COURSE CODE:	FWM 313
COURSE TITLE:	FOREST MENSURATION AND INVENTORY
NUMBER OF UNITS:	3 UNITS
COURSE DURATION:	4 Hours per week

COURSE DETAILS:

Course Coordinator: Dr. M.F. Adekunle *B.For, MF, PhD*

Email: **adekunlefm@yahoo.com**

Office Location: COLERM
Other Lecturers: Mr. Oladoye and Dr. Adetogun

COURSE CONTENT:

Measurement in forest; growth; increment; yield; purpose of measurement in forest (valuation, management and research); measurement systems; theory of tree measurements (diameter, height, crown measures); instruments for measuring diameter and height; instruments for measuring tree heights; direct method; indirect method; taper and form; stand measurement; representative stand height; crown closure; complete and incomplete canopy; introduction to volume estimation; measurements of volume estimation; methods of volume estimation; expression of form; volume table method of volume estimation; requirements of a good volume table method.

COURSE REQUIREMENTS:

This is a core course and compulsory for forestry option students. In view of this, students are expected to participate in all the course activities and have minimum of 75% attendance to be able to write the final examination.

READING LIST:

Forest Mensuration by Husch, Miller & Boers (1962) (Ronald Press).

2. Forest Inventory vols. I & II by Leotsch, Zohrer, & Haller (1973) (BLU – Verslag).
3. M. B. Shrivastava 2004. Introduction to Forestry. Department of Forestry The Papua New Guinea University of Technology Lae. Vikas Publishing House PVT Ltd 576, Masjid Road, Jangpura, New Delhi – 110 014
4. Pankaj, P and Bhardwaj, S.D. (2005). Handbook of Practical Forestry. Published by Agrobios (India), Agro House, Chopasani road, Jodhpur.

LECTURE NOTES

MEASUREMENT IN FOREST

What is measuration?

It is defined as the act, process, art or science of measuring; that branch of mathematics concerned with measures of approximate of lengths of lines, areas of surfaces and volumes of solids.

Other Definitions:

i) Bruce and Schumacher (1950), defines forest measuration as the determination of diameters lengths or volume either of standing timer or product got there from such as sawn logs and the determination of rates of growth.

ii) Graves (1906), defines it as the determination of volume of logs, trees, and stands and with the study of increment and yield.

iii) In 1965, Iloessals defined measuration as the inclusion of forest land areas, the measurement and the estimation of volume of trees, stands and forests. The investigation of development of tree and stand as well as the determination of the production of forest.

iv) Husch (1972), defines forest measuration as being one of the main stores in the foundation forestry. Whether one considers forest measuration to deal only with the determination of the volume of logs, tree and stands and the study of growth and yield or in a wider more modern context, hits main objective is to provide quantified information for intelligent decision making.

GROWTH:- It is a phenomenon of increase in size or general process of change with time.

INCREMENT:- A quantitative increase in size which results the penomenon of growth.

YIELD:- This refers to the accumulated increment, the aggregation of material useful for some purpose at a particular time.

PURPOSE OF MEASUREMENT IN FOREST

1. **VALUATION:** The more intensive the utilization the nearer will the out-turn approaches the total volume of the tree. Measurement will prevent cheating between the seller a buyer and consequently a standard would set.

2. **MANAGEMENT:** Measurement is undertaken to meet a continuous demand, the wood producer is interested in the extent of the forest and also in the quantity of the material standing in the forest.

    2. **RESEARCH:** Measurement is adopted to meet future demand in quantity and quality of the forest product i.e. Research is conducted into the system of Silviculture and management which mean result in higher rate of production or in maximum production of the desired material product.

MEASUREMENT SYSTEMS

There are 2 most important systems of measurement i.e.
(i) British or Imperial and (ii) Metric systems.

Conversion of Measurement Units

a) Conversion factors for linear measures

1 inch = 2.54cm	1 cm = 0.3937 inch
1 foot = 30.48cm	1 m = 39.38 inches
1 yard = 91.44cm	1 m = 3.2808 feet
1 mile = 1.6093km	1 m = 1.0936 yards
	1 km = 0.6214 mile

b) Conversion factors for square measures

1 sq. inch = 6.4516cm^2 1cm^2 = 0.1550 sq. in.
1 sq. foot = 0.0929m^2 1m^2 = 10.764 sq. ft.
1 acre = 0.40469ha 1 ha = 2.471 acres
1 sq. mile = 2.59 km^2 1km^2 = 247.1 acres
1km^2 = 0.3861 sq. mile

c) Conversion factors for cubic measures

1 cu. m = 16.387cm^3 1cm^3 = 0.610 cu. in.
1 cu. ft = 0.2832m^3 1m^3 = 35.314 cu. ft.
1 cu. yd. = 0.764553 1m3 = 1.308 cu. yd

d) Conversion factors for weight measures

1 oz = 28.35g 1 g = 0.0252 oz
1 ib = 453.60g 1 kg = 2.205 lbe.
1 qtr = 12.701 kg
1 cwt = 50.802 kg

THEORY OF TREE MEASUREMENTS

1. DIAMETER:

The diameter of a tree normally decreases from the base to the tip. For purpose of standardization the point of measurement of tree diameter has been kept at breast height practice though the exact point of breast height varies from 1.3m (51 inches) in countries with metric system to 4.5 feet (54 inches) in countries using imperial system such as Canada, U.S.A. Malaya, Ghana, Sierra Leone etc.

