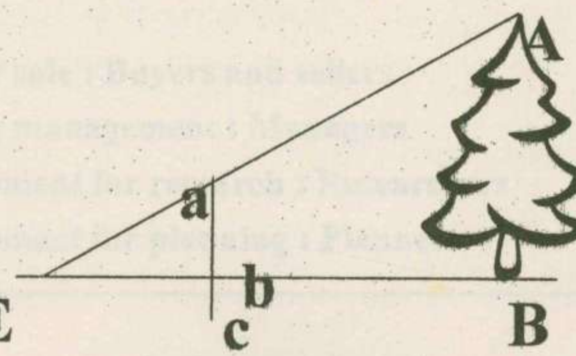
Lecture Notes on

Forest Mensuration



Prepared by

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Calculations for diameter using Relaskop

$d_{cms} = 2D \times L + (S + s \times 0.25)$

D = Distance, L = Large band S = small band,
s = fractions of small band

FOREST MENSURATION

- That branch of forestry which deals with the determination of dimensions (e.g. Diameter, height, c/s area, volume etc.), form, volume, age and increment of single tree, stands, or whole woods, either standing or after felling.
- Deals with linear, area, volume and weight measurements.

Object

*Basis for sale : Buyers and sellers

*Basis for management : Managers

*Measurement for research : Researchers

*Measurement for planning : Planners

Accuracy

Forest mensuration aims at reasonable or relative accuracy, i.e. maximum accuracy which is profitable and possible to obtain in practice.

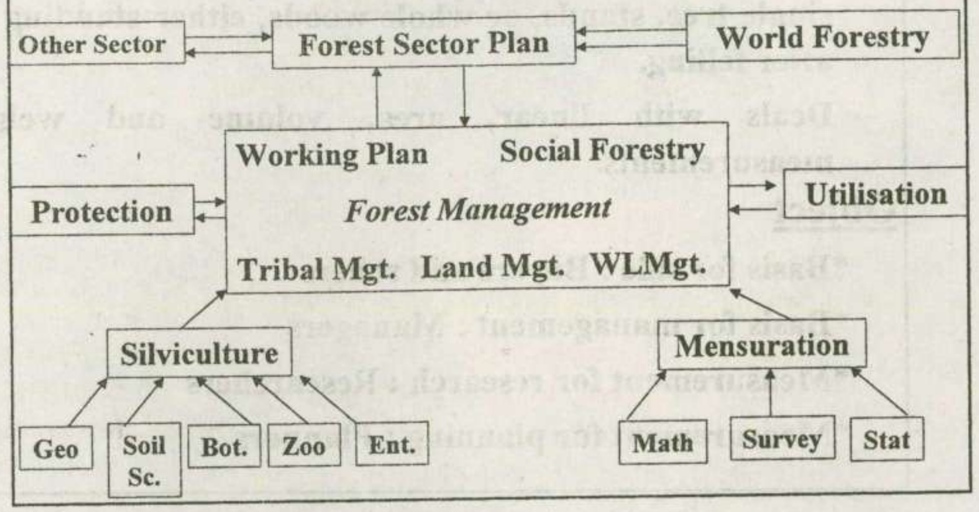
Factors Affecting Accuracy

Characteristics of trees.

- Varying methods and conditions of felling and conversion.
- Instruments and condition in which they are used.
- Personal bias of the estimation.
- Biological character of the forest.
- The use to which the measurements are to be put.
- Cost & Time.

FOREST MENSURATION

Application of measurement principles to obtain quantifiable information for making decisions in the management of a forest.(decision support)



- **Measurement of Diameter and girth**

The first important linear measurement is the measurement of the Diameter and girth of the tree, assuming the tree-section to be circular.

- **Place of measurement**

Diameters of girths are generally measured at breast-height.

Breast-height (B.H.) or (b.h.) is defined as almost universally adopted standard height for measuring girth, Diameters and basal area of standing trees.

In India b.h. is taken as 1.37m (4 ft. 6 in.) above ground level.

•Reasons for adopting b.h.

- **Convenient height.**
- **base of the tree is generally covered with grasses and shrubs and even thorns.**
- **Majority of the trees develop root swell near the base resulting in abnormal formation from ground level which disappears below breast height.**
- **Uniform point of measurement which helps in standardizing Diameter measurement.**
- **It is preferred to Diameter measurement at stump height because stumps are never cut at uniform height and as such standardization is lost.**
- **Even if the stump height is standardized, the value of such Diameter or girth measurement is completely upset by a change in utilization standards demanding either higher or lower stump.**

Description of Diameter and girth measurements

D.B.H. (or d.b.h.) : Diameter at breast height.

G.B.H. (or g.b.h.) : Girth at breast height.

Unless otherwise stated these are over bark (O.B. or o.b.) measurements.

D.B.H. (O.B.) or d.b.h. (o.b.):Diameter at breast height over bark.

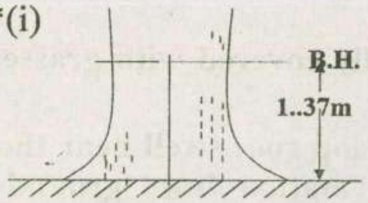
G.B.H. (O.B.) or g.b.h. (o.b.):Girth at breast height over bark.

D.B.H. (U.B.) or d.b.h. (u.b.) : Diameter at breast height under bark.

G.B.H. (U.B.) or g.b.h. (u.b.) : Girth at breast height under bark.

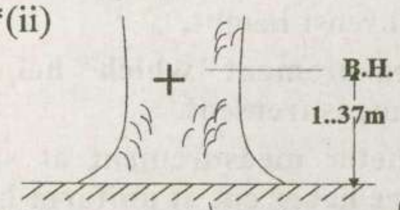
Standard Rules Governing Breast-Height Measurement

*(i)



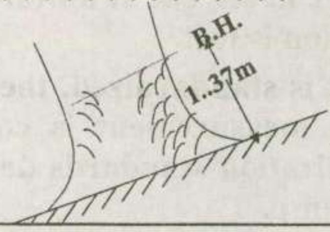
Breast height should be marked by means of a measuring stick on standing tree at 1.37m above the ground level.

*(ii)



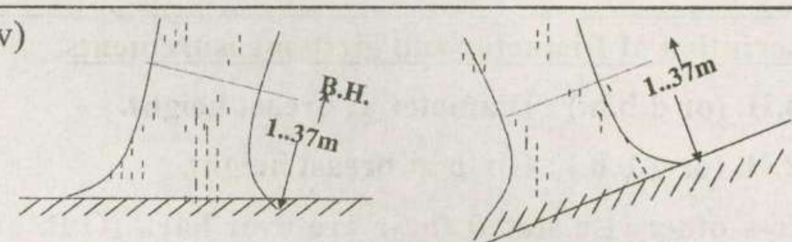
Breast height point should be marked by intersecting vertical and horizontal lines 12cm long, painted with white paint.

(iii)



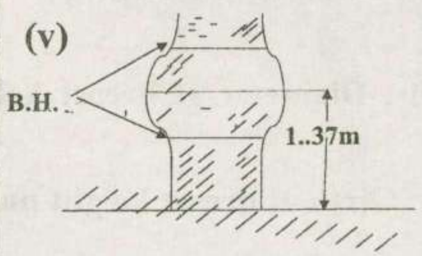
On sloping ground, the Diameter at breast height should be measured on the up hill side after removing any dead leaves or needles lodged there.

(iv)



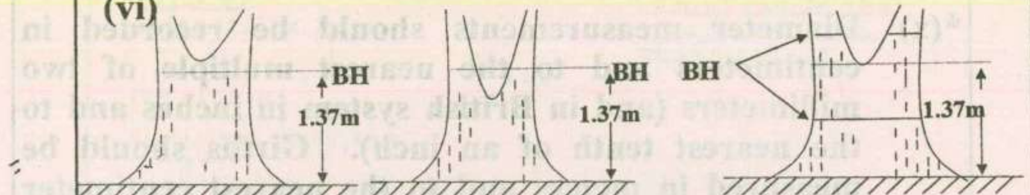
In case the tree is leaning, dbh is measured along the tree stem and not vertically, on the side of the lean for trees growing on flat ground and on the uphill side for trees growing on sloping ground

(v)

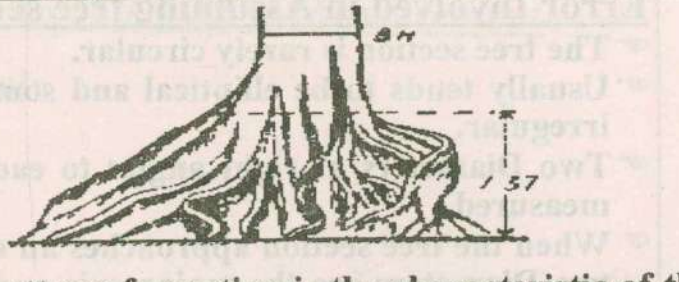


The dbh should not be measured at 1.37m if the stem is abnormal at the level. B-H mark should be shifted up or down as little as possible to a more normal position of the stem and then Diameter measured.

(vi)



When the tree is forked above the breast-height, it is counted as one tree but when it is forked below breast height,each fork should be treated as though it were a separate tree. If forking renders the breast-height point abnormal, the foregoing rule should be applied and the tree counted as one or two depending on the place of measurements.



(vii) When buttress formation is the characteristic of the species and is known or is likely to extend upwards with the development of the tree, the breast height should be taken at the lowest point above which the abnormal formation is not likely to extend.

***(viii) The height of the cross mark above the ground level should always be recorded for each tree measured.**

(ix) Moss, creepers, lichens and loose bark found on the tree must be removed before measuring the Diameter or girth over bark.

*(x) **Diameter measurements should be recorded in centimeters and to the nearest multiple of two millimeters (and in British system in inches and to the nearest tenth of an inch). Girths should be measured in meters and to the nearest centimeter (and in British System, in feet and to the nearest inch). Diameter or girth of each tree is recorded separately.**

* **For routine forest works some of the above rules are either not followed at all or modified to suit the convenience of swift working.**

Error Involved in Assuming tree section as Circular

- ☞ The tree section is rarely circular.
- ☞ Usually tends to be elliptical and sometimes, even more irregular.
- ☞ Two Diameters at right angles to each other should be measured.
- ☞ When the tree section approaches an elliptical shape, the two Diameters are the major axis and minor axis of the ellipse.
- ☞ The basal area is however calculated assuming the tree section as circular.

