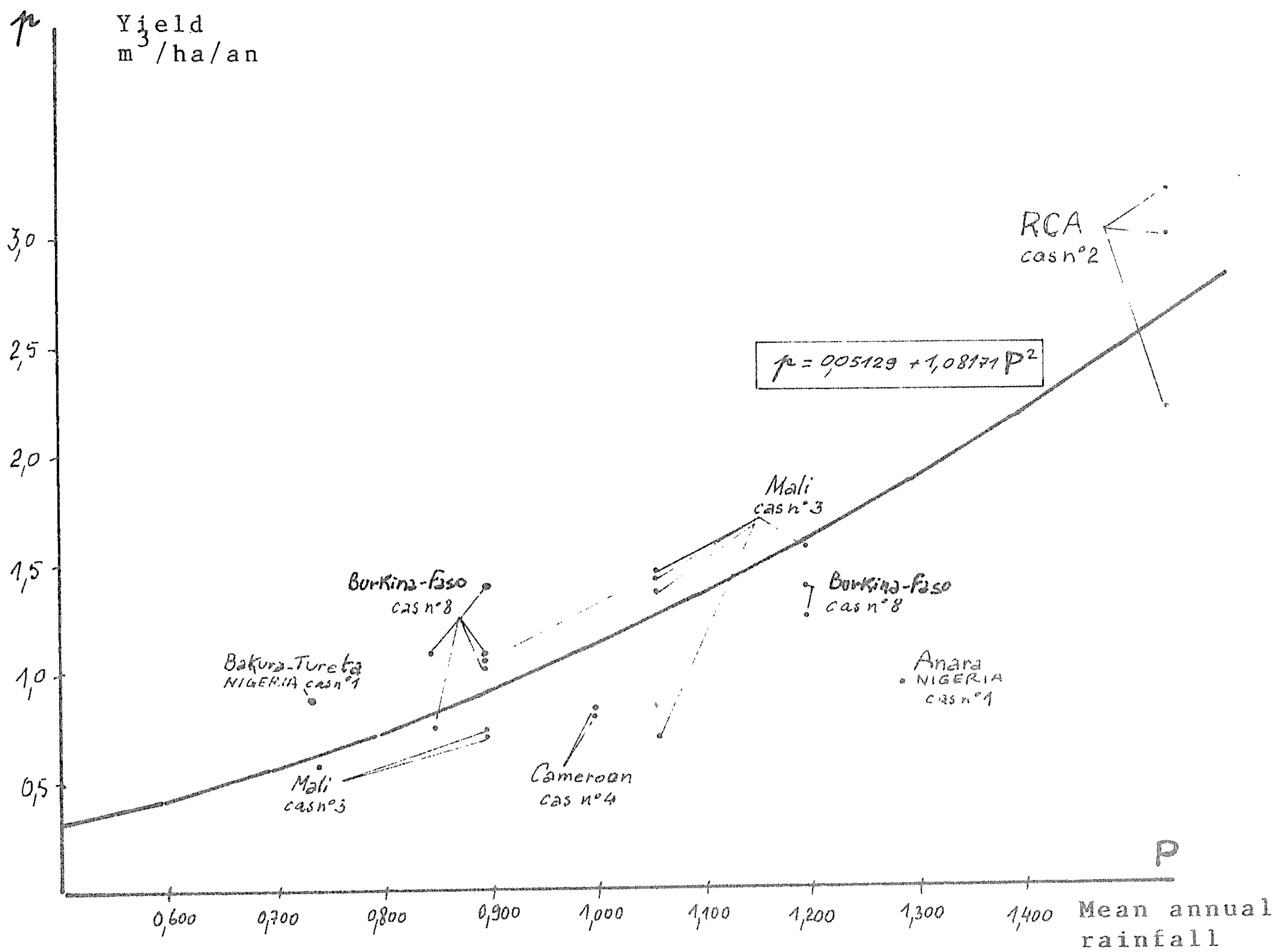
$$p = 0.05129 + 1.08171\, P^2$$

where P is expressed in meters (of precipitation).

This expression of yield omits the age, i.e. it assumes that the optimum age for exploitation is already known. For most of the experiments on which this formula is based the exploitation age was of the order of 20 years.

Graph no. 5

Yield observed as a function of rainfall
(from report by Clèment)



In fact it seems that the age appropriate for exploitation varies with the location. The greater the rainfall the later a stand can be exploited.

Assuming that age of exploitation increases linearly with precipitation:

15 years for P = 600 mm
30 years for P = 1200 mm

gives: $A = P/40 = 0.025\ P$

5 - CONCLUSIONS

In conclusion of this review, which makes no claim to be comprehensive but rather to bring out various problems, four points can be made.

51 - Importance of fuelwood supply in dry regions

For the past ten years or more the situation in a certain number of countries has been getting worse. The map of the fuelwood situation produced by FAO in 1981 underlines that in 1980 a fuelwood deficit affected more than one billion people.

Energy resources are vital for the whole of humanity. In numerous developing countries it is not petroleum nor electricity which is lacking but fuelwood, because this is the commonest form of energy resource and the easiest to use.

52 - Lack of information about dry forest formations

This lack is explained both by the low economic interest of the study of these formations and the lack of continuity of such studies.

This absence of information applies equally to volumes per hectare, annual production levels, variability of dimensions and volume tables. Consequently results are very meagre and it is difficult to establish a relationship between them, i.e. to set up models of productivity on which to base predictions.

53 - Differences between dry forest formations and dense forests

These must be emphasized because the methods suitable for dealing with the latter formations should not be applied without considerable thought:

- Remote sensing can lead to methods of estimation which are more reliable for the more open formations than for dense forests.

- Sample plots will generally be more accessible and can therefore be more widely dispersed and at the same time be made smaller.

- Volume measurements should be made by measuring the stacked volume and not by measuring the solid volume of logs. Under these conditions the sample tree is replaced by the sample plot and the tree volume table by a stand volume table.

54 - Possibility of managing natural formations

Numerous studies have shown that production from man-made forests is greater than that from natural formations and this has led to a certain lack of interest in the management of natural formations. However, from a global standpoint and given the considerable costs of establishment and maintenance for man-made forests, it is not certain that this is the best solution. It is possibly appropriate where there is an urgent problem to be resolved, but it is to be hoped that in many cases there will be a reversion to management. The example of India is interesting in this respect and one can see that it is very similar to the methods used in numerous developed countries at the time when fuelwood was still almost the sole source of energy.

These methods are characterised by:

- fire protection or, beter still, controlled burning

- a short felling rotation (of the order of 20 years)

- the possibility of leaving trees for several rotations for various uses (timber, fruit, environment)

REVIEW OF STUDIES CARRIED OUT AND OF THE RESULTS OBTAINED

The study of research reports and of some other documents has enabled results which have been obtained concerning the volume production of mixed (tree/shrub and grass) formations to be presented. The first fact which emerges is that little work has been carried out in this environment. Foresters soon realised that, under the same conditions, plantations had a much higher yield and that as a result there was no urgency to expend effort for a better understanding of the growth of natural formations. This is notably the conclusion reached by Jackson and Ojo (1971) who made a comparison of the experimental results obtained in Nigeria from 1939 to 1960 in various types of natural formations.

Three types of experiments or studies may be distinguished:

1 - Experiments conducted over a fairly long period (20 years) with continuity of enumerations and accurate volume measurements.

Three of these experiments have been reported. They will be analysed in some detail with a view to deriving the maximum value from them, both concerning the productivity of the formations and their development over time, as well as from their methodological aspects.

2 - Inventory operations conducted at a sufficiently large scale to take into account the heterogeneity of the forest concerned. These results provide a good indication of the variability of the parameters measured as well as of the relationship between them.

3 - Studies over limited areas with measurement of certain parameters which do not necessarily include volume. The interest in presenting these results lies in showing the shortcomings of methods which are not sufficiently thorough.

Type 1 Experiments

NIGERIA — Case study no.1

Six similar experiments were established in 1939 in six different climatic zones (Onochie, 1964). The objective was "to assess and compare the effect of different treatments on a savanna forest zone".