General Guide to Nigeria Practice in Breast Height Measurement

a) On sloppy ground, measure breast height from the ground on the uphill side of the tree.
b) Where tree develops a mound of soil and litter around the base, displace this if it is very loose otherwise measure from the highest point.
c) If the tree folks below breast height, treat as 2 stems but if the branching is above breast height treat as 1 stem.
d) Remove any material that is foreign at breast height point i.e. the material which is not an actual part of the tree such as vines, chimbers, loose bark etc.
e) If flanges (plank-like buttresses) develops up to and beyond breast height point, take the diameter or girth measurement where the

irregular feature appears to match with the main bole and record the height at which the measurement is taken.

f) If a bump develops at breast height or it is otherwise unrepresentative, measure 2 points subjectively equal distant above and below breast height and find the mean of the two. If there is a tree in which case where the bump develops to as near as possible to the surface of the soil, then we apply the same as if there are flanges.

Basal Area

The cross sectional area at breast height of a tree is called Basal Area and it is usually expressed in square units such as square feet, square metres, square inches and square centimeters.

Basal area is calculated from $\pi D^2/4$ when the Diameter is known of $g^2/4$ when girth is given while π is a constant 22/7 of 3.14.

2. **HEIGHT**

Tree height can be distinguished into the following categories:

i) Total Height: Which is the vertical distance between ground level and tip of the tree.

ii) Bole Height: This is the distance between ground level and crow point. The Crown Point is the position of the first crown forming living or dead branch. Bole height expresses the height of the clear main stem of the tree.

iii) Merchantable Height: It is the distance between ground level and the terminal point of the last usable portion of the tree (19cm dbh is adoptable). The upper terminal is dependent on a number of conditions some of which are:

(a) Purpose of which the tree is being felled.
(b) Physical appearance of the stem.

iv) Stump Height: This is the distance from ground level to the basal position of the main stem when the tree is cut.

3. **CROWN MEASURES**

Diameter directly reflects the size of the life functioning crown. The number of surviving trees is in inverse ratio to the size and the spread of the crown. Relationship between crown diameter and tree diameter at breast height over back (dbh ob) is used in deriving stem diameter through the measurement of crown diameter on aerial photographs.

Other important crown variables are crown depth, crown sectional areas, crown volume and crown closure.

Crown Diameter Determination

To determine crown diameter from the ground, project the edges of the crown to the ground by means of plumb stick and then measure the distance between appropriate projections. More than two measurements of crown diameter may be taken but usually the average of the longest diameter and diameter at right angle to this may be used as a measure of crown diameter.

Crown Depth: Crown depth is determined from the difference between total tree height and height from crown point.

Crown Closure: It is the ratio of the area of the vertical projections to the equivalent ground area of the stand. It is used as a measure of stand density and as an index in aerial photo interpretation.

INSTRUMENTS FOR MEASURING DIAMETER AND HEIGHT

A. Diameter Measurement

1. Girth or Diameter Tape: This is usually made of cloth or linen for rough work. But those that are made of cloth – metallic or fibre-glass and steel are for more precise measurement. The graduation can be in inches or centimeters depending on the make or system.

2. Quarter-girth Tape

   It is mostly used in Great Britain. 1 inch on the tape is equivalent to 4 inches of girth.

3. Calipers

   The calipers are used for direct measurement of diameter. A caliper consists of a graduated scale with 2 arms perpendicular to the graduated scale. One arm is being fixed at the end and the other sliding. There are different types of calipers such as (i)

Simple or traditional caliper (ii) Fixed arm or fixed angle caliper (iii) Finnish Parabolic Caliper.

The girth/diameter tape is the most commonly used because it is easy to understand, very conveniently used and it is very portable.

Although the caliper gives direct reading of diameter/girth, the main disadvantage is that it is heavy to carry and consequently constituting a problem. All calipers suffer from limitation of size and weight.

Diameter under-bark

Bark constitutes part of the diameter of a tree, but after felling the tree the bark is excluded in use, so, if the interest is in only the wood excluding all roughages the amount of bark should be determined. An instrument that could be used to measure the thickness of the bark is called Swedish Bark Gauge.

Bark thickness tends to vary in a regular manner from the ground towards the tip of the tree. In some species, bark thickness may vary according to size, age, genetic make-up, condition of growth, e.t.c. It is possible to establish a relationship between bark thickness and other stem variables e.g. Dbh ob or Db hub.

Swedish bark gauge could be used for measuring bark thickness of standing or felled trees.

B. INSTRUMENTS FOR MEASURING THREE HEIGHT

There are 2 ways of measuring tree height

i) Direct Method
ii) Indirect Method

DIRECT METHOD:

This method involves climbing and measuring with tape and using a graduated pole in those areas that are inaccessible. Another way is to fell the tree and determine the length of the tree, this method is destructive.

INDIRECT METHOD:

This method could be classified into those based on geometric principle and the ones base on trigonometric principle. It is these types of instruments that are used for the measurement.

1. i) Clinsten's Hypsometer

It is composed of folding scale about 10 inches long with irregular graduation. To use it, hold or place a 10ft. pole upright against the base of the tree to be measured. The instrument is then held vertically at a distance. This instrument is graduated from similar triangles.

Observer
eye piece

s OAB and Oab are similar

i.e. OAB = Oab

$$\text{Thus} \quad \frac{AB}{ab} \qquad \frac{AC}{ac} \qquad \frac{AB - CB}{ac}$$

$$\therefore ac = \frac{ab\ (AB - CB)}{AB}$$

Example:

For 15 in. instrument (ab) and for a staff which is 10ft long, the tree height is

$$\frac{15\ (\text{tree height} - 10)}{\text{tree height}}$$

Thus for tree of 40ft high

$$Ac = \frac{15\ (40 - 10)}{40} = 11.25''$$

Manipulation:

A staff of known height with which the instrument was graduated is placed against the tree in upright position at a distance. At the chosen distance the observer holds the instrument parallel to the tree exis so that the line of sight from the top and the bottom edges of the instrument respectively hit the top and base of the tree. The height of tree is given by reading C cut by the line of sight.