Error in calculation of basal area :

True area of the ellipse : πab

a : Semi major axis

b : Semi minor axis

e : eccentricity

$e^2 = (a^2 - b^2)/a^2$ always less than unity

Particulars of the basis of calculating area	Basal area	Error as compared to the true basal area of the ellipse
(i) True area of the ellipse	πab	-
(ii) Area of the circle based on two diameters		
(a) by the formula $\pi \left(\frac{a+b}{2}\right)^2$	$\pi ab \pm 2k/32$	$\pm 2k/32$
(b) by the formula $\pi \left(\frac{a^2+b^2}{2}\right)$	$\pi ab \pm 4k/32$	$\pm 4k/32$
(iii) Area of the circle based on girth measurement by formula $g^2/4\pi$	$\pi ab + 3k/32$	$+3k/32$

Where $k = e^4 (1+e^2/2) \pi a^2$

Thus, the error involved in calculating basal area after assuming a tree with elliptical cross section as circular is always positive and the Diameter measurements give the least error, provided basal area is calculated after finding out the mean of the two Diameters along the major and minor axis.

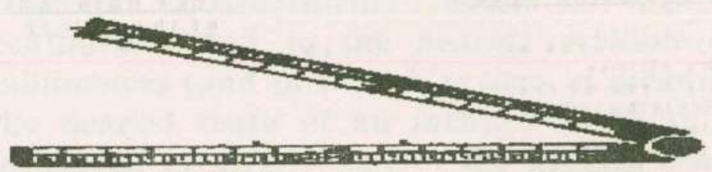
Instruments used in Measurement

- Wooden Scale
- Callipers
- Tape

The choice of the instrument to be used for Diameter or girth measurement depends upon

- ☒ Whether the tree is standing or felled.
- ☒ If felled, the condition in which the logs are lying.
- ☒ The degree of accuracy required.

Wooden Scale



A flat wooden piece marked in centimeters and millimeters

- available in two sizes, viz 30cm and 60cm. The 30cm wooden scale is about 3cm wide but the 60cm scale is about 1.5cm wide and has folding arrangement at every 15cm length.
- used for measuring Diameter of stump or end sections of logs exposed as a result of cross cutting. It is also used in stump and stem analysis for measuring radius at successive decade marks.

Rules to be followed while measuring Diameter with wooden scale

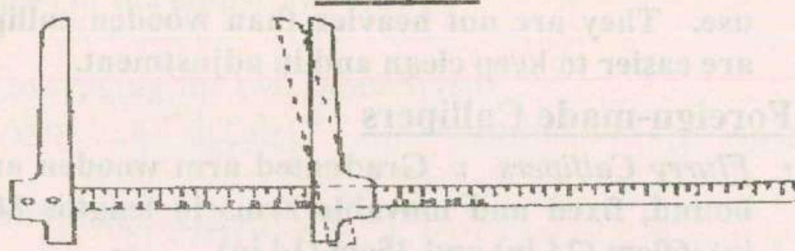
Diameter is measured along the line passing through the pith. In case of eccentric stumps or logs, two Diameters one along major axis and the other at right angles to it should be measured.

Measurement to be taken from first centimeter and not from the zero mark if the end of the scale gets worn off.

Scale is placed on edge so that the ends of the line to be measured coincide with the marks of the scale.

Parallax to be avoided while reading measurements.

Callipers



- Used to measure Diameters of standing trees and logs.
- Consists of a graduated rule and two arms, out of which one is fixed at right angles to one end of the rule in such a way that the inner edge lies on the starting point of the graduated scale. The other arm moves along the rule parallel to the fixed arm.
- Normally each arm should be at least half the length of rule. Callipers upto 120cm length are used in practice.

- The rule is divided into units, the size of which depends upon the desired degree of accuracy.
- For routine forest works callipers marked in centimeters and showing Diameter classes painted in different colours are used.
- Callipers are generally made of wood. In humid conditions due to absorption of moisture the movable arm gets jammed. The slot of the movable arm should therefore be of a size that avoids jamming but not so big as to make it difficult to keep it parallel to the fixed arm.
- This is usually done by making the slot oblique so that the arm could be tilted inwards but not outwards. In some callipers, the arms are made parallel by screw adjustments.

- Metal callipers made of alluminium alloy are also in use. They are not heavier than wooden callipers and are easier to keep clean and in adjustment.

Foreign-made Callipers

- ***Flurry Callipers*** : Graduated arm wooden and brass bound, fixed and movable arms in lengths 80cm, (32 in), 60cm (24 in) and 35cm (14 in).
- ***Fommes Callipers*** : All aluminium available in the same lengths as Flurry Callipers.

  Indian alluminium callipers are available in the lengths 50cm, 75cm, 100cm and they are graduated to show centimeters and millimeters.

Girth Callipers : graduated to give girth of a tree or log directly.

Girth : πd

Method of Use

- Handles of the arms held in two hands.
- Movable arm tilted inwards to make it free to move.
- Moved in that position to get a wide gap between the arms for the tree to be fit into it.
- Graduated rule made to touch the tree.
- Movable arm shifted inwards in the tilted position till the tree touches both the fixed and the movable arms.
- The movable arm is then slowly brought in perpendicular position to the graduated scale.
- Pressed so as to squeeze out any loose bark as well as ensure that there is no gap between the arms and use tree.
- The Diameter is then read off on the rule.

d_1 and d_2 : two Diameters of the elliptical cross section.

True area of the ellipse : $\left(\frac{\pi}{4} d_1 d_2\right)$

(a) By averaging the two Diameters :

Area : $\frac{\pi}{4}\left(\frac{d_1 + d_2}{2}\right)^2$

Error : $\frac{\pi}{4}\left(\frac{d_1 + d_2}{2}\right)^2 - \frac{\pi}{4} d_1 d_2$

$= \pi\ (d_1 - d_2)^2/16$ .... (1)

(b) By calculating the area separately and then averaging :

Area : $\frac{\pi}{4}\left(\frac{d_1^2 + d_2^2}{2}\right)$

Error : $\frac{\pi}{4}\left(\frac{d_1^2 + d_2^2}{2}\right) - \frac{\pi}{4} d_1 d_2.$

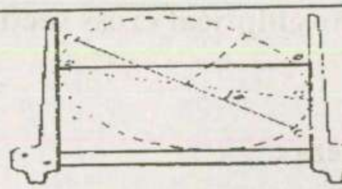
$= \pi\ (d_1 - d_2)^2/8$ .... (2)

The error is always positive but the error involved in method (b) is double that in method (a).

Precautions in use and errors from non-observance

- Callipers must be placed on the tree with movable arms, well opened and must not be forced on the tree thereby causing stress or damage to the arms.
- Reading must be taken before the calliper is removed.
- Two Diameters should be measured at right angles to each other and the Diameter is understood to be the average of the two Diameters.

Basal area is calculated by taking the average of the two Diameters and not by taking the Diameters separately and finally averaging the two areas.

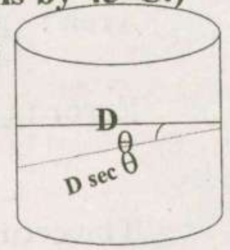


CC1 : Major axis
DD1 : Line of contact
DB : Diameter as read in callipers

- ➢ The two Diameters must be measured in proper orientation in proper orientation - they must be measured along the real major and minor axis.

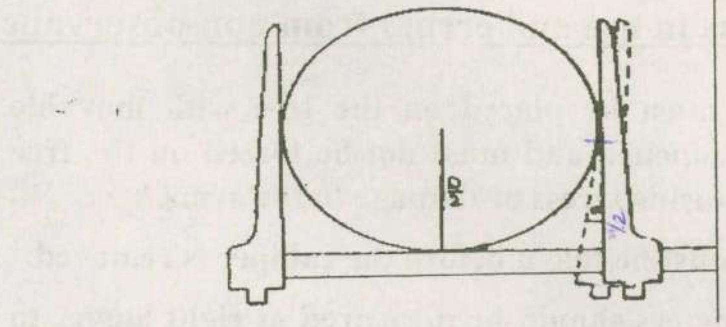
  (If the first Diameter is not measured on the major axis, the basal area is always underestimated. The error is always negative and the maximum error occurs when the line of contact deflects from major axis by 45°C.)

- ➢ Callipers must be placed at right angles to the axis of the tree. If the plane of callipers is inclined by an angle θ;



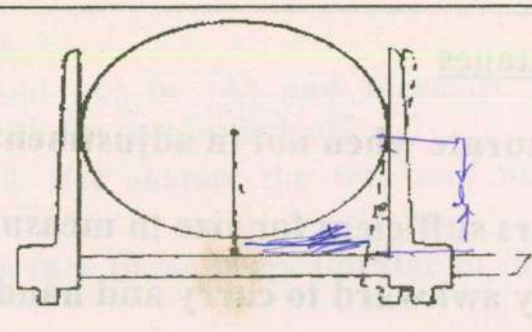
- ➢ Error = D Sec θ-D
  = D (Sec θ -1)

Percentage error
= 100 (Sec θ -1) : a function of θ.



- ➢ The two arms must be in contact with the tree and then movable arm should be at right angles to the scale arm.

  If the movable arm is not perpendicular to the scale arm and deviates from that position by angle + θ degrees the error in measured Diameter will be - d/2 tanθ and percentage error will be - 50 tanθ.



- ➢ The scale arms must also touch the tree (otherwise the percentage error will be -L tanθ /D x 100

  Where, L : Distance from scale to the point of contact of the movable arm and the tree.

  D : Diameter of tree

  ±θ : Angle of deviation of movable arm from the perpendicular position.

Advantages of Callipers

- ⌖ Diameter are read directly in centimeters and millimeters.
- ⌖ Points of arm touching the tree are always in sight and irregularities if any can be avoided.
- ⌖ By firmly pressing the arms against the tree bole, the loose swollen bark is crushed out and irregularity is avoided.
- ⌖ It is adaptable for use by unskilled labour.
- ⌖ Error are both positive and negative- Chance of neutralization.

tan θ = error / l   error = - l tanθ   % = error / dia x 100

Disadvantages

- Not accurate when not in adjustment.
- Callipers sufficient for size to measure large trees are very awkward to carry and handle.
- Two measurement are to be taken - often difficult in steep hilly terrain.
- Movable arm often sticks when the scale is wet or dirty thus wasting a lot of time

Tape

Band of cloth, reinforced cloth, plastic or steel about 1.5cm wide and of varying length.

- Used to measure girths of tree and logs.
- Usually graduated on one side in centimeters and millimeters but sometimes on both sides also to give measurements in metric system on one side and those in British System on the other.

Tree measuring tape : 3m long or 5m long

Land measuring tape : 5m, 10m, 20m, 30m, or even upto 50m.