The treatments were:

A - Complete protection from fire

B - Early burning every year

C - Early burning every other year

D - Early burning every fourth year

E - late burning every year

each treatment being carried out on three sub-plots:

1 - not exploited

2 - exploited by cutting at 1.30 m above ground level

3 - exploited by cutting at ground level

Of the six initial experiments three were abandoned and the other three were reported as follows:

Olokomeji	Keay and Charter (1960)
Bakura-Tureta	Onochie (1964)
Anara	Onochie (1961)

Only the last two are dealt with here.

Bakura-Tureta study

Location: 75 km south-east of Sokoto

Latitude: 12 °39' North

Reference: Onochie (1964)

Average rainfall: 730 mm

Soil type: sandy or sandy-clay with a concretionary horizon. Almost complete absence of humus.

Vegetation type: Sudan zone - *Combretaceae* savanna with continuous grass cover.

Sequence of operations

Layout of the experimental design

1939 - layout of the experimental design consisting of plots each of 1.1 ha of which the entire area was to be measured. Enumberation from 10 cm circumference (3 cm diameter). Exploitation without measurement of volume.

From 1969 to 1960 several intermediate measurements were carried out.

1960 - enumeration by circumference; clear felling and measurement of stacked volume by plots except for the plot under treatment A which was not felled in 1939 and left standing.

Anara study

Location: 20 km north-east of Kaduna

Latitude (approx.): 10°45' North

Reference: Onochie (1961)

Average rainfall: 1280 mm

Site: Deep variable clay gravel soils on granitic bed-rock. The vegetation is Northern Guinea savanna and corresponds to zone 17 on the A.E.T.F.A.T. vegetation map.

Sequence of operations

1939 - layout of the experimental design consisting of 15 plots of which only the central part (0.2 ha) was to be measured. Enumeration from 10 cm circumference (3 cm diameter). Exploitation according to the treatments given above and measurement of stacked volume.

Measurements in 1945 and 1950 (height measurements of the plots cut at ground level).

1961 - clear felling of all plots (central portion) except for that under treatment A (unfelled sub-plot) and measurement of production as stacked volume.

Results of volume measurements

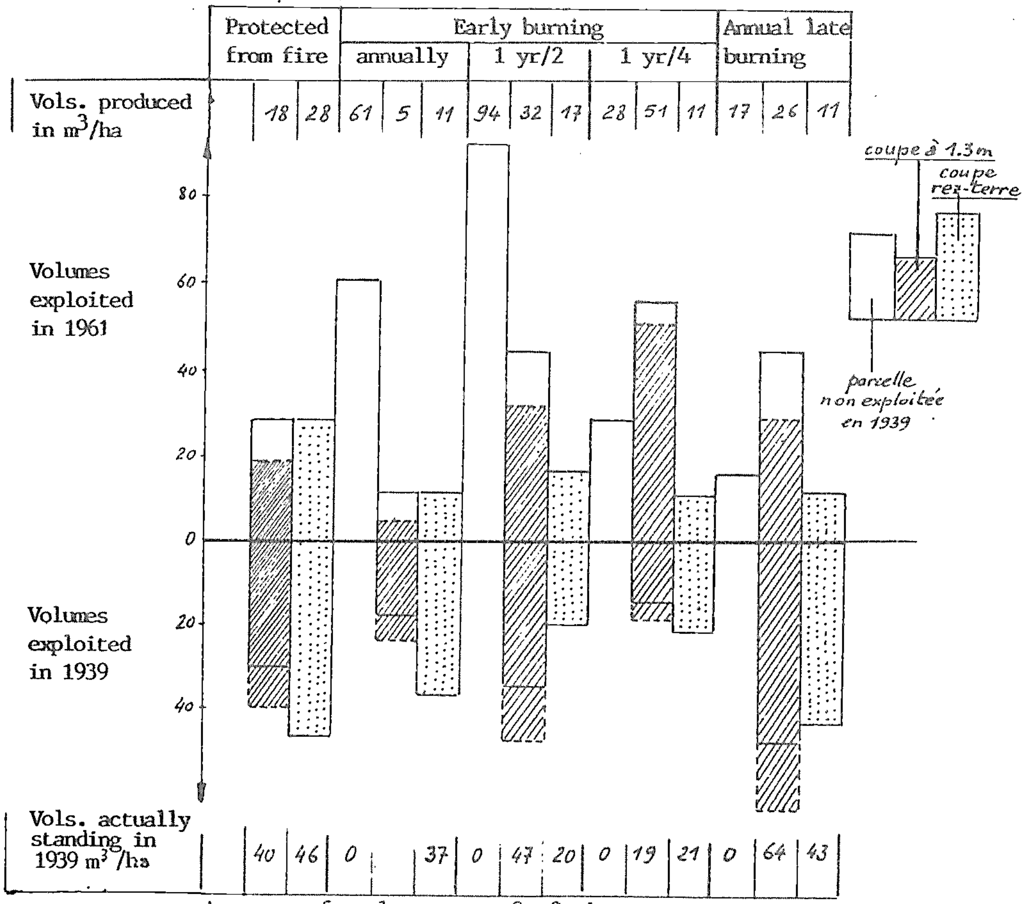
The results are shown in diagram no.6 and table no.10. The presentation of the latter calls for the following notes.

Note 1 - To give results which can be compared, it has been necessary to convert the original figures, expressing the stacked volumes as solid volumes. The stacking coefficient adopted is

Graph no.6

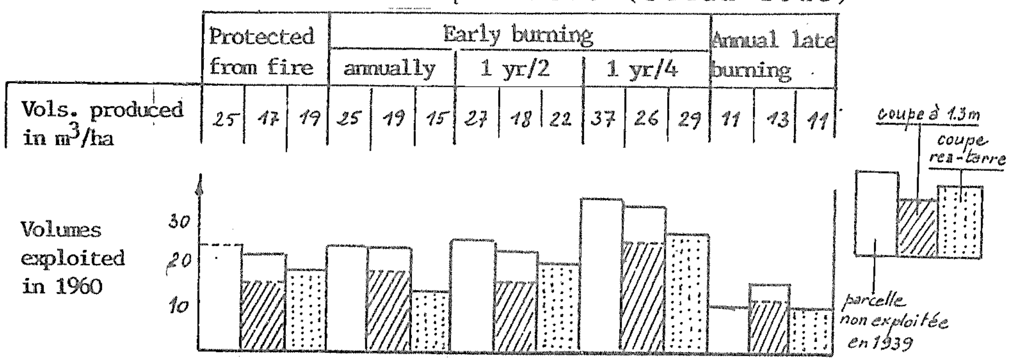
Case study no.1

Anara experiment (Northern Guinea zone)



Area of plots = 0.2 ha
Stacking coefficient = 0.31
For the plots cut at 1.3 m the vol. left standing was estimated at 1/4 of the total volume added in 1939 subtracted in 1961

Bakura-Tureta experiment (Sudan zone)



Area of plots = 1.1 ha
Stacking coefficient = 031
For the plots cut at 1.3 m the volume was reduced to take account of the portion left standing in 1939

0.31. This is the same as that obtained by Jackson and Ojo (1971) from their interpretation of these results. It appears low when compared to those obtained elsewhere. At present it is not possible to propose a better estimate.

Note 2 - Cutting at 1.3 m had the effect of leaving a significant part of the volume in place. A minimal value for this volume can be obtained by taking the basal area figure and multiplying this by 1.3 (section at 1.3 m x 1.3 m length).

However, for the Bakura-Tureta experiment the 14 plots clear-felled in 1960 provide values for the exploited volume and for the basal area. These give a basal area of 4.13 m^2/ha for 22.9 m^3/ha of solid volume, so that the volume between 0 and 1.3 m would represent 23.4% of the total volume, which has been rounded to 1/4.

Where cutting took place at 1.3 m the volume to be added to that exploited in 1939 and the same volume to be subtracted from that obtained in 1961 has been shown by dashed lines in the diagrams. For the Bakura-Tureta experiment, in the absence of the 1939 volume production, 1/4 has been subtracted from the volume produced in 1960.