Meirith Hypsometer

The function of the hypsometer is based on geometric principle. It is a crude but simple instrument made of straight graduatd stick which is held vertically with its lower end 25” from the eye and in line with the base of the tree. In using this instrument, the overserver must stand at a predetermined distance to the tree.

The main problem in using the instrument is that it may be possible to hold it vertically and precisely at 25” from the eye.

C. INSTRUMENTS BASED ON TRIGONOMETRIC PRINCIPLES

Take a horizontal distance OC between the observer eye “O” and the tree Ab.

OAC and OBC are right angled triangles.
If OC is known, then AB = OC tan (<AOC + <BOC)

Observer’s eye
piece

Two cases are known:

Case I: The observer stands at any convenient distance, OC is measured. <AOC and <BOC are determined with an instrument. Tangents of the angles are read from the table and the tree height is derived arithmetically. An instrument that can be used to determine angles is Abney Level.

Example:

If the horizontal distance is 20m and angles AOC = 55^{o} and BOC = 15^{o}, then the tree height will be 20 (tan 55^{o} + tan 15^{o}).

Case II: The observer stands at a specific distance or multiple or fraction of it for which the instrument is graduated. (Sme instruments are graduated in term of tangent of successive angles and the specific distance s that AC and CB can be read directly). The instruments in this category are (i) Topographic Abney Level, (ii) Engineering Abney Level, (iii) Haga altimeter and (iv) Spiegel Relascope.

$$AB = \{OC(\tan \quad)\} - \{OC(\tan \quad)\}$$
$$AC = OC \tan <$$
$$BO = OC \tan <$$
$$\therefore AB = AC - BC$$
$$= OC \tan < - OC \tan <$$
$$\therefore AB = OC(\tan < - <)$$
$$AC = OA \tan <a$$
$$AB = OA \tan <x$$
$$BC = OA \tan <a - OA \tan <x$$
$$= OA (\tan <a - <x)$$

TAPER AND FORM

1. Definitions:

Larsen (1963) defines taper and form and uses them synonymously as the relative rate of change in stem diameter with increasing tree height irrespective of the mathematical expression defining that change.

Gray (1956) defines form as the shape of the solid in diameter/height of which is determined by power index of the diameter or the particular fashion in which a solid narrows a diameter so as to produce a characteristic shape.

Gray defined Taper as the rate of narrowing a diameter in relation to increase in height of a given “shape” or ‘form’.

Taper is the rate of narrowing a diameter with height of a given shape or form.

Form is the total impression of shape given by the narrowing of stem or crown and the deviation from radial symmetry along the vertical axis of a tree.

2. FORM:

Variation occurs in the form of the main stems of trees, due to the variations in the rate of diminution in diameter from the base to the tip.

The various sections of the bole resemble certain geometrical solids whose cross sections at right angles to their long axis are circular. The commonest geometric solids are: (a) Cylinder (b) Paraboloid (c) Cone (d) Neiloid.

All these except the cylinder taper to a point and may be compared with the entire bole of the tree which seldom approximate either the cone or neiloid and never the cylinder.

Truncated sections severed by cross cuts are termed FRUSTRUM and may be compared with the entire bole length. Truncated paraboloid approaches the form of the average log. But logs may resemble the truncated neiloid owing to ilaring butts.

Top logs may have the shape of truncated cone.

3. TAPER

Taper is the decrease in diameter with tree height and it varies with species, diameter at breast height, age and site.

Cylinger Cone Paraboloid Neiloid

Variation of Taper with Typical Tree Forms.

(a) Typical Excurrent - (i) Conical tip (ii) Paraboloid middle section (iii) Neiloid basal section.

(b) Open grown Excurrent – (i) Long Conical top
(ii) Pronounced neiloid base
(iii) Truncated cone or paraboloid in central section.

(c) Close grown Excurrent – (i) Short conical top
(ii) Central and basal sections approximate to cylinder or truncated neiloid.

TAPER MEASUREMENT

(i) Standing Trees:

Diameter is measured at successive heights by either climbing or using optical devices such as the Spiegel Relasscope.

The use of tapes or calipers, raised on poles. When diameters at successive heights have been taken, plot diameter against height.

(ii) Felled Trees

Tapes, calipers or measuring rods are used. More detailed measurements are possible particularly for under bark of the trees.

STAND MEASUREMENT

Purposes of stand measurement from national point of views:

Measurement is necessary for involving and implementing satisfactory national policies since there is the need to know the location ad extent of forest.

Measurement is also required for Resource Inventory resulting in efficient management.

From the research point of view and for experimental investiageions, detailed measurements and highly necessary.

1. STAND DENSITY

Under the umbrella of stand density, stand structure could be discussed. Stand Structure can be categorized into (i) even-aged stand and (ii) Uneven-aged Stand.

(i) Even-aged Stand

This is a man-made forest in which all trees belong to the same age class and the trees are consistent in height depending on position in the canopy and most trees cluster round the mean.

(ii) Uneven-aged Stand

It is a natural forest which contains a large number of small trees which belong to many ages with corresponding sizes and are all of varying heights.

Stand Density

Stand Density can be defined in 2 ways

(a) Absolute Stand Density: Basal area/hectare

It is expressed as basal area per hectare of which expresses density on specific area basis. It refers to concrete characteristics.