Some tapes have graduations to read the Diameters directly - Diameter tapes.

$$\text{girth} = \pi \text{ Diameter}$$

Precautions

- Tape should not be old and therefore stretched or possibly with the end broken off.
- It must lie flat against the tree and not in twisted manner.
- It must lie in a plane perpendicular to the axis of the tree.
- The climber or shrub or branch if any vitiating girth measurement should be cut out before swinging the loose and of the tape round the tree.
- After the tape has been swung round, the end of the tape in the right hand of the measurer, should be brought under the starting point of the tape in the left hand to enable reading of the correct girth or Diameter.
- The tape should not be trailed on the ground and should not be rolled when wet or twisted

Advantages

- Convenient to carry.
- Does not require constant adjustment.
- Only one measurement is to be taken even with irregular trees.
- Easy to measure Diameters of logs lying on the ground.
- Error is always positive and systematic and easily adjustable.
- It negotiates whole circumference.
- Readings are consistent.

Disadvantages

- Exaggerates Diameter or girth measurement for a rough bark.
- Somewhat slower to use in areas with dense shrub growth.
- Lack of sight of full circumference.
- Inconsistency in plane of the tape around the tree.
- Difference in tension of the tape due to elasticity.
- Large trees : Difficult to handle for a single person.

Comparison between Tape & Calliper

- Error in basal area with taped girth is more than that calculated with callipered Diameter. 3k/32 and 2k/32 where

  Where $k = e^4(1+1/2e^2)\pi a^2$

- Operation of calliper is more difficult. Errors in operation of calliper are not negligible where as those with tape are negligible.
- Girth is approximately three times the Diameter. So tapes are expected to give more accurate result.

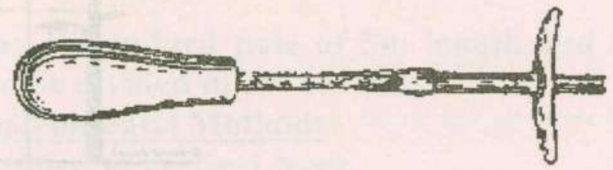
- Measurements with tape are more consistent.
- Easier to standardize the errors of tape which are always positive.
- Tape operation is simple - only one measurement.
- Easier to use a tape in case of a felled tree.
- Time factor.

<u>Choice between the two will depend upon the kind and circumstance or work.</u>

<u>Both are generally checked and standardized with steel tape before use.</u>

Bark Thickness

Measured by Swedish bark gauge



Instrument is in a form of a chisel which is pushed into the bark - provided with a cross arm which is curved to fit in with the curved tree surface. The tube fitted at the back of cross arm moves on chisel which is graduated in inches and centimeters.

As the edge penetrates the bark the tube is pushed back and the extent of penetration gives the thickness of the bark and is read off on the scale.

D.O.B = D.U.B +2 Bark thickness

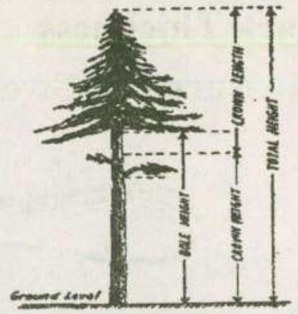
g=g.u.b., g′=g.o.b., t : thickness of bark

$g = 2\pi r = 2\pi (r' - t)$ r = radius U.B

$= 2\pi (g'/2\pi - t)$ r′= radius O.B

$= g' - 2\pi t$

Measurement of Height



Total Height : Straight line distances from the tip of the leading shoot (or the highest point of the crown) to the ground level.

Bole Height : Distance between ground level and crown point - the position of the first crown forming living or dead branch.

Commercial Bole Height : height fit for utilisation as timber.

Stump Height : height of top of the stump.

Standard timber bole height : height of the bole upto the point where average Diameter over bark is 20cm.

Crown length : Vertical measurement of crown from the tip of the crown to the point (x), half way between lowest green branch forming green crown all around and the lowest green branch of the bole.

Crown height : Height of (x) from the ground.

Methods of Measurement of Height

Ocular Estimate :

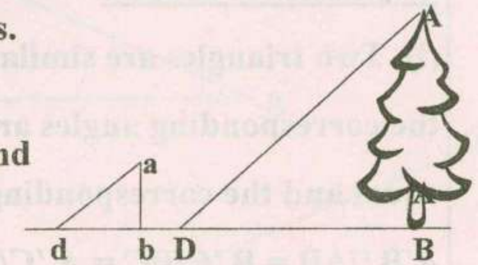
- Estimator judges the height by keeping a standard in mind.
- Taking a standard pole of 3m length and imagining the tree to be divided in 3m sections.

Non-instrumental Methods

– Applied to vertical trees.

- **Shadow Method**

A pole of convenient length is fixed upright on the ground and its height is measured. The shadow of the pole and the tree are measured



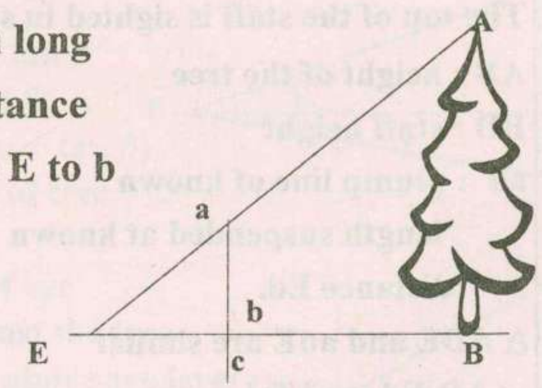
AB/ab = Bd/bd

$= AB = \frac{BD \times ab}{bd}$

Single Pole Method

AB : ht. of the tree

ac : pole about 1.5m long held at b so that distance from observer's eye E to b equal to ab



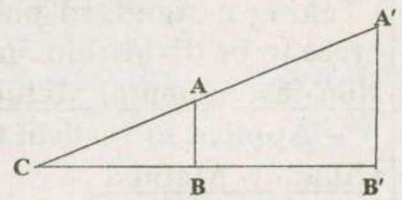
AB/ab = EB/Eb

$\Rightarrow$ AB = EB

Instrumental Methods

Based either on geometric principles of similar triangles or on trigonometrical principles on relations between the sides of a right angled triangle.

Geometric Principles



(i) Two triangles are similar if the corresponding angles are equal and the corresponding sides are proportional.

A'B'/AB = B'C/BC = A'C/AC(Applicable when the tree is vertical & tip and the base are visible)

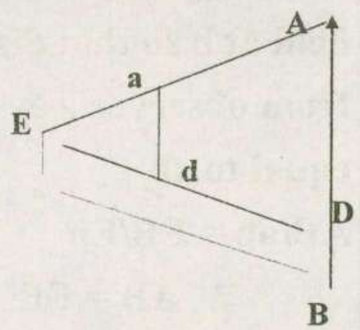
(ii) When the base is not visible, -A staff of height equal to observer's eye height is placed against the tree.

The top of the staff is sighted in stead of the base.

AB : height of the tree

BD : staff height

ad : plump line of known length suspended at known distance Ed.



Δ ADE and adE are similar

⇒AD/Ed = ad/Ed

AD = ad x ED/Ed

AB = AD + BD

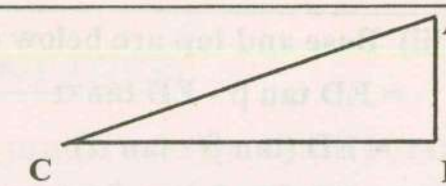
Trigonometric Methods

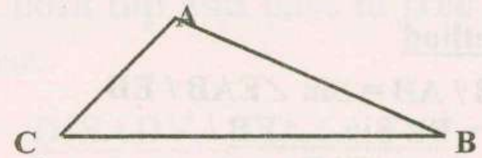
Sin ∠ACB = AB/AC

Cos ∠ACB = BC/AC

tan ∠ACB = AB/BC

Sin ∠ACB /AB = Sin∠CAB /BC = Sin ∠ABC/AC





Tangent Methods

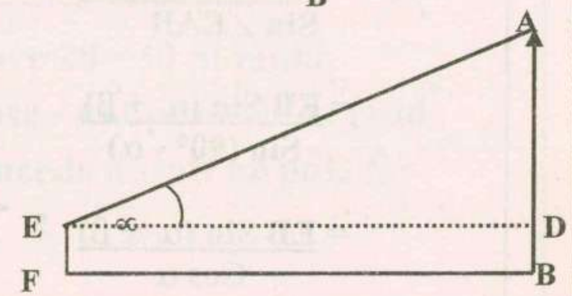
Level Ground

AD = ED tan α

AB = AD + BD

= EDtan α + EF

= BF tan α + EF



Sloping Ground

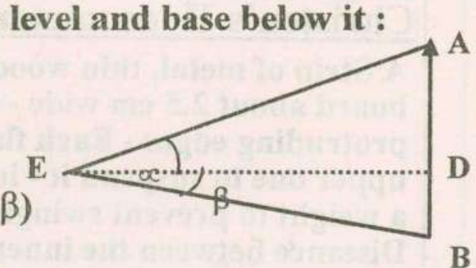
(i) Top of tree above the eye level and base below it :

AB = AD + DB

= ED tan α + ED tan β

= ED (tan α + tan β)

= EB Cos β (tan α + tan β)



EB : distance of base of tree from observer's eye

for accuracy a staff of eye height is placed against the tree.