Note 3 - The volume figure for the plot which was not cut in 1960 in the Bakura trial has been obtained on the basis of the basal area figure, but taking into account the observations made below concerning basal area, a value of 25 m^3/ha has been used.

Note 4 - The variability of the results of the Anara trial is due:

- to the variability of the site conditions underlined by Onochie (1961)
- to the size of the plots on which the measurements were made (0.2 ha).

CONCLUSIONS

1 - Level of volume production

Although the variability of the results obtained for the Anara trial somewhat diminishes the validity of the conclusions, it appears that volume production is barely greater in the Northern Guinea zone. Over a period of 21 years ater clear cuting a maximum production of 2.3 m^3/ha/yr can be obtained, but the average production is 0.95 m^3/ha/yr.

In the sudan zone the average is 0.9 m^3/ha/yr.

2 - The effects of fire

Complete protection against fire cannot be ensured over a long period even for an experimental area. Consequently some accidental fires occurred. It was noted that these accidental fires were more damaging than the deliberate and controlled

Table no.10

Case study no.1

Results of enumerations carried out at 20 years of age (in 1959)

	Protected from fire	Early burning			Annual late burning
		Yearly	1 yr/2	1 yr/4	
	A	B	C	D	E
Anara trial (Northern Guinea zone)					
No.of stems/ha					
Plots not felled in 1939	770	450	1035	1030	570
Plots cut at 1.3 m	770	395	860	975	775
Plots cut at ground level	960	520	875	950	285
Breakdown by diameter class					
Plots not felled in 1939					
3 cm < diameter < 9.5 cm	58%	32%	62%	72%	74%
9.5 cm < diameter < 28.5cm	8%	25%	8%	1%	
28.5cm < diameter <	1%	2%	2%		
Bakura-Tureta trial (Sudan zone)					
No. of stems/ha					
Plots not felled in 1939	1424	769	883	1315	294
Plots cut at 1.3 m	1548	967	879	1518	272
Breakdown by diameter class					
3 cm < diameter < 8 cm	73%	70%	77%	74%	73%
8 cm < diameter <16 cm	23%	26%	21%	25%	23%
16 cm < diameter <	4%	4%	2%	1%	4%

burning carried out at the appropriate time. An interval of two or four years seems more favourable than annual burning and late burning is unfavourable in every case.

3 - Effect of felling

Confining consideration to the treatments with early burning and comparing volume production over the twenty years after felling either to the initial volume (Anara trial), or to the volume on the unfelled plots (both trials), then it appears that:

- in the Sudan zone, the volume after 20 years is very slightly less than that on the unfelled plots. This would indicate that around this age the maximum value for this volume is reached, taking into account natural mortality and fires. The prolongation of such a trial would be very instructive in this regard, but one can already assume a levelling off around a volume of 30 m^3/ha (range of 25-35 m^3/ha) at 25 years with periodic controlled burning.

- in the Northern Guinea zone, in spite of the variability, it appears that for the majority of the treatments the volume in 1961 on the plots felled in 1939 was less than the initial volume and than the volume reached on the unfelled plots. This would indicate that at 20 years the stands had not yet reachjed the development of maximum volume production. A reasonable assumption would be the production of 70 m^3 at 40 years with controlled burning.

Results of basal area measurements at 20 years of age

Anara trial (Northern Guinea zone)

Since the figurs are not given in the Onochie report it has not been possible to calculate other than approximate values for the plots not felled in 1939, using the breakdown by diameter classes.

Table no.11

Unit = m^2/ha	A	B	C	D	E
Plots not felled in 1939	-	-	-	3.8	4.5

Bakura-Tureta trial (Sudan zone)

Table no.12

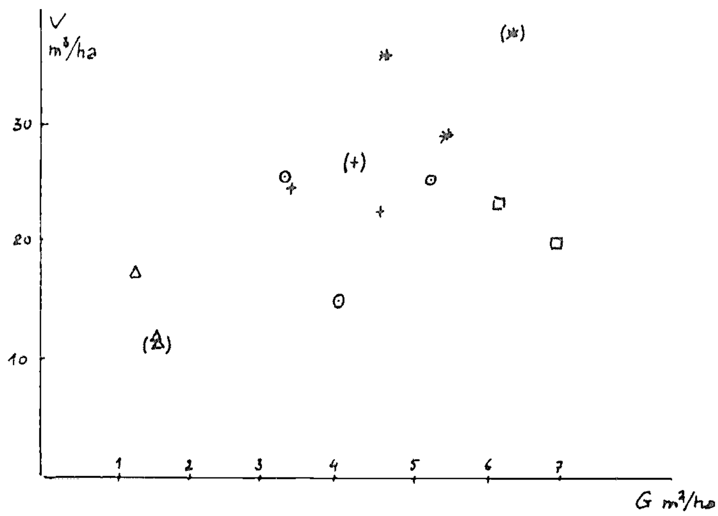
Unit = m^2/ha	A	B	C	D	E
Plots not felled in 1939	8.3	5.1	4.2	6.3	1.6
Plots cut at 1.3 m	6.2	3.2	3.4	4.7	1.2
Plots cut at ground level	7.0	3.8	4.5	5.4	1.6

These figures have been presented on a graph to show the relationship: volume x basal area. (Graph no.7)

Graph no.7

Bakura-Tureta trial (Sudan zone)

Measurements made at the age of 20 years on plots of 1.1 ha.



Treatments from 0 to 20 years (1939 - 1959)

- □ Protection from fire
- ʘ Early burning annual
- + Early burning every 2 years
- ✳ Early burning every 4 years
- Δ Late burning annual

between ( ) Plots not felled in 1939

Volume = stacked volume x 0.31

Case study no.2

CENTRAL AFRICAN REPUBLIC

A plot of 13 hectares was delimited and protected against fire in 1951.

Location: 1.5 km north-east of Bambari

Average annual rainfall: 1,550 mm

Site: Sandy to sandy-clay ferralitic soil with an indurated concretionary horizon at depth. The original vegetation was a highly impoverished tree savanna.

Sequence of operations

In 1959 a large part was burnt and in 1960 the entire plot was cut at ground level. The felling and stacking of the wood on two strips of 0.2 ha gave the following results:

Strip A 42.5 steres/ha

Strip B 45.0 steres/ha

the mean being 43.75 steres/ha.

The stacking coefficient was not measured. Adopting a value of 0.50 gives 22 m^3/ha.

In 1978, 18 years later, the vegetation which then had the form of dense bush with a maximum height of 8 to 10 m dominated by *Hymenocardia acida* was again clear cut on two strips of 0.2 ha. The two strips gave 105.5 steres/ha which, taking the same stacking coefficient of 0.50, gave a yield ov 53.75 m^3 in 18 years = 3 m^3/ha/yr.

Also in 1978, to take advantage of an area whose history was well known, a sample inventory of the whole 13 ha was undertaken. 24 square sample plots each of 25 x 25 m were systematically distributed on continuous strips. The strips were at a spacing of 200 m and the total area of the sample plots was therefore 1.5 ha.

On each sample plot:

- were measured:
  Height of trees less than 5 m tall
  Circumference of trees more than 5 m tall.

- the wood was clear felled and stacked and the stacked volume was measured. The wood was separated into small (diameter < 3 cm) and large (diameter > 3 cm) so that the same stacking coefficient could be used as had been obtained from another operation in Cameroon (case study no.4) where the same breakdown had been made:

stacking coefficient for small sizes = 0.24

" " for large sizes = 0.43

Result of the inventory: 57.2 m^3/ha

The annual yield over 18 years is therefore: 3.2 m^3/ha/yr

Also studied during this operation were V_1 (volume of the small sizes), V_2 (volume of the large sizes) and V_3 (total volume), as well as the characteristics:

x_i number of trees in the four height classes h_i

$i < h_i < i + 1 \quad i = 1$ to 4

x_5 number of trees over 5 m tall

C_5 mean circumference of these trees

It was observed:

- that the variables x_1 to x_4 could be regrouped and only had the effect of explaining V_1
- that the variable x_5 allowed V_2 and even V_3 to be evaluated
- but that the combined variable x_5C_5 gave a better estimate

These results contribute valuable methodological information.