(b) Relative Stand Density: % of stocking based on basal area

The expression is usually based on predetermined standard with which the stocking is compared. It is always expressed in percentage of standard stocking on basal area basis.

Apart from these two ways, there are other definitions of stand density. It could be expressed in volume per hectare/acre. In this case, volume is estimated from height and diameter of individual trees. This is an expensive method, if interest is mainly in density.

Another method is enumerating the number of trees unit area. It is not very reliable, non-precise quantifiable because of wide range of frequency distribution. It is however qualified by tree sizes.

REPRESENTATIVE STAND HEIGHT

Girth diameter Tree of Mean Basal Area.

To secure a representative stand measure, the arithmetic mean is commonly used. It is derived by measuring the required variable for a few sample of trees. For instance to obtain the mean height, measure the height of sample trees, sum up all the values and divide this by the number of sample trees making up the total which will give the arithmetic average i.e. the mean height. Thus, the mean height in this case is therefore an approximation to true mean.

There are various methods of obtaining representative stand measure, two of which are (i) Arithmetic Mean Method – In this case height of sample trees are measured and more weight is given to larger trees and the mean is found.

(2) Graphical Method:

A smooth curve is plotted which has a height of diameter and determine tree to average basal area. Using the height of this to read from the height/diameter curve obtain average mean height if the stand.

Crown Closure and Crown freedom are 2 ways of expressing sstand characteristics.

CROWN CLOSURE:

It is sometimes required to estimate what proportion of total stand crown area is occupied by sample trees.

COMPLETE AND INCOMPLETE CANOPY

Where complete canopy is present, it is required to project the crown of individual sample tree and use if to calculate the area occupied by individual crown – called the crown area. Crown area occupied by sample tree crown will constitute crown closure.

Where a gap occurs in the canopy, gaps can be used to determine the crown density. Where the crowns do not touch, it is said to be crown freedom. Crown freedom is an index of freedom from physical interference, been estimated as the proportion of crown margin actually touching or that may touch when a gentle wind blows against the stand.

Scores are based on an imaginary crown pentagon.

Scale 5 - (no contact) – there is a complete freedom of movement in a light breeze.

Scale 4 - (minimum contact) – one or two sides of the imaginary pentagon are in contact with other crowns.

Scale 3 - (medium contact) – free sides of the pentagon are touched by neighbouring crowns.

Scale 2 - (partial maximum contact) – in which the crown is free at least on one side. Four sides of the pentagon are in contact with the crowns of neighbouring trees.

Scale 1 - (maximum contact) – Here, it indicates severe crown competition which free sides of the pentagon are in contact with or threaten to get in contact by the crowns of neighbouring trees.

STAND MEASUREMENT

UNEVEN-AGED STAND

There is an equation to measure the frequency of distribution in an uneven aged stand: $Y = Kx^e$ which can be transformed into

$$\text{Log } Y = \text{Log } K - ax \log e$$

Where Y = No. of trees in a given dbh class

K and a are constants

X = diameter at breast height class

STAND DENSITY

A useful form of finding the stand density of eve-aged stand is by the use of Reineke's Stand Density Index – which is read from a graph in which the logarithm of no. of trees per hectare is plotted against the logarithm of mean deb.

Mean Dbh

INTRODUCTION TO VOLUME ESTIMATION

There are 3 types of dimensions

(1) Linear (2) Area (3) Volume

In forestry practice, are measurement is on two forms (ii) Territorial or Cadastral form (ii)Area in plan related to individual trees.

For instance basal area is obtained by conversion from girth or diameter. Crown are is obtained by direct estimation as an individual area for single tree and by proportion for stand. For individual tree volume, measurement is considered for the stem or bole, any distinct section of the stem and for the crown.

Stand Volume is the sum of volumes of constituent trees. Stand volume can also be obtained by direct estimation.

MEASUREMENT OF VOLUME ESTIMATION

The form of the volume to be estimated normally related to the stage of conversion. There are four main forms of conversion of the trees:

1. The Standing Individual Tree which is unconverted.
2. The Felled Tree with partial primary conversion for transport but with identity of the original tree retained.
3. Primary converted produce collated for transport with the individual tree identity lost e.g. cord wood or fuel wood.
4. Produce after subsequent industrial conversion e.g. sawn-wood, veneer or composite wood-chips, particles or saw dust etc.

METHODS OF VOLUME ESTIMATION

There are three main methods of volume estimation.

1. Analytical Volume Estimation
2. Volume Estimation by Displacement of Water
3. Graphical Method of Volume Estimation

ANALYTICAL METHOD

Solid volume is approximated to three dimensional models e.g. the following formulae for calculating volumes of different geometric solids could be adopted:

Where V = volume, A = area of lower base

A_m = area of mid-section parallel to A_b and midway between Au

Au = area of an upper section.

Cylinder $V = A_b h$

Cone $V = 1/3\ A_b h$

Frustum of Cone $V = h/3\ (A_b + Am + Au)$

Sphere $V = 4/3\ r^2 h$

Frustum of a Paraboloid

$V = A_b + Au$

---------- d
2

Paraboloid $V = 1/2 \; A_b h$

Frustum of Neiloid
$V = d/b(A_b + Am + Au)$

Neiloid $V = 1/4 \; A_b h$

DISPLACEMENT METHOD

In this method, xylometer are used for obtaining absolute measures of solid volumes. It is the most accurate method and it is based on the principle of fluid displacement.

The xylometer is in form of a water tank with a device for measuring water volume.