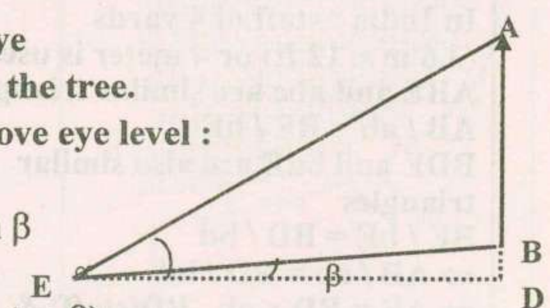
(ii) Top and base are above eye level :

AB = AD - BD

= ED tan α - ED tan β

= ED (tan α - tan β)

= EB Cos β (tan α - tan β)

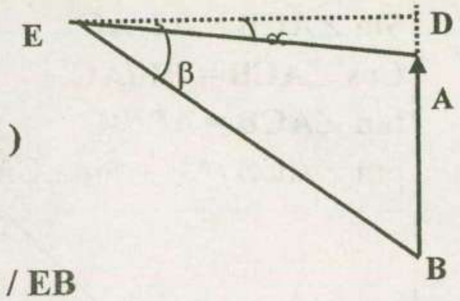


(iii) Base and top are below eye level : $AB = BD - AD$

$= ED \tan\beta - ED \tan\alpha$

$= ED (\tan\beta - \tan\alpha)$

$= EB \cos\beta (\tan\beta - \tan\alpha)$



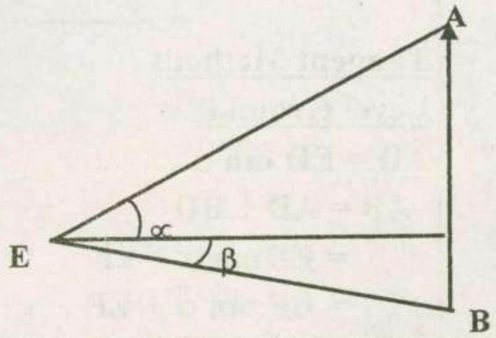
(ii) Sine Method

$\sin\angle AEB / AB = \sin\angle EAB / EB$

$\Rightarrow AB = \dfrac{EB \sin\angle AEB}{\sin\angle EAB}$

$= \dfrac{EB \sin(\alpha + \beta)}{\sin(90° - \alpha)}$

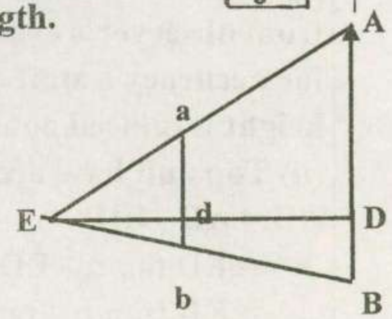
$= \dfrac{EB \sin(\alpha + \beta)}{\cos\alpha}$



Instruments based on Geometric Principle

Christen's Hypsometer

A Strip of metal, thin wood or even card board about 2.5 cm wide - two flanges or protruding edges - Each flange having a hole - upper one to suspend it - lower one to suspend a weight to prevent swinging.
Distance between the inner edges : 33 cm
Graduated for a staff of known length.
In India : staff of 4 yards (3.6 m ≈ 12 ft) or 4 meter is used.
ABE and abe are similar triangles:
$AB / ab = BE / bE$
BDE and bdE are also similar triangles
$BE / bE = BD / bd$
$\Rightarrow AB / ab = BD / bd$
$\Rightarrow AB = \dfrac{BD \times ab}{bd}$ BD(staff) & ab are constants

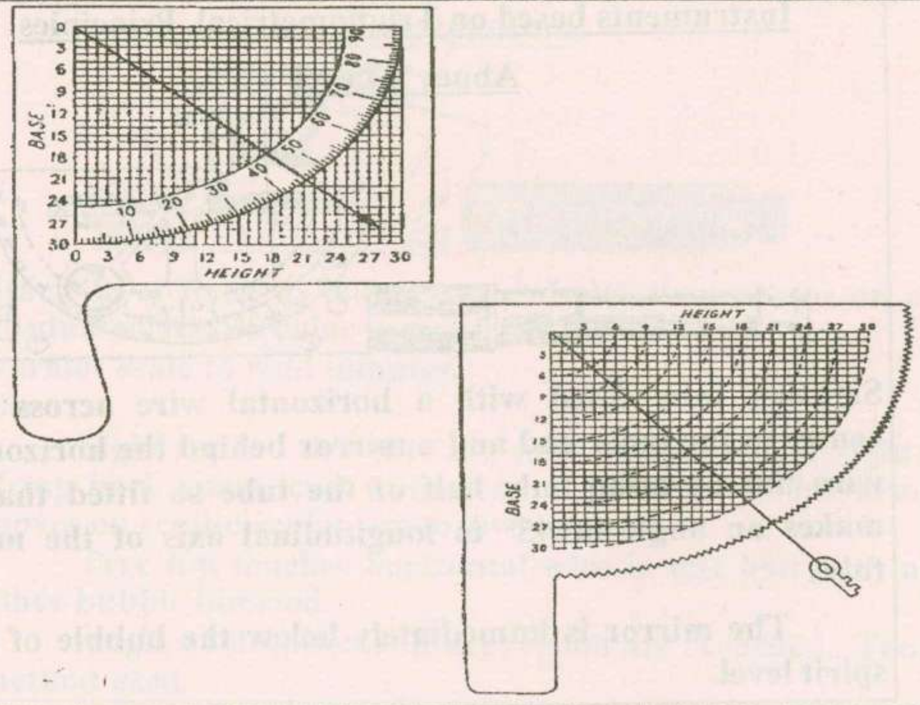


ADVANTAGES

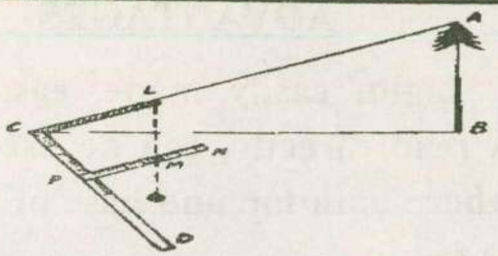
Light, easily made, easily transported, heights read directly, can be used from a point from where both top and base of tree are visible, quicker to use.

DISADVANTAGES

Heights above 20 - 30 m make graduations very close - not possible to read accurately - always needs a staff or pole for measurement.



IMPROVISED CALLIPERS



1) The sliding arm is graduated.

2)A plumb line is attached to the fixed arm.

The calliper is opened out to keep the sliding arm to read centimeters on scale arm equal to distance of observer from the base of the tree in meters.

CP in cm represent BC in meters.

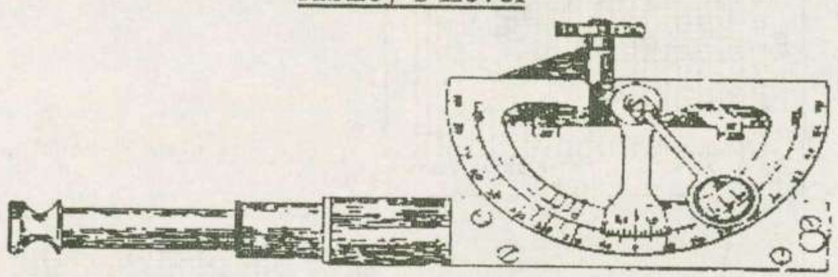
Δ s ABC and MNL are similar

$\Rightarrow AB / BC = MN / LN = MN / CP$

$\Rightarrow AB = \frac{BC \times MN}{CP}$ (MN represents ht. in mt)

Instruments based on Trignometrical Principles

Abney's Level



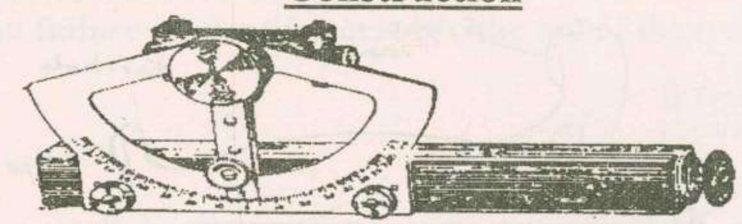
Sighting tube fitted with a horizontal wire across the centre at the inner end and a mirror behind the horizontal wire but covering only half of the tube so fitted that it makes an angle of 45° to longitudinal axis of the main tube.

The mirror is immediately below the bubble of the spirit level.

Topographical Abney's Level

Protactor - graduated on both sides - one side gives rise and fall per chain horizontal distance and the other side gives the percentage rise and fall (i.e. percentage slope) - The instrument used with a trailor tape - which is an ordinary steel tape 1 to 2 chains long - on one side the tape is graduated to read distance while the other side gives trailor additions corresponding to various slopes recorded by Topo Abney's land. These trailor additions represent the distance which must be added to the sloping chain length to make it equivalent to horizontal distance for a particular slope read by Topo Abney's level.

Construction



Spirit level fixed to index arm ⊥ Index arm moves on a graduated semicircular arc.

Vernier scale to read minutes.

Use :

Sight top --- this tilts the tube bubble out of sight. Bring back spirit level to horizontal position - index arm moves on semi-circular arc to give angle.

Tree top touches horizontal wire in one half and in other bubble bisected.

Angle of elevation and depression are recorded. Tan method used.

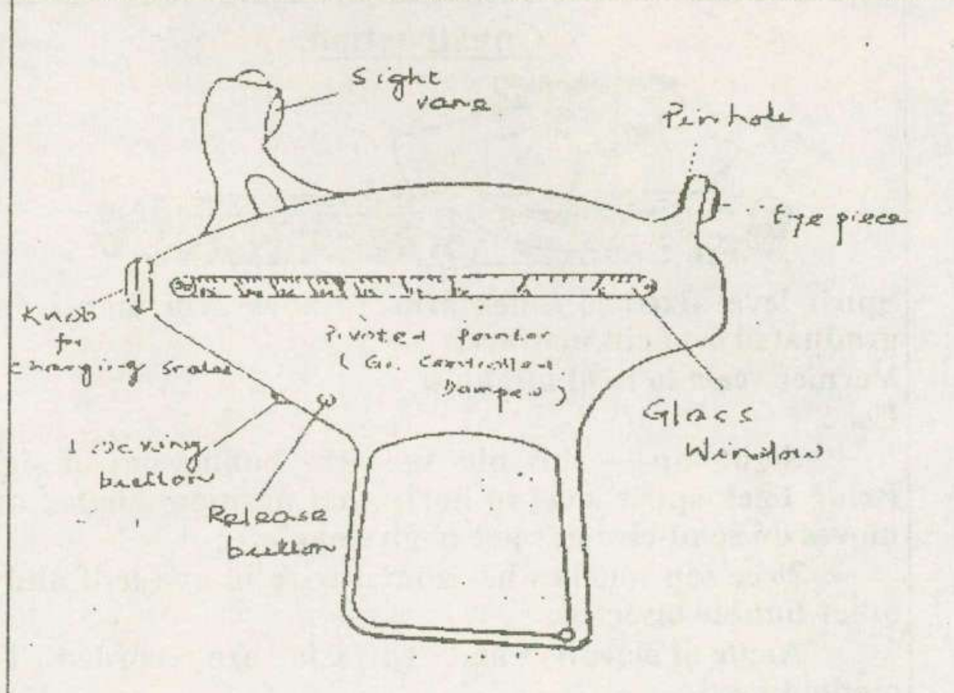
Abney's Level

Advantages :-

- **Accurate angle (because of vernier)**
- **Small, light useful in hills.**

Disadvantages :-

- **No stand - shaking of hands sighting top and bottom difficult at times time consuming.**
- **Adjust spirit level while simultaneously looking to top or bottoms.**



HAGA ALTIMETER

Gravity controlled damped, pivoted pointer, six scales one each on Hexagonal bar.