Case study no.3

Type 2 Experiments

MALI

Complete and sample inventory of forest resources over a total area of 470 ha (1976 - 1977) - Reference: Morel (1981).

This inventory was carried out by the Forest Service in the framework of the Forest Management and Production Operation with the collaboration of the students of the I.P.R., Katibougou.

In 1976 three blocks with a total area of 50 hectares were completely enumerated and 4 hectares were clear felled.

In 1977 six blocks with a total area of 220 hectares were completely enumberated and one block of 200 hectares was sampled at an intensity of 18%; 10 hectares were clear felled.

Location and rainfall of the blocks:		Rainfall
Blocks 1 to 4	Forest of Mandingo Mountains; Bamako region	1050 mm
Blocks 5 to 8	Faya forest; Bamako region	900 mm
Block 9	Dioforongo forest; 30 km south-east of Segou	750 mm
Block 10	Forest of Bougouni Foulaboula	1200 mm

Inventory method, blocks 1 to 9:

Inventory by complete enumeration of square recording units of 0.20 ha of all stems from 2.5 cm upwards; the stems were botanically identified and grouped by 5 cm diameter classes. The results were aggregated by 5 squares (1 ha) and then by blocks. This laborious procedure enabled the coefficient of variability of the basal area to be determined:

- of the order of 37% for the individual squares (o.20 ha)

- of the order of 15% for groups of 5 squares (1 ha)

This allows verification of the known empirical law that the coefficient of variation is inversely proportional to the square root of the area of the sample plot (FAO Manual of Forest Inventory p.179).

Ratio of areas = 5 = 2.2

Invers ratio of the coefficients of variation = $\frac{37}{15}$ = 2.5

It can also be assumed that for plots of 1,000 m^2 (10 ares) the basal area would have a coefficient of variation of the order of 50%.

Inventory method, block 10:

The block of 200 hectares was divided into 18 strips, each 20 meters wide and 1,000 meters long, on which the same enumeration as above was carried out.

Volume determination

In 1976 felling was carried out on a block of 4 hectares in a forest in the Mandingo Mountains (same locality as blocks 1 to 4). These 4 hectares were divided into 40 plots each of 1,000 m^2 on which the standing crop was inventoried as described above, subsequent to which the following operations were carried out:

- extraction and conversion of dead wood
- cutting at ground level
- debranching, cross cutting
- measurement with a tape of log mid-section to obtain volume
- weighing by plot
- careful stacking by steres

The results were: $G = 6.8\ m^2/ha$
$V = 34\ m^3/ha$

- stacking coefficient = 0.50
- weight: 1 m^3 weighed 1 tonne in the green state, 800 kg 4 months later
- 1 m^2 of basal area correspond to 10 steres or 5 m^3, giving a relationship of V = 5G (V in m^3, G in m^2).

This is therefore the stand tariff established from the 40 sample plots.

Three other linear regressions were calculated:

$V = a + bD$

$V = a + bG$

$V = G(a + bD)$

The second of these gives the best results.

In 1977 a block of 10 hectares in the same forest was exploited in the same way, with the following modifications:

- solid volume not measured (stacking coefficient)

- plots of 2,000 instead of 1,000 m^2

- less accurate stacking than in 1976

Results obtained:

- 1 m^2 basal area gave 10.75 steres

Assuming that the relationship V = 5G held good, it was concluded that the 10.75 steres represented a solid volume of 5 m^3, so that the unmeasured stacking coefficient would be equal to 0.46.

On the 10 hectares the stacking coefficient of 0.46 gave:

$G = 5.84\ m^2/ha$

$V = 28.9\ m^3/ha$

This allowed several stand tariffs to be calculated, using the basal area per hectare G and the diameter of the mean tree D.

This gives:

$V = 5.9\ G - 5.5$

$V = 262\ D + 4.59\ G - 21.6$

where V is in m^3/ha, G in m^2/ha and D in m

$V = (38\ D + 1.44)\ G$ with the variables in units as above.

Table no. 13

Main results by block

Block no.	Area (ha)	N/ha	G/ha (m^2/ha)	V/ha (m^3/ha)	Assumed age years	Mean tree diameter (cm)
1	20	1.198	7,3	35	26	8,8
2	10	1.053	7.6	38	30	9,6
3	40	1.745	7,6	33	25	7,5
4	40	696	4,6	24	37	9,2
5	20	406	6,5	40	60	12,1
6	40	541	6,5	41	42	12,4
7	40	593	5,8	34,5	50	11,2
8	40	814	6,7	36	42	10,2
9	20	1.530	4,8	17	32	6,3
10	200	810	8,3	46,5	32	11,4

Stacking coefficient used equals 0.46

Table no. 14

Results by climatic zone (means weighted by area of blocks)

Block no.	Area (ha)	N/ha	G/ha (m^3/ha)	V/ha (m^3/ha)	Rainfall (mm)
1 - 4	110	1.201	6,5	30,5	1.050
5 - 8	140	614	6,4	37,5	900
9	20	1.530	4,8	17,0	750
10	200	810	8,3	46,5	1.200

Case study no. 4

CAMEROON

1 - Estimation of fuelwood yield of two blocks with a total area of 3,661 ha.

Location: East of Garoua, Bibemi region (Cameroon)

Reference: Bergonzini (1981)

Average rainfall: 1,000 mm

Vegetation type: formerly cultivated tree savanna very degraded by fire.

Study carried out in 1979, consisting of a sample inventory. Plots of 50 x 25 m were laid out in continuous strips 1,000 m apart. The total plot area was 91.5 ha.

Enumeration: the identified woody species were enumerated by one meter height classes up to 5 m; circumference and height were measured for those above 5 m. The species were broken down into three classes in accordance with their suitability for fuelwood.

Volume: twenty five plots were selected to establish volume tariffs. On each plot all the stems were felled and cut into 1 m lengths. These were then classified as large if the diameter at the larger end exceeded 5 cm and otherwise as small. This allowed separate stacking coefficients to be calculated: 0.43 for the large sizeds and 0.24 for the small.

The volume tariffs equal stand tariffs due to the following characteristics:

x_i number of stems in the different 1 m height classes up to 5 m

x_5 number of stems over 5 m

C mean circumference of trees over 5 m

H mean height of trees over 5 m

$V = f(x_1, x_2, x_3, x_4, x_5, C, H)$

The regressions obtained were not very good, but considering the magnitude of the sub-sample measured for volume (65 m^3) the overall result can be considered satisfactory.

The results were: Volume per hectare = 20.7 m^3
No. of stems per hectare = 928

Table no.15

Detailed results by classes

Unit: m^3/ha	good fuelwood	moderate fuelwood	poor fuelwood
Large sizes	9.96	2.38	4.64
Small sizes	2.47	0.90	0.32
Total	12.43	3.28	4.96

Mean (weighted) stacking coefficient = 0.40

2 - Experimental felling on 2 blocks, each of 96 hectares.

Location: Ndonga forest area, between Adoumri and Bibemi

Average rainfall: 1,000 mm

Reference: Meurillon (1980) and Meurillon (1982)

Stand physiognomy: tree savanna highly degraded by fire

Felling carried out in 1979 - 1980 on 24 plots of 4 hectares.

Cutting at three heights: 1 m, 0.3 m and ground level, the same procedure started again in 1981 on the same area of 96 ha.

All the wood cut was stacked separately on each plot. The stacking coefficient was not measured. It was taken to be the same as that obtained for the study carried out in 1979, i.e. 0.40.

Overall results	1st zone	12.6 m^3/ha
for volume	2nd zone	15.5 m^3/ha

Basal area 1st zone 3.5 m^2/ha

Table no.16

Number of stems/ha by height classes

	<2m	2-3m	3-4m	4-5m	5-6m	6-7m	7-8m	8-9m	9-10m	>10m	Total
1st zone	9	18	26	24	20	15	11	8	3	3	137
2nd zone	2	15	40	57	44	29	22	13	7	5	236

<u>TANZANIA</u>

Inventory of fuelwood resources.