GRAPHICAL ESTIMATION

The graphical method is suitable for both felled and standing trees. Overbark and bark thickness measurements are taken at various points of the stem. The closer the points of measurement, the greater the accuracy of the volume obtained. Diameters squared of sectional areas are plotted against length as the abscissas – x – axis.

Volume is obtained by area enclosed by the curve. An estimate is therefore obtained which is more accurate than the analytical method.

Basal area

Horizontal, 1cm = 2m Length (m)
Vertical, 1 cm = 0.01m2

ANALYTICAL METHOD

This is the most favoured method although the basal sections may be troublesome. Still and buttresses are normally not measured. A buttswell may be estimated by approximation as stump volume of a stem of uniform taper. Volume is estimated in sections.

Volume is estimated in sections of straight and non-straight stems. The crown and branches (branch wood) require smaller sectional lengths. The relation between section volume and stacked volume is used and is usually labour saving.

Analytical Method Formulae:

1. Newton's Formulae

$$V = h/6\,(A_b + 4a_m + Au)$$

$$\frac{h\,(Ab + 4am + Au)}{6}$$

Where V = Volume I cubic meter or other units

h = Total height above stump – 6m

A = Sectional area at the base $0.4m^2$

A^b = Sectional area at the middle $0.3m^2$

Au^m = Sectional area at the top $0.2m^2$

Newton's formula is the most flexible for determining volume of a whole stem or portion of it. The formula is applicable to any of the three possible stem forms, be it Neiloid or Paraboloid or Conoid.

2. Schiffel's Formula:

$$V = h(0.16\,A_b + 0.66\,A_m)$$

$$= h(0.16A_b + 0.66\,A_m) \text{ where } Au = 0$$

This is a modification of Newton's formula. It is only used for determining total stem volume i.e. volume from ground level of stump height to the tip of the stem. (Au) tip's cross sectional area is equan to zero.

3. Smalian's Formula:

$$V = \frac{h(A_b + Au)}{2} \quad \frac{h(Ab + Au)}{2}$$

This deals with frustum of a paraboloid.

4. Huber's Formula:

$$V = h.Am$$

This also deals with the volume for frustum of a paraboloid.

Both Smalian and Huber's formulae give inaccurate estimate of volume of stem section which are not truly frustum of paraboloid. Smalian's formula tends to overestimate while Huber's formula under-estimates. The error due to using Smalian's formula is usually twice that of Huber's formula. Smalian's formula is apparently easier to apply especially with regards to felled logs.

The accuracy of estimating total or merchantable stem volume by means of either Smalian and Huber's formulae is increased by dividing the stem into a number o short sections and adding together the sectional volumes.

5. Pressler's Formula

$$2/3\,(Ab \times H \times \tfrac{1}{2} D)$$
$$2/3[Ab + H \times D/2]$$
$$V = 2/3\,(A_b\ H1/2D)$$

Where H = height above ground
1/2D = half the basal diameter

$$2/3\,(A_b \times H\ D/2)$$

6. Hossfeld's Formula

$$V = h/4\,(3\ A1/3 + A_b)$$
$$h/4\,(3 \times A/3 + A_b)$$

where A1/3 = the cross sectional area in square units at one third of the height above stump.

The two formulae above i.e. 5 and 6 aim at reducing the amount of work necessary in obtaining requisite measurements. These formulae refer essentially to cubic measure.

OTHER TYPES OF VOLUME ESTIMATION

1. Board Foot American
2. Mill Tally Volume
3. Hopus Foot – British

These are known as allowance measures.

They derive volume in terms of utilizable portions of the log.

BOARD:

It is a unit of volume measurement commonly used in North America to estimate the actual volume of wood utilized in form of sawn timber from the stem or portion of it. The unit is applied to planks produced from Saw mills and also to estimate the utilizable quantity of timber from a standing tree.

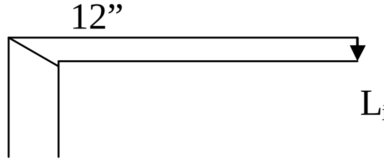
The definition of Board Foot is a unit of 12 inches long, 12 inches wide and 1 inch thick. The generalized formula for the volume of a sawn board is L_i WT

Where Li = Length in inches
W = Width in inches
T = Thickness in inches

12”

MILL TAB

12”



One inch

L_iWT – Volume of a sawn board

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3. Hopus Foot – British

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MILL TALLY VOLUME

Mill Tally Volume is the Board foot volume determined directly by observing and felling the actual quantity of timber as it is sawn in a mill.

HOPPUS FOOT

In Great Britain, cubic volume of logs have until recently being commonly measured using Quarter Girth or Hoppus rule, in which girth is measured in middle inches and the length is measured in feet; volume in cubic fit.

$$V = \left(\frac{G^2}{4}\right) \frac{L}{144} \qquad (G^2/4)\,L/144$$

The hoppus rule gives 78.4% of the cubic volume of the cylinder. Thus allowing a waste of 21.6%.

CONCEPT OF TREE VOLUME

Most tree are naturally irregular. The problem is whether to include such irregular portion in volume estimation to obtain a biological volume which is unreal in term of utilization. To what extent should irregularities be omitted in volume estimation considering basic taper and cross section alone is another problem. Some cases produce quite a misleading estimation.

VOLUME ESTIMATION OF TREES IN CONVERTED FORM

Cord Volume Estimation

Materials involved are billets of wood for pulp, particle board firewood, split or unsplit size materials such as pit prop, posts and less regular materials in quantity hillet forms for charcoal. These materials are traditionally aggregated in cords.