Fixed Distance Scales

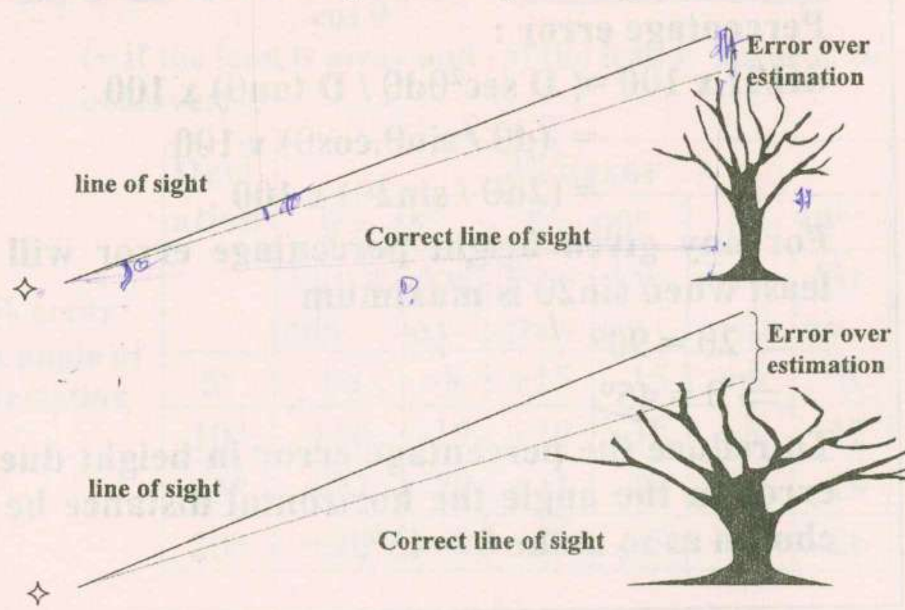
15	**20**	**25**	**30**	**m**

Use one standing at that distance, read height on the scale.

If % scale is used than % of horizontal distance is the height.

In case land is not level make another shot at the base. Add or subtract if tree base below or above ground.

FIGURE 10 Errors in height measurements from failure to identify correctly the top of the tree



$\tan\theta = \frac{H}{D}$

$\Rightarrow H = d\tan\theta$

$\tan(\theta + d\theta) = \frac{H+dh}{D}$

$\frac{\tan\theta - \tan d\theta}{1+\tan\theta\tan d\theta} = \frac{H+dh}{D}$

Sources of Error in Height Measurement

✡ **Instrumental Errors**

✡ **Personal errors**

✡ **Error due to measurement**

- distance measurement
- angle measurement

$H = D \tan\theta$

H : height,

D : horizontal distance

θ : angle of elevation

Error :

$dH/d\theta = D \sec^2\theta$

Percentage error :

$dH/H \times 100 = (D \sec^2\theta d\theta / D \tan\theta) \times 100$

$= (d\theta / \sin\theta.\cos\theta) \times 100$

$= (2d\theta / \sin 2\theta) \times 100$

For any given height percentage error will be least when sin2θ is maximum

$\Rightarrow 2\theta = 90°$

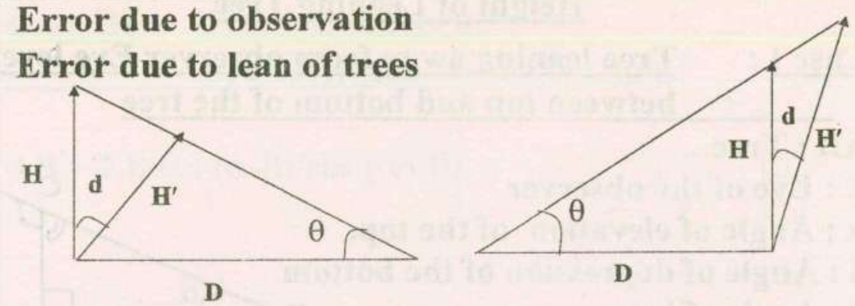
$\Rightarrow \theta = 45°$

To reduce the percentage error in height due to error in the angle the horizontal distance be so chosen as to make θ = 45°.

sin 2θ = 2sinθ cosθ

sin(θ+θ) = sinθ cosθ + cosθ sinθ = 2 sinθ cosθ

- **Error due to observation**
- **Error due to lean of trees**



θ : angle of elevation

d : angle of lean

$H = D \tan\theta$ ....(1)

$H'/\sin\theta = D / \sin(180° - \{\theta + (90° - d)\}$

$= D / \sin\{\theta + (90° - d)\}$

$= D / \{\sin\theta \cos(90 - d) + \cos\theta \sin(90 - d)\}$

$= D / \cos(\theta - d)$

$H' = D \sin\theta / \cos(\theta - d)$

$= D \tan\theta . \cos\theta / \cos(\theta - d)$............... (2)

Percentage error = (H-H′)/ H′ x 100

$= \{ \frac{\cos(\theta \pm d)}{\cos\theta} - 1 \} \times 100$

(+ if the lean is away and - if the lean is towards the observer)

% error α angle of deviation

Deviation	% Error θ = 45°		θ = 60°		θ = 30°	
	Towards	Away	Towards	Away	Towards	Away
5°	+8	-9	+15	-15	+5	-5
10°	+16	-19	+29	-32	+8	-12
15°	+22	-29	+41	-48	+11	-19
20°	+28	-40	+53	-65	+13	-26

Height of Leaning Tree

Case I : Tree leaning away from observer Eye level lies between top and bottom of the tree

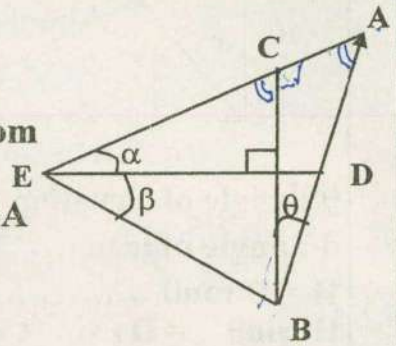
AB : Tree

E : Eye of the observer

α : Angle of elevation of the top.

β : Angle of depression of the bottom

θ : Angle of lean



In Δ ACB : $\angle ECB = \angle CAB + \angle CBA$

$\Rightarrow \angle CAB = \angle ECB - \angle CBA$

$= (90 - \alpha) - \theta$

$= 90 - (\alpha + \theta)$

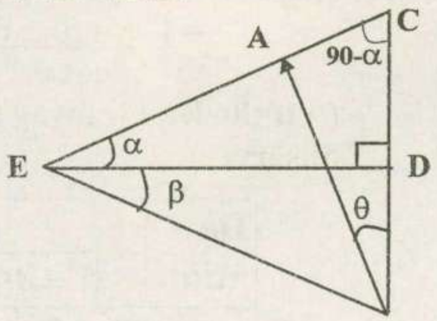
In Δ AEB : $AB / \sin \angle AEB = EB / \sin \angle EAB$

$\Rightarrow AB = EB \sin \angle AEB / \sin \angle EAB$

$= EB \sin (\alpha + \beta) / \sin [90° - (\alpha + \theta)]$

$\Rightarrow AB = EB \sin(\alpha + \beta) / \cos (\alpha + \theta)$

(CaseII : Leaning towards the observer)



In Δ ACB

$\angle EAB = \angle ACB + \angle ABC$

$= 90 - \alpha + \theta$

In Δ ACB

AB/Sin AEB = EB/Sin EAB

$\Rightarrow$ AB = EB.Sin AEB/Sin EAB

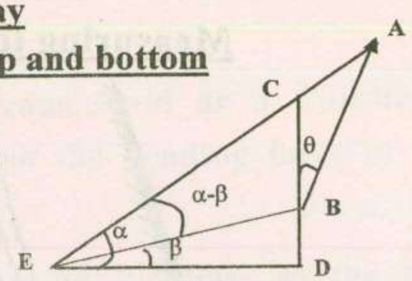
$= EB \operatorname{Sin} (\alpha + \beta)/\operatorname{Sin} (90 - \alpha + \theta)$

$= EB \operatorname{Sin} (\alpha + \beta)/\operatorname{Sin} [90-(\alpha - \theta)]$

$AB = EB \operatorname{Sin} (\alpha + \beta)/\operatorname{Cos} (\alpha - \theta)$

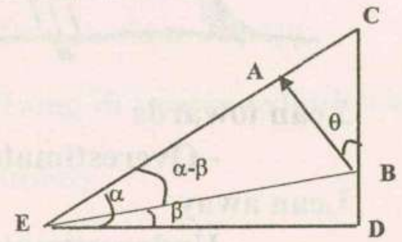
Case III : Tree leaning away Eye below the top and bottom

$AB = EB \sin (\alpha-\beta)/\cos (\alpha + \theta)$



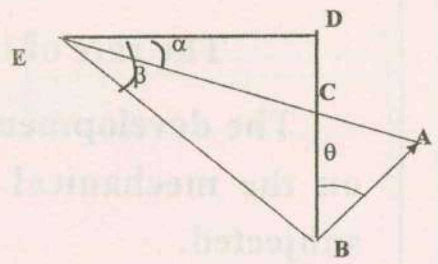
Case IV : Tree leaning towards observer Eye below the top and bottom

$AB = EB \sin (\alpha-\beta)/\cos (\alpha-\theta)$



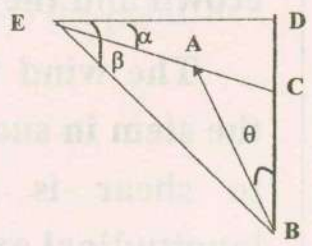
Case V : Tree leaning away Eye above the top and bottom

$AB = EB \sin (\beta-\alpha)/\cos (\alpha-\theta)$

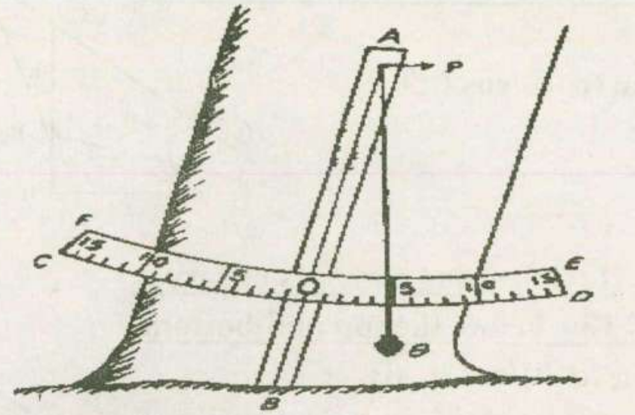


Case VI : Tree leaning towards observer Eye above the top and bottom

$AB = EB \sin (\beta-\alpha)/\cos (\alpha+\theta)$



Measuring the Lean of a Tree



Lean towards
- Overestimated

Lean away
- Underestimated

STEM FORM

The rate of taper of a log or stem.

The development of the form of stem depends on the mechanical stresses to which the tree is subjected.

Stress come from dead weight of stem and crown and the wind force.