Location: 6 areas in the arid and semi-arid region of Tanzania: Arusha, Nwanza, Shinyanga, Tabora, Singida, Dudora.

Reference: Kaale (1982)

The objective of the inventory was to evaluate the fuelwood resources available for 14 villages in the six areas concerned. It was carried out between March and May 1982.

Sampling was carried out for each village in the following manner. After stratification into 5 categories from observations which were mapped, each stratum was sampled by a transect which originated at the centre of the village. 16 equally spaced transects were drawn on the map and that which most nearly passed through the centre of a stratum was sampled. The transects extended to the village boundary or for 10 km, whichever was shorter.

Circular sample plots of 400 m^2 were established every 500 m and the enumeration was done by three stem categories:

1 - over 15 cm diameter with diameter measurement

2 - 5 to 15 cm diameter with diameter measurement

3 - less than 5 cm diameter

For categories 2 and 3 volume tables were prepared from a separate sample for each stratum. For category 1 an existing volume table was used.

Table no.18

Results for the 4 strata with trees

	Volume in m^3/ha			TOTAL
	Category(1)	Category(2)	Category(3)	
Plantations	15,1	13,3	2,0	30,4
Closed forest	95,2	8,1	2,5	105,8
Miombo woodland	17,4	5,1	2,3	24,8
Tree savanna	7,6	2,4	2,3	12,3

The conclusions which can be drawn from this study are:

- practical sampling method because simple to execute and directly applicable to the objective being sought.

- low values for volume/ha compared to those obtained in the savannas of this type in Tanzania (cf. Temu study).

Case study no.6

NIGERIA

Inventory of 275,000 hectares in the Derived Savanna Zone.

Location: Jebba

Reference: Undertaken by a paper company and cited in Abayomi (1982).

The volume was evaluated for sizes with an end diameter down to 10 cm and ranged from 20 to 50 m^3/ha.

Case study no.7

BURKINA FASO

Evaluation of the woody vegetation and identification of forested areas suitable for production management.

Reference: Cameratti (1982)

This inventory covered the entire extent of Burkina Faso and was implemented according to a two-stage sampling design:

- 71 randomly selected primary sampling units
- 11 secondary units (0.25 ha plots) within each primary unit

Interpretation of Landsat images for the entire country enabled a classification compatible with that arrived at from ground survey to be set up. Seven classes were distinguished but were regrouped into 3 principal types:

- shrub savanna and burnt areas	42 %
- tree savanna and woodland	19%
- fallow and cultivation	36%

A map at 1/200,00 was prepared and used to calculate the area of these formations.

Volume tariffs

Due to its destructive nature the stand tariff method was avoided. Nevertheless 450 trees were felled and measured (total volume of stems plus branches) to calculate a two entry tariff:

$V = 0.074 + 0.72\ D^2H$ V in m^3, D and H in m

This two entry tariff was applied by calculating a separate regression for shrub savanna and tree savanna of the form:

$H = a + bD + cD^2$

Classification by utilisation classes

All the trees enumerated (from 7.5 cm diameter upwards) were classified according to their potential utilisation:

1 - saw timber diameter over 40 cm

2 - saw timber diameter under 40 cm

3 - pole wood

4 - fuelwood

5 - fruit production

Since the wood from a given tree can fall into several utilisation classes a tree assigned to a potential utilisation class will in practice contribute to several actual utilisation classes.

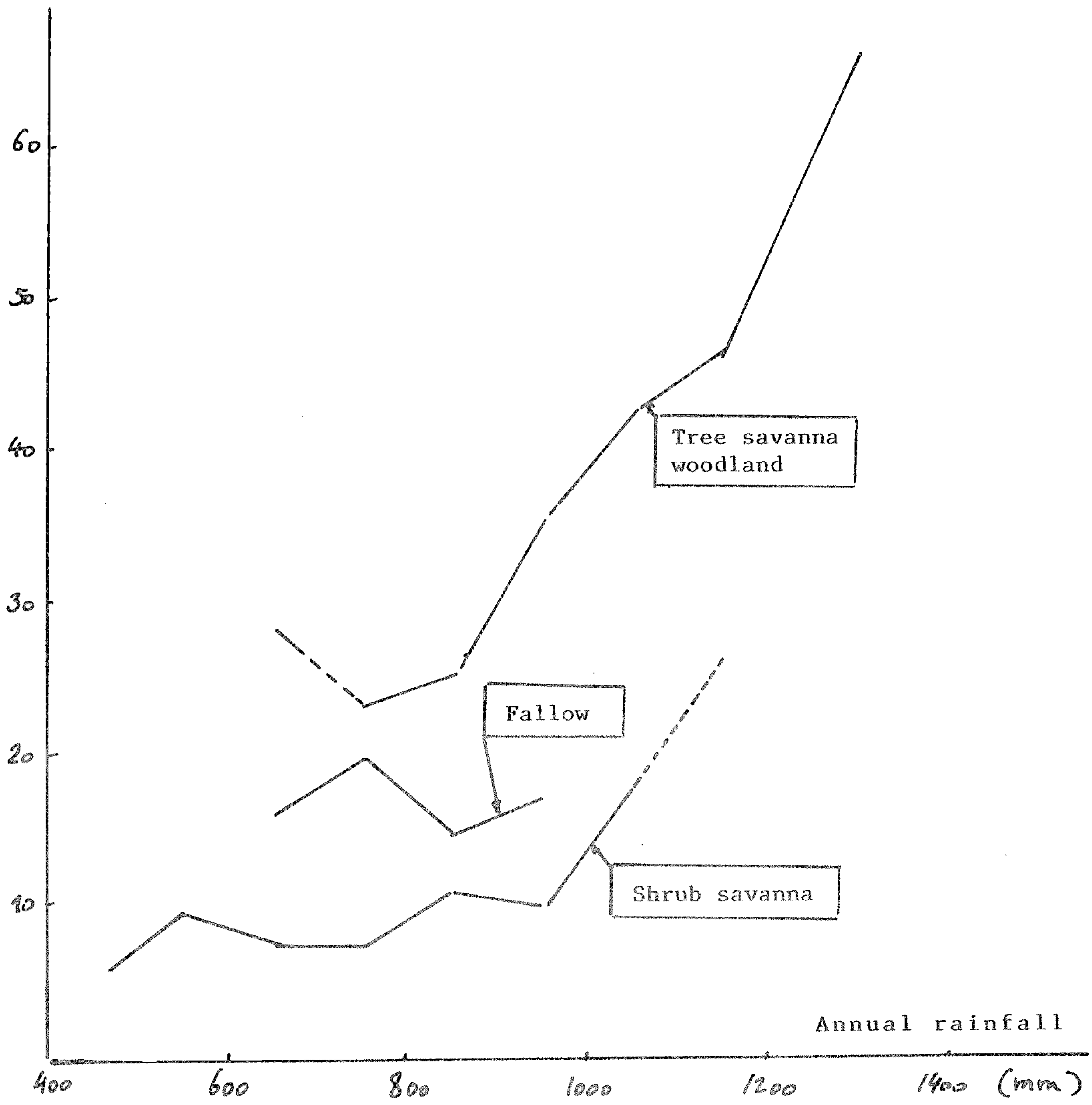
A conversion system to distribute volume by potential utilisation class among actual utilisation classes was therefore established and is shown in the following table:

Table no.19

Breakdown of 100 m^3 among actual utilisation classes

Actual utilisation classes

Pot.utilstn. class of tree	1	2	3	4	5	Total
1	31		27	42		100
2		35	17	48		100
3		4	46	50		100
4				100		100
5					100	100