A standard cord is 8ft by 4ft i.e. 128 cubic feet. Length of each piece of wood being 4ft. The solid wood content of a cord is always much less than 128cu. Ft and presence and thickness of bark and the method of palling. There are more air space in a cord of crooked and knotty pieces of wood than in one of straight pieces of wood with well straight boles. Cords of split wood contain less solid volume than round wood. The relative amount of space in a cord will also increase as the diameter of pieces of wood decreases.

Other measures of stacked materials are:

(i) CUNIT – Which is used in Australia. It represents 100 cubic feet solid wood volume occupying about 145 cubic fee of space.

(ii) STERE or RAUM – Metre – Which is used in Western Europe and is the cord equivalent to 1 cu. m. 1 cord = 3.6 steres approximately.

Conversion factors by which stacked cubic feet (Cord) may be converted into solid volume are:

(a) Pitwood and pole = 0.75
(b) Split fuel-wood = 0.75
(c) Small branch hard wood = 0.35
(d) Roots and stumps = 0.5

$$\text{The Conversion factor} = \frac{\text{Solid volume}}{\text{Stacked volume}}$$

The scaling of cords is done by measuring the 3 dimensions of length, width and height in feet. The overall volume in cubic feet is divided by 128 to obtain the number of cords.

Some precautions are necessary in measuring and preparing cords:

(i) Height measurements are taken at regular intervals of 1 or 2 feet – average and allowance of 3 – 4 inches being made for shrinkage and settling.
(ii) Length of the cord should be measured on both sides. The length of pieces of wood should be checked for uniformity. It is very important especially on sloping ground to measure the cord height and length at right angle to each number.

The scallion of pulpwood in cord units, deduction are normally for defective wood and loose piling. Defective wood include burnt or rotten; wood not meeting height requirement and partially the debarked wood.

Each stick in a cord is examined and the total volume of all rejected pieces subtracted from the gross volume of the cord. To deduct for loose piling, the total volume of number of sticks that can be added to the cord is subtracted from the gross cord volume.

OTHER METHODS OF OBTAINING SOLID VOLUME OF CORD:

1. Direct measurement through displacement method.
2. Summing cubic volume of individual pieces derived by formula method – Smalian's or Huber's.
3. Scaling from photographs, ratio of air space to piled wood in percentage may be used to estimate solid volume by the dot-grid method.
4. With finer conversion at stump (particularly blown slurried fibre) volume is best ascertained by using containers –bins of known dimension.

TREE FORM AND VOLUME ESTIMATION

Form and taper vary with age, diameter and height class.

EXPRESSION OF TAPER:

Taper is the deviation by narrowing of stem from radial symmetry along the vertical axis of a tree that has been expressed in mathematic functions. The following are examples:

(a) Hojer's Formula $\frac{d}{b} = C \log \left(\frac{C + L}{c} \right)$

Where $L = \frac{\text{Total height} - \text{ht of "d" above ground}}{\text{Total height} - \text{breast ht}} \times \frac{100}{1}$

d = diameter at a distance L from tip of the tree

D = diameter at breast height

C & c = Constants depending on absolute form quotient

(b) Tor Johnson's Formula $\frac{d}{D} = C \log \left(\frac{C + L - 2.5}{C} \right)$

This is a modification of Hojer's formula; value 2.5 is a biological constant which corrects for error in upper tree diameters.

(c) Behre's Hypoperbolic Formula:

$$Y = \frac{x}{a + bx} \text{ or } \frac{d}{D} = \frac{L}{a + bL}$$

$$Y = \frac{d}{D}$$

$$X = L$$

a and b = constants which vary with form quotient but in all trees a + b = 1.

EXPRESSION OF FORM

Tree stem form generally approaches that of any solid revolution. Stem volume can be approximated by the formula for solid of the same basal diameter and height. Any difference in stem volume and that of solid revolution is due to the variation in stem form from the standard chose. The ratio of the 2 volumes is termed Form Factor.

$$\text{FORM FACTOR} = \frac{\text{Volume of tree}}{\text{Vol. of Geometrical Solid}}$$

Depending on the geometrical solid used which may be cylindrical or conical stem factor. The cylinder is the usual reference geometric solid is determining stem factor which is usually defined as the – coefficient by which the volume of a cylinder having the same cross-section as the tree must be multiplied to obtain tree volume.

$$\text{Form Factor} = \frac{\text{Tree Volume}}{\text{Vol. of Cylinder of same Ht \& DBH}}$$

Form factor can also be classified according to the position of basal diameter e.g. in absolute form factor, the basal diameter is taken at ground level. Basal diameter is usually taken above ground level because of the difficulties due to irregularities and buttress at ground level.

Basal diameter is usually taken at breast height which result in Breast Height Factor and sometimes at arbitrary point say 5 or 10% of the total height of the tree to obtain a normal Form Factor. The advantage of Normal Form Factor is that the basal diameters are more closely related to the tree for (in trees of different form and height). The normal form factor also describes actual tree form much more efficiently. The disadvantage in using normal for factor is the difficulty in determining the position of the basal diameter.

The portion of the tree, the volume of which is being determined can also be used in classifying form factor e.g. Merchantable Form Factor is one in which the merchantable length of the stem is used as the height while in the Stem Form Factor total height of the tree is taken. A Tree Form Factor results if the total height is used and the tree volume contains the volume of braches, wood and stump. The frustum is similar to merchantable form factor but uses the volume of the frustum of a cone.

USES OF FORM FACTOR

Form factor is used for estimating volume of standing trees from diameter at breast height and height.

$$V = S \times h \times f$$

Where V = volume
S = basal area (cross sectional area)
h = tree height
f = form factor

Note: S x h is volume of a geometric solid usually a cylinder

Form factor varies with tree species especially according to the position occupied in the canopy. Volume estimation by form factor is a circuitous and unsatisfactory approach. It is of interest essentially where the labour has already gone into the computation and presentation of statistics of form and taper of individual species.