The wind force causes the tree, to construct the stem in such a way that the relative resistance to shear is same at all the points on the longitudinal axis of the stem.

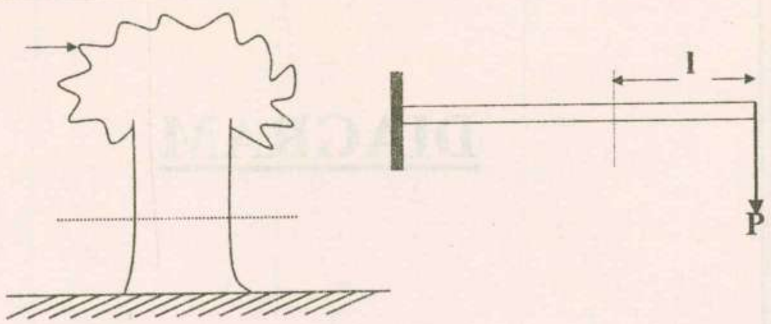
METZGER'S THEORY :

Tree stem should be considered as a Cantilever beam of uniform size against the bending force of the wind.

The greatest pressure is on the base so the tree reinforces towards the base. More material deposited at lower ends.

Tree in Open	Vs.	Tree in close canopy
(Short, with rapidly tapering boles)		(Long & nearly cylindrical boles)

$W = P/A$



P : Force applied at the free end.
l : distance of a given cross section from the point of application of this force.
d : Dia. of the beam at this point.
S kg/cm² : Bending Stress

By rule of mechanics : $S = 32Pl/\pi d^3$

If W : Wind pressure per unit area

A : Crown area

then $P = W \times A$

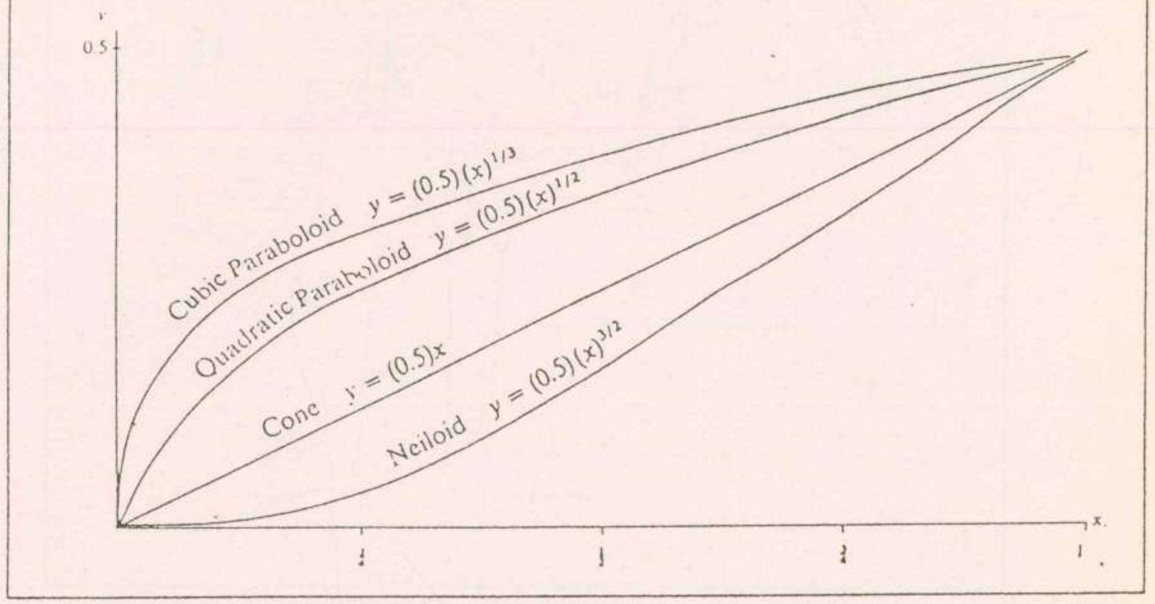
$$\Rightarrow S = \frac{32}{\pi} \times \frac{W \times A \times l}{d^3}$$

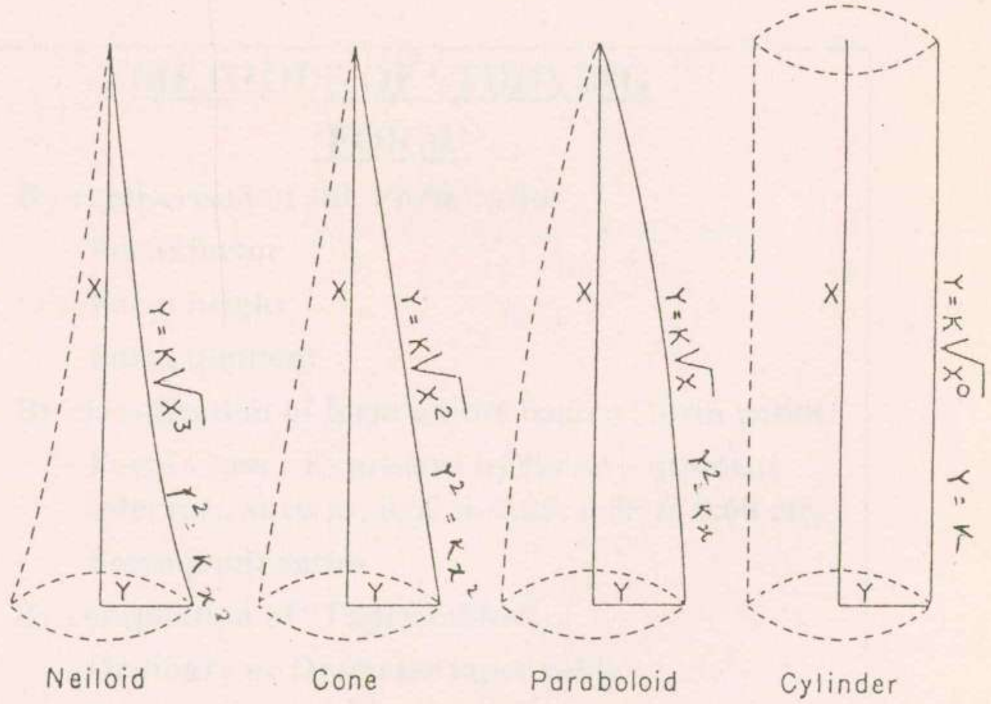
$$\Rightarrow d^3 = \frac{32 \times W \times A \times l}{\pi \times S} \approx kl \text{ for a given tree}$$

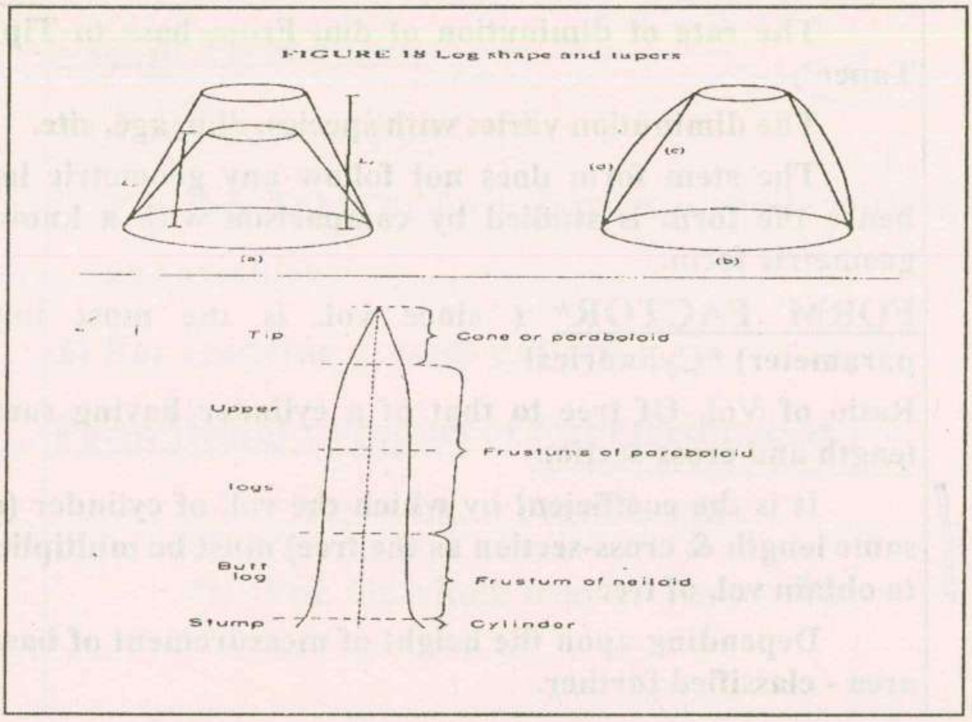
$\boxed{d^3 \approx kl}$: Cubic paraboloid

DIAGRAM

FIGURE 17 Solids of revolution







METHODS OF STUDYING 'FORM'

A) By comparison of std. Form ratios

- **Form factor**
- **Form height**
- **Form quotient**

B) By classification of form on the basis of form ratios

- **Form Class : Expressed by forms - quotient intervals, such as. 0.50 to 0.55; 0.55 to 0.60 etc.**
- **Form point ratios**

C) By compilation of "Taper tables"

- **Ordinary or Diameter taper table**
- **Form class taper table**

The rate of diminution of dia. From base to Tip - Taper

The diminution varies with species, dbh, age, site.

The stem form does not follow any geometric law hence the form is studied by comparison with a known geometric form.

FORM FACTOR* (since vol. is the most imp. parameter) *Cylindrical

Ratio of Vol. Of tree to that of a cylinder having same length and cross-section

It is the coefficient by which the vol. of cylinder (of same length & cross-section as the tree) must be multiplied to obtain vol. of tree.

Depending upon the height of measurement of basal area - classified further.

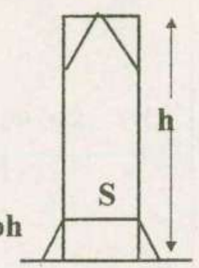
Artificial Form Factor

= Vol. of whole tree / Vol. of cylinder with bh. basal area

bh is arbitrary no reln. to tree ht.

but used universally for bh is std.

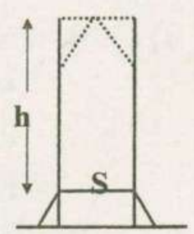
$V = f.S.h. \Rightarrow f = V/Sh$



Absolute Form Factor

= Vol. of tree above pt. of 'S' measurement / Vol. of cylinder of S & h dimensions

(Basal area measured at any convenient ht.)



Normal Form Factor (True Form Factor)

Vol. of whole tree / Vol. of cylinder with S measurement of some % of ht.

Absolute and normal are no longer used.