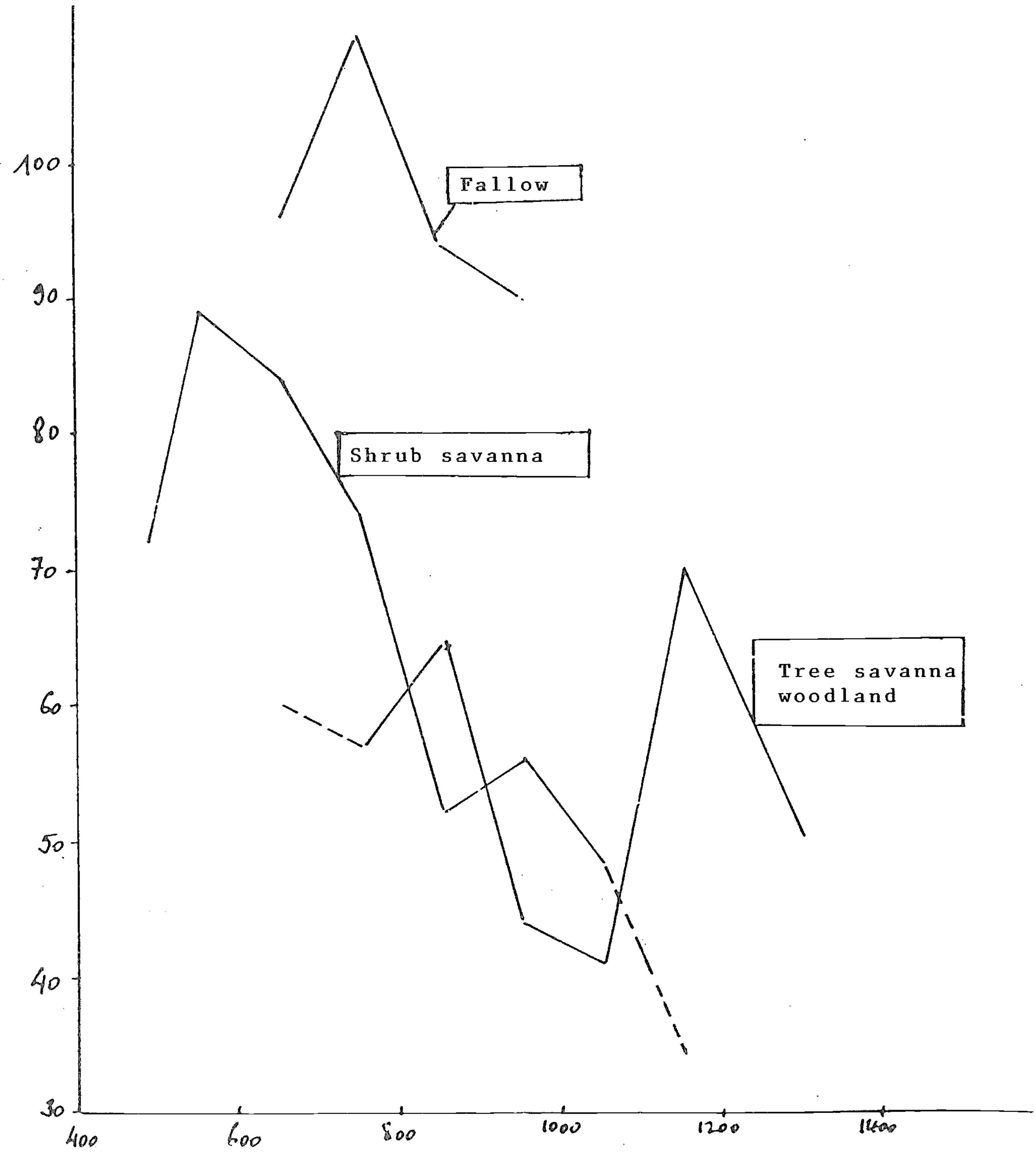


Graph no. 8

Inventory in Burkina Faso (Case Study no. 7)

Volume per hectare as a function of rainfall and vegetation type

N.B. Only values based on at least 20 sample plots are shown with the exception of the 2 extrapolations (dashed lines)



Graph no. 9

Inventory in Burkina Faso (Case Study no. 7)
Coefficients of variation of volume on 0.25 ha plots as a function of annual rainfall and vegetation type

N.B. Only values based on at least 20 sample plots are shown with the exception of the two extrapolations (dashed lines)

Results

Only those of sufficiently general relevance have been shown on graph no.8 - volume per hectare and graph no.9 - coefficient of variation, both as a function of rainfall.

Increment

No measurement of increment was carried out in the context of the inventory itself. Such measurements were made and analysed by Lillelund (1981) and led to increment classes based on rainfall and on the type of formation.

Case study no.8

Type 3 Experiments

BURKINA FASO

Studies of productivity of natural savannas with stands of known age. Reference: C.T.F.T. annual reports on Burkina Faso (Haute-Volta).

These studies have been conducted since 1963 in two different climatic zones:

- Sudan zone of southern Burkina Faso. Area of Dinderesso and Toumousseni. Rainfall 1200 mm.

- Sudano-sahelian zone of northern Burkina Faso. Area of Gonse and Wayen. Rainfall 850 to 900 mm.

In 1963 experiment areas were set up consisting of 7 plots of 0.5 ha which were clear felled and stacked after a complete inventory of all the vegetation on 1/5 of each plot had been made. The objective of these areas, which were established simultaneously at Dinderesso, Toumousseni and Gonse, was to study the effect of early burning. This was not pursued, but from the known age of the original stands and the stacked volume of the plots it was possible to obtain accurate volume figures:

Table no.20

Results

	N/ha (d>0)	N/ha (d>4cm)	G/ha (m^2/ha)	V/ha (m^3/ha)	Age
DINDERESSO	1.090	280	7,7	32,1	23
TOUMOUSSENI	-	-	-	31,2	25
GONSE	568	274	6,2	26,2	25

This table separates the number of stems in all diameter classes (d>0) and the number of stems with a diameter above 4 cm (d>4 cm).

The stacking coefficient was not measured and taken as 0.5.

In 1978 an experimental plot of 1 ha was established at Gonse and at Wayen to investigate the regeneration of the savanna with complete protection after clear cutting.

In 1982 these two plots were measured again. For the estimation of volume, measurements were taken at 1 m and at 2 m on individual stems and the volume calculated as for conical sections. The stems in bushy clumps were classified using a grid; a volume was assinged to each class derived from this.

Table no.21

Results

	V/ha (m^3/ha)	Increment (m^3/ha/yr)
Gonse	27.2	1.4
Wayen	26.6	1.1

The stacking coefficient was not measured and taken as 0.5.

Case study no.9

ZAIRE

Study of age and diameter increment in a Miombo woodland.

Location: near Lubumbashi.

Reference: Malaisse (1978)

The study was carried out in the context of the International Biological Programme. The plot studied had an area of 0.125 ha. The basal area was 13.3 m^2/ha with an increment of 0.30 m^2/ha/yr. But these figures, obtained on such a small area for such a variable formation, must be treated with reserve.

Case study no.10

MALAWI

Study of a savanna 21 years after clear cutting.

Location: Bunda

No. of stems/ha - 2,192 (minimum diameter not stated)

Basal area: 11.9 m^2/ha

Mean annual increment over 21 years: 0.57 m^2/ha/yr

Volume per hectare: 73.5 m^3/ha

The stacking coefficient which was used (0.60) was not measured. It is considered somewhat high when compared to the usual values and the value for volume should therefore be accepted with some reservation.

Study of different savanna types

Location: Mua Livulezi

Reference:

Different types of savanna were investigated and measured. The figures for basal area range from 4.3 to 19 m^2/ha and only serve to underline the variability of the conditions encountered without providing any elements to assess their general significance. The figures for increment over 11 years were not given because some measurements indicated a reduction in basal area during this interval. This example underlines the need for the greatest care in the periodic inventories for such experimental investigations.

Case study no.11

NIGERIA

Study of a savanna in the southern Guinea zone

Location: Mokwa forest reserve

Reference: Allan and Akwada (1964) cited in Abayomi (1982)

The study was conducted on an area of 1.8 ha. Stems above a minimum diameter of 5 cm were enumerated.

Number of stems per hectare: 750

Basal area per hectare: 12.1 m^2/ha

The area consisted of dense savanna woodland verging on woodland. There are no figures for volume.

Study of a savanna in the northern Guinea zone

Location: Afaka forest reserve near Kaduna

Reference: Kemp (1963) cited in Jackson and Ojo (1971)

The study was conducted on 71 plots of 0.3 ha.