FORM QUOTIENT

Form quotient is another expression of tree form. In contrast to form factor which is a ratio of volume, form quotient is a ratio of 2 stem diameters. The lower diameter being taken at breast height. The following are four types of form quotient:

1. Normal Form Quotient:

The original concept of form quotient is based on the diameter at ½ height to diameter at breast.

$$\text{Form Quotient} = \frac{d\,(1/2)}{d\,(bh)}$$

The defect of this form quotient is that, as the tree height becomes shorter a stage is reached when d(1/2) will coincide with diameter at breast height i.e. (d(b.h) for a tree whose height is double the breast height.

2. Absolute Form Quotient:

This is formulated to remove the defect of normal form quotient.

$$\text{Absolute Form Quotient} = \frac{d\,(1/2h.a.b.h.)}{d\,(b.h.)} \quad \text{1/2 ht after breast height}$$

3. $$\text{Girard Form Quotient} = \frac{d\,(u.b)\text{ at }17.3}{D\,(b.h.\ overbark)}$$

4. Gieruszynski Form Quotient

$$= \frac{A\ (0.5)}{A\ (0.1)}$$

Where A(0.5) = cross sectional area at ½ stem length
A(0.1) = cross sectional area at 0.1 stem length
(starting from the base).

FORM POINT

This is another index of tree form. It is based on the mechanistic theory i.e. the form of trees depends on mechanical stress to which a stem is subjected e.g. dynamic stresses resulting in bending moment induced by wind and static forces due to crown weight.

It is assumed that the form of a stem is dependent on the position of the point of greatest resistance to wind pressure called the Form Point. The form point is located at the centre of gravity of the crown.

FORM CLASS

This is the expression of form point as a percentage of tree total height. The following procedure is used to determine the form class of a tree: The position of form point is estimated by eye. The ratio of this height (from tree base) to the total height in percentage constitutes the tree's form class:

$$\text{Form Class} = \frac{\text{Height of form point}}{\text{Total tree height}} \times \frac{100}{1}$$

ESTIMATION OF VOLUME OF STANDS

A stand may be defined as an aggregation of trees in a specific area, and sufficiently uniform in composition, age, arrangement etc. to distinguish it from forest on adjoining areas. Stand volume estimation usually involves sampling techniques. An estimate of stand volume with an assignable error is sort.

There are 3 major approaches to Stand Volume Estimation:

(i) Sample Tree Method
(ii) Graphical or Regression Method
(iii) Volume from Aerial Photographs.

SAMPLE TREE METHOD:

Sample trees are selected. Their volumes are obtained and then extrapolated to give estimates for stand volume.

GRAPHICAL OR REGRESSION METHOD:

In the graphical method, relationship is established between individual stem volume and an easily measurable statistics (Dbh or Gbh). Graph is then plotted and used to estimate sample tree volumes which are subsequently applied to stand enumeration to obtain stand volume.

AERIAL PHOTOGRAPH VOLUME ESTIMATION METHOD:

This method entails direct estimation of stand volume from aerial photographs through prior knowledge of the relationship of air crown cover and stand volume.

SAMPLE THREE METHOD:

This approach is the oldest method of stand volume estimation in Forestry but it is being superseded by volume table method. Relatively, few trees are measured into details and stand volume is derived generally from the formula V = V(mean tree) x No. of trees in stand.
Three systems are distinguishable:

(a) Concrete/Direct-crop volume is calculated from concrete sample trees by proportion.
(b) Concrete/Graphical – (as for "a") but graphical methods are used.
(c) Abstracts – Volume is calculated from abstract sample trees obtained from graphs and volume tables.

CONCRETE DIRECT METHOD:

(i) Selection of Sample Trees:

Sample trees are chosen from trees with diameters as near as possible to tree of mid basal area and are expected to conform in height, stem and crown shape to the mean tree. This is impossible in practice.

(ii) No. of Trees:

This is variable, general rules are impracticable because of varying circumstances of stands and growth. The more varied the stand the greater the number of sample trees required.

(iii) Measurement of Sample Trees:

Where possible sample trees should be felled for measurement and are usually selected from thinning or the surrounds.

Method 1 – Simple Sample Tree Selection.

Enumerated trees are grouped in diameter classes (1" or 2.5cm). One or more trees are selected from each class and measured for volume. There is therefore a disproportionable weight in sample in this method. Using the formula

$$V = \frac{V \times S}{s}$$

where V = volume of diameter class
v = volume of sample trees (s)
S = basal area of diameter class
s = basal area of sample tree (s)

Method 2 – Arithmetic Mean Method

Enumeration and calculation are done as in method 1. The basal area of plot mean tree is calculated from the formula

$$\frac{\text{Sum of Basal Area}}{\text{Total no. of trees}}$$

Mean basal area is concerted to diameter. Abeokuta 3 – 5 mean trees are selected and measured for volume. Volume of the plot is calculated using the formula:

$$V = \frac{V \times S}{s}$$

Method 3 – Huber's Method.

Group enumerated trees into equal number of diameter classes. Several classes are then grouped together and a mean tree is calculated for each group. The procedure for method 1 is calculated for each group. The procedure for method 1 is then followed. This method requires fewer sample trees than method 1.

Method 4 – Urich's Method:

A more efficient method than method 3. Grouping is done is such a way that each group has the same number of trees. Equal number of sample trees are measured from each group.

V x S

Volume of the plot = V = --------
s

where v = total volume of sample tree
s = total basal area of sample tree
S = total basal area of plot.