Unless otherwise stated Form factor in India means artificial with ba. at 1.37m

Uses of Form Factor

1) For computation of vol.

For this Table of form factors is made with d, h as variables

2) For studying growth pattern

Form Height : Product of form factor & ht.

V/S = f.h. = Form height.

'V' Vol. Of whole tree 'S' ba. at dbh.

Form Quotient :

Absolute F.Q

q = mid dia. above bh / dia. at bh

Normal Form Quotient

= dia.at 0.5 h / dia at bh

but for h = 2bh   q = 1.

Unless otherwise stated Form Quotient means **"Absolute Form Quotient"**

= dia at ½ (h-4.5) / dia at bh

Form Point Ratio

% ratio of the height of the centre of wind resistance(Form point) to the total tree height. The Form point is located approximately at the centre of gravity of crown since crown offers max. resistance. This point is the focal point of wind force.

The Greater the Form point ratio the more nearly cylindrical will be the from of tree.

The point is difficult to locate in crown; (Subjective).

Taper Table :

If sufficient dia. are taken at successive pts. along stem. One can prepare taper tables.

Form

Form Factor

Form Quotient

Form Point Ratio

Form Class : Intervals in which the range of Form Quotients of trees is divided for classification.

Taper Table : Actual form is expressed by dia at fixed points from base to the tip of the tree.

(i) *Diameter Taper Table :* give taper directly for dia at brease height, without refering to the tree form.

(ii) *Form Class Taper Table :* Dia at different fixed points on the stem expressed as percentage of d.b.h. (u.b) for different form classes.

Taper Table portrays stem form in such a way that the data can be used in calculation of stem vol. or in construction of Volume Table.

Equations of tree form

Despite the fact that trees don't conform to any Geom. Shape, Some equations to describe tree form were made;

$$\text{Diameter quotient} = \frac{\text{d at any given point}}{\text{d.b.h.}}$$

Behre's Formula

$$d/d.b.h. = l/(a+bl)$$

a and b are constants such that a+b = 1& l is the distance from the tip of the tree. 'l' is in terms of % of length of tree bet. bh & tip.

Hojer's Formula

$$d/d.b.h. = C \log [(c+l)/c]$$

d is Dia at 'l' (same meaning as above). C, c are constants for each form class.

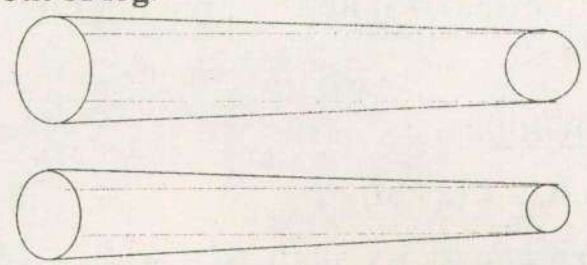
"Trees assume infinite variety of shape"-- explicit analytic definition of tree form requires considerable computational effort -- yet lacks generality"

Hence simple functions, graphical methods is adequate for most purposes.

Measurement of Vol. of logs or felled trees

The ultimate purpose is to estimate wood& sell. So volume measurement is important.

Dia at the thin end of log determines the sawn vol. that can be taken out of log.



With taper Sawn % decreases

Lengths depend on market requirement.

Volume of Logs

Form	Vol. of the whole solid	Vol. of Frustum
1) Cylinder	S.l. ($\pi r^2 l$)	S.l.
2) Paraboloid	$\frac{S.l}{2}$	$\frac{(S_1+S_2)}{2} \times L$ -- Smalian's Formula Sm x l ----- Hubers formula

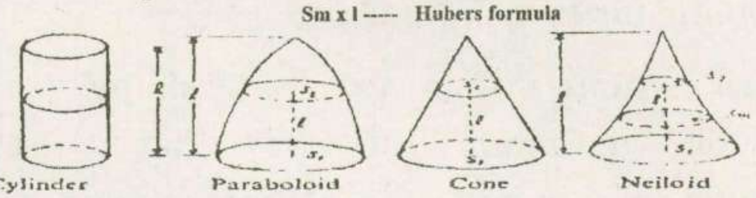


Fig. 70 Figure to illustrate formulae used to calculate volumes [ ] various solids or their frustums

Form	Vol. of the whole solid	Vol. of Frustum
3) Cone	$\frac{S.l}{3}$	$\frac{(S_1+S_2+\sqrt{S_1S_2})}{3} \times l$
4) Neiloid	$\frac{S.l}{4}$	$\frac{(S_1+S_2+4Sm)}{6} \times l$

S is sectional area at the base
S_1 is sectional area at the thick end
S_2 is sectional area at the thin end
S_m is sectional area at the middle

Smalians Formula : Easy when logs are stacked but slightly over estimates

Quarter Girth Formula

In India & UK Quarter Girth Formula is used (called Hoppus rule in UK)

Vol. of log $=(g/4)^2 \times l$

g is girth at middle

Vol $= \pi r^2 l$ $r = g/2\pi$

$$= \left(\frac{g^2}{4\pi} \times l\right) \text{ if } \pi \approx 4$$

Vol $=(g/4)^2 \times l$

Since 4 in place of π in denominator, it underestimates.

Vol. by Quarter Girth Formula is 78.5% of true vol. (used for rough approximation of usable - except bark, rough squarred)

Preferred because of its simplicity

Characteristics of QG Formula

- **Vol. less than that of cylinder**
- **This gives fair idea of squared vol. full circular vol. does not represent marketable vol.**
- **Compensates +ve error in basal area (circle - minimum circumference)**
- **Requires one measurement : easy to adopt.**
- **Using QG Vol. / True Vol. = π/4 ;True vol. can be found.**
- **At present ISI std. for purchase of timber for Railway, Defence specify vol. by Quarter Girth Formula.**

Some terms used for Stem Wood vol.

Commercial Vol. : Vol. of stem measured upto which conversion is done except stump.

Std. Stem timber : Round Vol. of stem upto 20cm ob (but vol. Ub) from ground level.

Std. Stem Smallwood : Round vol. of stem between 20cm & 5cm Ob. (vol. inclusive of bark)

Measuring Branches

Direct Method :

Big branches can be measured for vol.

Small ones are stacked. Stacks of known std. LBH (24′ x 6′ x 5′) or 1.8 x 1 x 1m

But firewood is sold in Qtls. (Weight conversion of stacked to weight of branchwood is essential).

Xylometric Method

Accurate method of irregularly shaped branchwood. Pieces of wood & sub-merged in the vessel.

Measured by vol. of water displaced in a Xylometer. (Graduated vessel tank.).

Specific Gravity Method

If Sp. Gravity of wood is known vol. can found.

Sp. Gravity = wt. of wood/wt. Of same vol. of water

Vol.in cc = Weight(in gms.) / Sp. Gravity-in cgs sym.

Conversion Factors : For practical use

Solid vol./Stacked vol. = determined by Expt.

Pine 0.46 UP Ranikhet

Oaks 0.50

Weight/Stacked vol. = determined by Expt.

5.76 qtl. Per m^3 stack (Oak)

3.48 qtl. Per m^3 stack(others)

On Stacking : Moisture losses : 20-30% Oaks

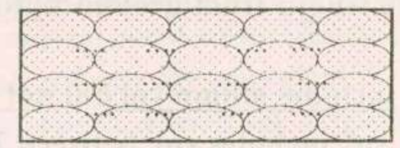
by weight 50% Rhododendrom

Depends on time. 75% in 177 ; 90% 276 days-oaks

Stacked Vol. into Solid Volume

Contd.

Photographic Method



Optical axis of Camera Lens ⊥ to side of pile.

Dots in solid / dots in total photo

= f = Solid Vol. / Stacked Vol.

Use dot grid

Sources of Error In Vol. Measurement

- **Errors arise because cross-sections are not circular.**
- **Errors due to abnormal taper or other defects.**
- **In broad leaved there are alterations due to branching. If separation not done at such joints errors are introduced. (Faulty logging).**
- **Error due to : Calliper or tape not held ⊥ to axis.**
- **Extent of error increases with the increase in the length of log.**
- **Errors due to defects : rot, burn, hollowness.**
- **Errors due to curvature of the stem length measured in st. line between two ends.**
- **In basal area computation better results with dia with callipers than with tape.**
- **In Stacks : Errors due to faulty stacking crooked ones : stacked with difficulty.**
- **Moisture losses & season : Height of stack changes.**

Timber and Smallwood Vol.
Rules of Measurement (FRI)

- ⇨ Timber vol.be measured ub
- ⇨ Small wood vol. be measured Ob.
- ⇨ Std timber bole length from ground upto 20cm dia ob in st. line.
- ⇨ Std timber vol includes stump vol but not bark vol.
- ⇨ Std smallwood vol. includes vol. between 20cm and 5cm Ob. (≥ bark vol)
- ⇨ Of felled
  - ⇨ Measured by dividing tree in equal sections.
  - ⇨ Measure length of each section.
  - ⇨ Ub Dia at middle of each section.
  - ⇨ Ob Dia at middle of each smallwood
  - ⇨ Length of section 3m, end part added if less than 1.5 or separate.
  - ⇨ If middle is abnormal equal short distance on both side and av.

Vol. Of Standing Trees

Need :

- To know volume standing; production; productivity.
- To know pattern of increment in an interval - increment studies.
- To monitor the yield and to control removals.
- Technical inputs : eg. For fixing age of maturity (Rotation); choice of species.
- For Planning felling : Removal expected; expenditure; transport revenue etc.

VOL. OF STANDING TREES

METHODS OF ESTIMATION

Ocular Estimate :

By seeing the tree carefully based on past record; experience: Subjective : requires great practice with occasional verifications.

Partly Ocular & Partly by Measurement:

Measure dia, height; estimate vol. Assuming form factor: Subjective: needs experience

Direct Method:

By measuring height and dbh and also dia at various heights or taking measurements as if tree is felled by climbing.

Time consuming : one or two possible.

Indirect Method:

By measuring dia. at various heights by instruments (dendrometer/ Relaskop).

Volume Table

Volume of a species for one or more given dimensions based on the measurement of large number of trees.

Assumption:

Trees of same species of same dimensions have same volume.

Applicability:

See if the table is applicable to the locality. Even if applicable, may not give correct vol. (Based on the study of a large population : Gives fairly good estimate of volume of a population)

Variables:

Variables are / can be dia/ht/form
(Some measure of form)

$$V = f(d, h, f)$$

Correlation with

d only	**: applicable to small area.**
d, h	**: applicable to larger area, more measurements required**
d, h & f	**: more precise but difficult to use**

Volume Table

Gives volume of a tree of known dimensions.
Volume of a tree depends of dia, ht, form.
$V = \pi . r^2 . h . f$

r is squared, error also gets squarred. So dia be measured accurately.