Measurements of stems of 1.6 cm diameter and above:

No. of stems/ha above 10 cm diameter = 425

No. of stems/ha above 6 m height = 125

Basal area/ha (of all stems enumerated) = 7.1 m^2/ha

Volume (stacking coefficient not stated)= 21.7 m^3/ha

Basal area increment over 4 years = 0.24 m^2/ha/yr

Jackson and Ojo (1971) proposed an age of 50 years to calculate a mean annual yield over 50 years of 0.43 m^3/ha/yr. This figure is arguable as there would have been losses from mortality and fire during these 50 years.

Case study no.12

ZAMBIA

Study of a Miombo woodland

Location: Ndola

Reference: Endean (1968)

The investigation was carried out in 1936 with the following treatments:

1 - control without treatment

2 - felling of all trees except those yielding saw timber

3 - felling of trees yielding saw timber only

4 - thinning of dominant trees leaving understorey untouched

Measurements made on the control plot on trees of 5 cm diameter and upwards gave:

- Basal area = 16.1 m^2/ha

- Mean annual increment for a period of 20 years = 0.15 m^2/ha/yr

On the other plots volume was distributed as follows at the end of 20 years: (the stacking coefficient applied was probably 0.60 although it was not measured).

Table no.22

Saw timber volume (m^3/ha)	Fuelwood volume (m^3/ha)	Total volume (m^3/ha)
36.3	143.4	179.7
25.2	35.9	61.1
38.6	63.3	101.9

Although these figures are subject to some reservations stemming from the stacking coefficient, they show that this type of woodland can be considered as productive.

Case study no.13

GHANA

Study of a savanna

Location: Mole game reserve

Reference: Lawson et al. (1968)

Site type: Northern Guinea zone

The study was conducted on a series of plots distributed along a topographic gradient from the top of a hill to the floor of a valley.

The vegetation consisted of Northern Guinea zone species (Isoberlinia doka, Terminalia avicennioides).

The six plots were of 0.25 ha each.

Table no.23

Results

	N/ha	G/ha (m^2/ha)
Hill top	840	4.9
Mid slope	1,042	9.4
Valley floor	496	9.6

Case study no.14

NIGERIA

Study of a savanna woodland.

Location: Olokomeji forest reserve

Reference: Hopkins (1962)

A comparative study was made of two types of vegetation present in the Olokomeji Forest Reserve.

- Semi-deciduous forest
- Savanna woodland: successionary stage after fire

The two areas were previously cultivated.

Two plots of 0.25 ha were established at each site, 5.5 km apart.

The following table summarises the results.

Table no.24

	Forest		Savanna	
	N/ha	G/ha (m^2/ha)	N/ha	G/ha (m^2/ha)
Trees > 10 m high	424	25	48	2,5
Trees between 5 and 10 m	196	2,1	260	4,4
Shrubs < 5 m	3.520	1,5	2.368	0,8
TOTAL	4.140	28,6	2.924	7,7

It should be noted that in the forest only shrubs over 1.5 m were counted, whereas in the savanna all the stems were counted.

It was noted that the forest was floristically richer.

Case study no.15

BRAZIL

Study of Cerrado vegetation.

Location: the very extensive area over which this vegetation occurs, the bulk of which is found in Brazil.

Reference: Carneiro (1982)

This study contributes information on the structure and composition of the different types of Cerrado with distribution curves for height and diameter.

Two volume tables are presented, based on basal area and a stcking coefficient of 0.7:

$V = 6.3\ G$ or $V = 8\ G - 12$ V in m^3/ha, G in m^2/ha

but the details on the basis of which these were established are not given.

Case study no.16

NICARAGUA

Study on fuelwood supply for the area of Las Maderas.

Location: area of Las Maderas in the vicinity of the town of Managua, covering 68,000 hectares.

Latitude: 12° North

Reference: Park, Newman and Ford 81982)

Site type: Rainfall of 1000 mm (850 - 1150)
Extensive area of range in the middle of a savanna woodland
Clay soils of volcanic origin considered unsuitable for agricultural production over 90% of the area.

The area is subjected to intensive exploitation for fuelwood to supply the city of Managua (pop. 650,000).

The study was made at two sites:

1 - savanna woodland (La Concha)

2 - tree savanna (San Antonio)

with three plots of 500 m^2 at each site.

Table no.25

Measurements on stems of 3 cm diameter and above; enumeration of smaller stems

Site	N/ha	G/ha (m^2/ha)	V/ha (m^3/ha)
1 - La Concha	1.880-3.300	6,7 - 10	50
2 - San Antonio	940-1.120	5,9 - 8	-

What is surprising in this study is the felling rotation which resulted in the removal of half the stems every three years. It was observed that growth fell off considerably towards the age of 10 years and that cutting had therefore to be done fairly early: "the mean age of the dry forest formations in the area of Las Maderas could be less than 6 years."

Under these conditions the yield figure of 8.5 m^3/ha/yr given by the author is rather high.

Here again the results must be treated with some reservation as the design of the study has some weaknesses:

- small area and number of plots
- no measurement of volume by felling and stacking
- absence of repeated observations to follow the development of a plot

Case study no.17

INDIA

Data taken from Singh (1980)

Dry forest and savanna in India cover 29 million hectares, which represents 38% of the total forest area. This entire area is managed and administered by the Forest Service.

The figures given below are therefore mean values obtained from very large areas and do not represent results from experimental plots.

Table no.26

Bioclimatic and vegetation types

	Rainfall (mm)	Altitude (m)	Forest type
Khandwa North	987	300-750	Dry & very dry Tectona grandis forest Southern mixed dry deciduous forest
Bharatpur	650	400-700	Northern mixed dry deciduous forest Anogeissus pendula forest Desertic thorn-forest
Dudhi	1,000	215-400	Shorea robusta forest Riparian forest Northern mixed dry forest

Table no.27

Figures for mean annual yield (m^3/ha/yr)

Division	Area ('000 ha)	Period	Timber	Fuel wood	Char-coal	Total
KHANDWA-North	224	1956-1964	0,095	2,230		2,325
BHARATPUR	244	1976-1978		0,041	0,005	0,046
DUDHI	143	1965-1972	0,081	0,136	0,241	0,458
DHULIA	132		0,062	0,029	0,007	0,098
RAJPIPLA	170	1959-1970	0,111	0,138	0,488	0,737
CENTRAL-CHANDA	77	1960-1964	0,025	0,322		0,347

It may be noted that due to the large extent of the areas, the figures obtained are low in comparison to those from small experimental areas. Furthermore the total volume of fuelwood is not recorded.

Other figures for yield from this report show that there are major differences according to the type of operation carried out.

Table no.28

Yield in the Tiruchirappalli Division	
Area being re-established	2.68 t/ha
Area exploited for fuelwood	12.94 t/ha
Area planted with Casuarina	38.86 t/ha

Case study no.18

INDIA

Dudhi Forest Division

Reference: Singh (1980)

Area = 143,063 hectares

Description

The forest contains abundant Shorea robusta; situated in the hill zone at an altitude ranging from 215 to 400 m. Rainfall is 1,000 mm with a long and very dry summer (42.6^{o} mean maximum for May).

Management

The greater part of the forest is treated in accordance with the standard procedure of marking standards and cutting regrowth; the rotation is 30 years; the following special measures are applied:

a) 15 species must be systematically reserved for one reason or another:

- fruit production (mango .....)
- bird nesting (Dicus and Bridelia)
- gum production (Sterculia urens)
- 5 rare species (Teak, Gomelmier, Gmelina, Dalbergia sissoo)

The latter are cut when above 40 cm diameter, the remainder from 30 cm diameter.

b) Patches of bamboo are preserved

c) 6 species are marked for reservation as standards at an early stage, when less than 10 cm in diameter

d) 25 to 50 stems per hectare of these 6 species are reserved when between 10 and 18 cm diameter.