This method is used by the British Forestry Commission for determining volume of temporary sample plots for Yield Table Construction. It is not necessary to calculate group volume in this method.

Method 5 – Hartig's Method:

This involves groups of equal basal area. It is assured that errors of volume estimates are proportional to group volumes and are compensating. Group volumes are calculated separately using the usual formula.

Method 6 – Block Method:

This method aims at removing defects in the former methods. The defects are that the same trees are not being sampled at each re-measurement of a permanent sample plot and that final crop trees are grouped in the thinnings at each measurement. In this method therefore, the largest trees are in group one, the next largest in group two etc, the number of trees increasing in the lower groups. There is therefore a selection of greater number of sample trees for groups containing the larger trees on account of the greater economic importance of the latter. The volume of each group is calculated as before from mean basal area sample trees. Not less than 2 trees are measured for each group.

CONCRETE/GRAPHICAL METHODS:

Sample trees are selected without regard to grouping, instead selection covers the whole range of diameter classes. A graph is prepared from the data obtained.

(i) Volume Curve Method:

Volume of sample trees are plotted against diameter and a smooth curve is drawn. The mean tree diameter is calculated and its volume read off the graph.

V (gp) = v x n
V (gp) = volume of girth class
v = volume of mean tree
n = number of trees in the group.

(ii) Form Factor Method:

This is similar to the first method but form factor diameter curve is used. Diameter/height graph is prepared. The diameter of the mean tree of each group is calculated. Its form factor and mean height are read from the graph and its volume obtained from

V = s.n.f.
S = basal area of sample tree
h = mean height
f = mean form factor.

ABSTRACT METHOD

Abstract sample trees are used. Any method of grouping except the arithmetic mean method is allowed. Height/diameter graph is prepared from sample trees of each group. Then for each group, calculate mean tree diameter, read height from graph, read volume from volume table using height and diameter. Obtain group volumes and then plot volumes from this abstract sample trees. This method presupposes the existence of volume tables.

CRITICISM OF SAMPLE TREE METHODS

1. They are inconvenient, though this is not peculiar to sample tree methods.
2. Methods of selection of sample trees are frequently prone to errors.
3. Sample is usually small, hence representativeness is dubious.

VOLUME TABLE METHOD OF VOLUME ESTIMATION

The volume table method was mentioned under approach (b) of the last lecture.

DEFINITION:

The tree volume table is a statement of the AVERAGE value of VOLUME of a tree of a particular DIMENSION.

AVERAGE:

Trees are irregular enfid bodies and appearances are bound to occur in volumes of trees of the same dimensions. Volume is determined by any of graphical, sectional or other methods and it provides only an estimate.

Dimensions imply limited statistic e.g. D.b.h. over bark, height and expression of taper.

The main purpose of tree volume table is for application to standing trees to give average volume of a number of trees in dimension classes.

REQUIREMENTS OF A GOOD VOLUME TABLE METHOD

1. The ideal method should be simple i.e. free of complex mathematics and should involve relatively few parameters.
2. A large number of tree measurements must be available to give well defined trends.
3. Need of special equipment should be held to a minimum.
4. It should be objective and hence graphical representation of relationship should be by straight lines rather than curves.
5. It should lead to reasonably accurate results of predictable precision.

REQUIREMENTS FOR THE CONSTRUCTION OF VOLUME TABLE

A. DIRECT CONSTRUCTION

1. The following specifications are necessary at the planning stage:
   - (a) Tree statistic or statistic to be employed.
   - (b) The type of volume to be estimated.
   - (c) Species to be considered.
   - (d) Territorial range of species selected.
   - (e) Size of range covered.
   - (f) Degree of precision required.

2. A Sampling Operation:

Sufficient data within limit set by time and cost.

3. Establishment and Computation of the Volume:

Tree statistics are tested in diverge combination of variables. The best equation with lowest standard error or highest correlation coefficient should be chosen. Precision and biased are important.

Biased regression is one which overestimates younger tree volumes and underestimate volume of larger trees.

Biased Regression

4. Presentation:

The print-out should be convenient and should contain texts in identification material, descriptive materials including extent of extrapolation; comparative material in form of existing volume table for testing purposes and instruction for application and modification particularly local correction factors.

B. INDIRECT CONSTRUCTION

Indirect method may involve relating tree diameter and height to an indirect measure of volume like form factor or taper and the construction of the volume table as a separate step from the form factor table or taper curves.

Requirement presupposes the existence of a body of information on the tree form.

There are 2 types of Volume Tables, namely:

1. Local Volume Table: which is for a specific locality. It consists of one independent variable which is the dbh i.e. volume related to dbh.

2. Standard Volume Table: It consists of two independent variables which are the dbh and height i.e. the volume is related to dbh and height. It is used for a country or for a larger extent.

TARIFF TABLE:

Tariff is derived from a French word Tariff be cubage (meaning volume table) and is used in Western Europe and refers to particularly to one way volume table.

In Britain, tariff implies one of the family of one way volume tables. If the volume, basal area lines of a stand becomes older, the increase in tope heights increases the regression coefficient of volume basal area line and decreases the regression constant. The point of intersection of the volume line with the basal area axis remain approximately constant.

A tariff table may be regarded as a series of local volume table. In the U.K. Forestry Commission, tariff table provided by Humell each member of the series of the local volume in Hopus feet for a quarter girth basal area of one square foot.

The British tariff tables were originally meant for estimating the volume of thinnings before felling. The tariff tables are however been increasingly used for estimating standing volume at different ages of the stand. Tariff is not of particular interest to Tropical Forestry.

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