Table no.29

Inventory of stands

	No.of stems/ha by diameter class							Basal
	<10cm	10-20	20-30	30-40	40-50	>50cm	Total	area (m^2/ha)
Shorea robust	14,2	16,5	5,6	0,7	0,1		37,1	0,69
Species of economic value	77,6	70,9	19,5	5,9	2,4	1,1	177,4	3,58
Other species	35,8	16,5	4,9	1,6	0,6	0,4	59,8	0,95
All species	127,6	103,9	30,0	8,2	3,1	1,5	274,3	5,22

Table no.30

Development of stands between 1964 and 1972

	Number of stems/ha over 10 cm	
	1964	1972
Shorea robusta	33,5	22,2
Acacia catechu	16,7	18,5
Boswellia serrata	18,6	14,0
Lannea coromandelica	5,3	4,6
Other species	149,8	97,9
Total	223,9	157,2

This degradation is explained by the exploitation following the installation of industrial complexes in the area.

TABLE SUMMARISING THE RESULTS OF THE FOREGOING STUDIES

LOCALITY	REFERENCE	TYPE OF SAVANNA	Rain fall (mm)	Area (ha)	Age (années)	Stems/ ha	Min. diam. (cm)	Ratio vol/ b.a. (m)	Basal area (m^2/ha)	Solid volume (m^3/ha)	Stacking coefficient	A Increments Basal area (m^2/ha/yr)	A Increments Volume (m^3/ha/yr)	Years increment measured
CAMEROON Ndonga	MEURILLON 1980, 1982	Tree savanna, very degraded inventory and felling inventory and felling	1 000	96 96		142 242	6 6	3,7	3,50	12,6 15,5	0,40 0,40			
CAMEROON Bibemi, east of Garoua	BERGONZINI 1981	Tree savanna, very degraded sampling inventory	1 000	61/2830 18/830		942 880				21,0 19,5	0,40 0,40			
BURKINA FASO Dinderesso	C.T.F.T.-B.F. Annual reports	Sudan zone	1 200	3,5	23	5 440	0	4,2	7,67	32,1	0,50		1,40	23
BURKINA FASO Toumousseni	C.T.F.T.-B.F. Annual reports	Sudan zone	1 200	3,5						31,2	0,50		1,25	25
BURKINA FASO Conse	C.T.F.T.-B.F. Annual reports	Sudano-sahelian zone	900	3,5 1,0		2 840	0		6,20	26,1 21,4	0,50 0,50		1,04 1,4	25 4
BURKINA FASO Wayen	C.T.F.T.-B.F. Annual reports	Sudano-sahelian zone	850	1,0		2 309				26,5	0,50		1,1	4
C.A.R. Bambari	Ministère des E. et F. - R.C.A. 1980	tree savanna initial situation 18 years after felling	1 550	0,4/13 0,4/13 1,5/13		6 000	0			22,0 53,7 57,2	0,50 0,50 0,50		3,0 3,2	18 18
C.A.R. Bambari	Nouvelet 1983	very degraded tree savanna, clear cut	1 550	4,64		2 238	0			9,4	0,56			
MALI	Morel in	savanna in various conditions												
Forest of Mandingo Mts.	Clement 1982		1 050	110		1 201			6,5	30,5	0,46			
Forest of La Faya			900	140		614			6,4	37,5	0,46			
Forest of Dioforongo			750	20		1 530			4,8	17,0	0,46			
Forest of Bougouni-Foulaboula			1 200	36/200		810			8,3	46,5	0,46			
MALI Forest of Mandingo Mts.	Morel in Clement 1982	clear cut	1 050	4 10				5 0 4,9	6,80 5,84	34,0 28,9	0,50 0,46			

Area= 1.5/13 signifies that a study was conducted on an area of 13 ha with a sampling area of 11.5 ha.

LOCALITY	REFERENCE	TYPE OF SAVANNA	Rain fall (mm)	Area (ha)	Age (yrs.)	Stems/ ha	Min. diam. (cm)	Ratio vol/ b.a. (m)	Basal area (m^2/ha)	Solid volume (m^3/ha)	Stacking coefficient	A Increments Basal area (m^2/ha/ yr)	A Increments Volume (m^3/ha/ yr)	Years increment measured
NIGERIA Anara	ONOCHIE 1961	Northern Guinea zone 1st clear cut 2nd clear cut (21 years later) control not cut	1 250	2,0 2,0 0,8	21					39,0 26,1 50,0	0,31 0,31 0,31		1,24	21
NIGERIA Bakura-Tureta	ONOCHIE 1964	Sudan zone control not cut 21 years after felling	730	5,5 11,0	21					25,1 22,0	0,31 0,31		1,05	21
NIGERIA Nimbia	JACKSON & OJO 1971	Derived savanna								19,6				
ZAMBIE Ndola	ENDEAN 1968	Miombo woodland control various silvicultural treatments			20 20 20				16,1 - - -	- 179,7 61,1 101,9			9,0 3,1 5,1	20 20 20
MALAWI Bunda	ABAYOMI, J.O. 1982	savanna woodland 21 years after felling				2 192		6,2	11,9	73,5	0,60	0,57	3,5	21
NIGERIA Afaka	KEMP 1963	Northern Guinea zone savanna woodland		2,1 21,3	50	425	9,7		7,1	9,1-36,4		0,24		
NIGERIA Mokwa	ALLAN & AKWADA 1974	Southern Guinea zone savanna woodland		1,8/ 16,4		750	5		12,1					
NIGERIA Olokemeji	HOPKINS 1962	degraded savanna woodland		0,25		2 924			7,7					
GHANA Mole Game Reserve	LAWSON & al 1968	savanna woodland slope summit thalweg		1,00 0,25 0,25		1 042 840 496	0 0 0		9,4 4,9 9,6					
ZAIRE I.B.P. Research Site	MALAISSE 1978	Miombo woodland		0,125					13,3			0,39		4
AFRIQUE DU SUD Nylsvley Nature Res.	GRUNOW & al.	savane arborée							6 à 12					
MALAWI Mua Livuleli	ABAYOMI, J.O. 1982	bamboo savanna thorny shrub savanna savanna woodland with bamboo savanna woodland savanna woodland					9,5		15,9 6,7 11,2 19,0 15,0 4,3			0,20 - 0,25 - 0,21 0,47		11 - 11 - 11 11

Area = 1.5/13 signifies that a study was conducted on an area of 13 ha with a sampling area of 11.5 ha.

LOCALITY	REFERENCE	TYPE OF SAVANNA	Rain fall (mm)	Area (ha)	Age (yrs)	Stems/ha	Min. diam. (cm)	Ratio vol/b.a. (m)	Basal area (m^2/ha)	Solid volume (m^3/ha)	Stacking coefficient	A Increments: Basal area (m^2/ha/yr)	A Increments: Volume (m^3/ha/yr)	Years increment measured
TANZANIA Areas: Arusha, Nwanza, Tabora Shinyanga, Singida, Dudora	KAALE 1982	arid and semi-arid zone Miombo woodland tree savanna forest								 24,8 12,3 105,8				
BRAZIL	CARNEIRO 1982	cerrados						6,3			0,70			
NICARAGUA Las Maderas	PARK & al. 1982	savanna woodland tree savanna	850 1 150			1880-3300 940-1120			6,7-100 5,9-8,0	50,0			8,5	
TANZANIA Tabora area ora	TEMU 1981	Miombo woodland		2 080		292	5	7,1	11,4	81,0				
INDIA Dhulia Div. Hill Block	SINGH, S.P. 1982	dry forest situation in 1921 .... situation in 1960				 241 246	 10 10		 10,8 8,1					
INDIA Dhulia Div. Deomogra	SINGH, S.P. 1982	situation in 1935 .... situation in 1960				93 251	10 10		3,3 8,9					
Godavari	SINGH, S.P. 1982	improvement fellings coppice cutting				39-56 332	10 10	6,5	4,1 12,5	26,6				
Rajpipla	SINGH, S.P. 1982	coppice cutting protection				223 133	10 10		7,6 6,3					
Central Chanda Dudhi	SINGH, S.P. 1982	treated areas untreated areas				467 243	10 10		13,3 11,9					
DUDHI	SINGH, S.P. 1982	dry forest with Shorea robusta	1 000			146,7	10		5,2					

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M-35/T0253E/1/12.89/1800
ISBN 92-5-102184-8