If the volume table is to be based on a single variable then it must be dbh.

Reasons:

- **Involves min error**
- **Easily measured**

An error of 10% in Dia.Results in greater error in vol. than a similar error in ht. or form.
It is safer to assume trees of similar dbh to have same ht and /or form than vice-versa

Effect of Error in Dia & Ht. Measurement

dbh(ob) 30cm : ht 20m : FF 0.3

Dia cm	Ht m	FF	Vol m^3	%±
30	20	0.3	0.4239	-
33 (10%)	20	0.3	0.5129	+20.99
30	22(10%)	0.3	0.4663	+10%

Volume Table Types

Based on no. of variable	Based on scope of application	Based on kind of out turn
1) diam. Only (One Va) local Vol.T.	1) Considers Av. Vol. Of trees over large area **General Vol. T** Two variables D & H	1) **Std. Vol. T** Base to 20cm Std. Timber. D is dbh (ob) V is ub. (Stem) and Small-wood (20cm - 5cm)
2) Dia & Ht (two) (i) Total ht. (ii) Merchantable ht. (iii) Site Quality. As ht. is a index of, S.Q	2) Over a limited region. **Regional Vol.T**	2) **Comm. Vol. T** Without Stump. Upto Comm. Usable. Market change useless. Coups
3) Form class Vol. Table (3. Var.) Accurate but difficult: not made in INDIA	3) **Local Vol. T.** Study of a small area. One Var. (D). Generally derived from Gen. Vol.T.	3) **Sawn out turn Vol. T.** Without Stump sawn timber.
		4) **Assortment Table** Various thin end dia. 15, 20, 25 cm
		5) **Sawn out-turn assortment T** No. of std. size sawn pieces

Preparation of Volume Table

Methods Available

- Graphical Method
- Regression Eqn. (Method of Lease Square,best fit)
- Alignment Chart Method

Graphical Method

Old Traditional now less used

Selection of Trees

- Trees of typical height and development
- Evenly distributed over entire range of distribution of D &H, with defect other than normal not selected.
- Average, not bigger ones.

No. of trees required depends on

Grouping adopted; Precision desired; Individual deviation from mean.

Covering whole range of Dia and height, 1000 trees selected gives satisfactory results. [Silvicultural Research Code].

Preparation by Regression Method requires less no.

A smaller no. of properly selected trees give better than large no. with improper selection.

MEASUREMENT

Depends on kind under Preparation.

General Volume Table

Standard Timber and Small wood measured separately dividing length in 3m secn. Part if less than 1.5m added- kept separate if more than 1.5m. Volume of stem timber Ub at mid of each secn &Ob at mid of each small wood section Calculated separately, added. Similarly Branchwood.

Data of individual tree compiled (incl. Solid Branch

TABLE I

Shorea robusta

Commercial timber in the round.

(Volume calculated by full basal area).

Diameter class	Total height of tree				
	41'—60'	61'—80'	81'—100'	101'—120'	121'—140'
Inches	c. ft.	c. ft.	c. ft.	c. ft.	c. ft.
Over 8—12	5	7	9½	...	...
,, 12—16	8½	16	23	28	...
,, 16—20	13½	27	38	49½	61
,, 20—24	21	39	56½	74	91
,, 24—28	30½	54½	77½	101½	125
,, 28—32	45	73	102	132½	161
,, 32—36	...	...	132½	164	199½

N. B.—Only exceptional divisions export trees below 8" diameter as timber. In these divisions the local officer must use his local figures for the lower diameter classes.

TABLE II

Shorea robusta

Sawn Timber. Normal good coupe.

Diameter class	Total height of tree				
	41'—60'	61'—80'	81'—100'	101'—120'	121'—140'
Inches	c. ft.	c. ft.	c. ft.	c. ft.	c. ft.
Over 8—12	1½	3	4	...	...
,, 12—16	4	7½	10½	13½	...
,, 16—20	6½	12	18	23	28½
,, 20—24	9½	18	26½	34½	44
,, 24—28	13½	25½	37	48½	60½
,, 28—32	20	35½	50	64½	78½
,, 32—36	...	...	65½	81	96½

N. B.—Only exceptional divisions export trees below 8" diameter as timber. In these divisions the local officer must use his local figures for the lower diameter classes.

Volume Table Types

Based on no. of variable

1) diam. Only (One Va) local Vol.T.

2) Dia & Ht (two)
   - (i) Total ht.
   - (ii) Merchantable ht.
   - (iii) Site Quality. As ht. is a index of, S.Q

3) Form class Vol. Table (3. Var.) Accurate but difficult: not made in INDIA

Based on scope of application

1) Considers Av. Vol. Of trees over large area <u>General Vol. T</u> Two variables D & H

2) Over a limited region. <u>Regional Vol.T</u>

3) <u>Local Vol. T.</u> Study of a small area. One Var. (D). Generally derived from Gen. Vol.T.

Based on kind of out turn

1) <u>Std. Vol. T</u> Base to 20cm Std. Timber. D is dbh (ob) V is ub. (Stem) and Small-wood (20cm - 5cm)

2) <u>Comm. Vol. T</u> Without Stump. Upto Comm. Usable. Market change useless. Coups

3) <u>Sawn out turn Vol. T.</u> Without Stump sawn timber.

4) <u>Assortment Table</u> Various thin end dia. 15, 20, 25 cm

5) <u>Sawn out-turn assortment T</u> No. of std. size sawn pieces

Ht. Class

Dia class	7.5 5-10m				12.5 10.1-15m				17.5 15.1-20m				22.5 20.1-25m			
2.5-7.5 5*	D	H	V	N	D	H	V	N	D	H	V	N	D	H	V	N
7.51-12.5 10*																
12.51-17.5 15*																
17.51-22.5 20*																

Table of Basic Averages

Guidelines for Dia Ht. Class - Interval

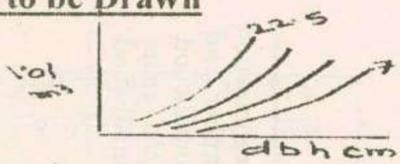
Dia Class
4″ Attaining maturity 20″dbh +
2″ 12″ - 20″dbh
1″ under 12″ dbh

Ht. Class
20′ Attaining maturity at 80′ and +
10′ below 80′

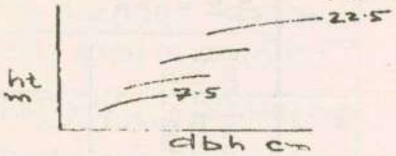
General Volume Table

Graphical Curves to be Drawn

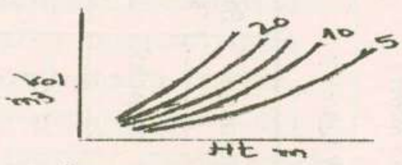
- **Av. Dia bh plotted against Volume for each ht. class separately. Smoothened & harmonized volumes against mid Dia read and tabulated**



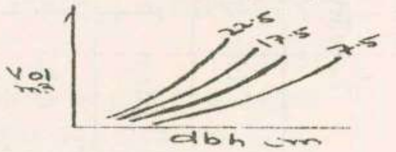
- **Av. Ht. plotted against Av. Dia for each ht. class separately**
  Smoothen: Harmonise.
  Av. Hts. for mid Dia read and tabulated



- **Av. Vols. and Av. Hts. plotted for each Dia class separately data from 1 & 2 used.**
  smoothen: Harmonise.
  Av. Vols. read for mid-ht. class and tabulated



- **Av. Vol. From 3 above plotted against mid Dia. Separately for each ht.class**
  smoothen: Harmonise.
  Final Vol. Read against mid Dia and tabulated



Test of Precision of Volume Table

To check how accurate volume table is some checks are applied.

In these tests the felled tree data used in making volume table is used to compare with that obtained by volume table.

♦ **Aggregate Check**

The total volume obtained from field for all Dias and heights is compared with that obtained from volume table (or from Curves by taking actual average Dia and actual average height. Difference be less than 1%.

♦ **Height / Dia. Class Check**

Applied to each Dia & height class field data volume and volume obtained from table (Curve) for a class (should not differ by more than 5%)

About 20 Trees per class.

Relative Check

When two or more tables are derived from same data but independently e.g. Local Volume Table made directly based on field data and Local Volume Table derived from General Volume Table made on same field data.

The difference should not exceed 3%.

Average Deviation Check

Laborious : applied in exceptionally important case.

The value obtained from table (Curve) and field of a tree differ.

The average of deviation should be as low as possible.

TABLE III

Shorea robusta

Locality Quality I.

Diameter class	Timber in round		Smallwood stem and branch	Branchwood timber and smallwood *plus* stem smallwood
	Stem	Branch		
Inches	c. ft.	c. ft.	c. ft.	c. ft.
Over 4—8	0	0	8½	8½
,, 8—12	13	0	9½	9½
,, 12—16	33	0	10	10
,, 16—20	60	4½	15½	21
,, 20—24	98	9	26	37½
,, 24—28	147	14	37	54½
,, 28—32	206	18½	48	71½

N. B.—All the above are standard volumes except that in column 5 bark is included even in the branchwood timber. That is why an addition of columns 3 and 4 will not equal column 5.

TABLE IV

Shorea robusta

Locality Quality II.

Diameter class	Timber in round		Smallwood stem and branch	Branchwood timber and smallwood *plus* stem smallwood
	Stem	Branch		
Inches	c. ft.	c. ft.	c. ft.	c. ft.
Over 4—8	0	0	6½	6½
,, 8—12	9	0	8	8
,, 12—16	26	0	9	9
,, 16—20	51	4½	14½	20
,, 20—24	85	9	25	36½
,, 24—28	129	14	35½	53½
,, 28—32	185	18½	46½	70½

N. B.—All the above are standard volumes except that in column 5 bark is included even in the branchwood timber. That is why an addition of columns 3 and 4 will not equal column 5.

SOURCES OF ERROR
Graphical Method of
Volume Table Construction

- Insufficient no. of proper trees.
- Failure to draw an average Curve through plotted points, personal bias - (esp. non-linear Curves).
- Use of unsuitable scale on graph.
- When more than two variables (D, H) are involved data has to be grouped (D and Ht. class). Grouping done on arbitrary definition. This introduces bias change in graph changes final Curve.

More variables chances of introduction of error are more.

Preparation of A Local Volume Table

GRAPHICAL:

- DBH (OB) and volume of large number of trees are recorded.
- Average volume for each Dia class is found out.
- Volume (Y) and DBH (X) are plotted smooth Curve drawn.
- V is read for mid Dia class and tabulated.

Measurement of large number of volume involved : Seldom followed.

EASIER TO DERIVE FROM GENERAL VOLUME TABLE.

Local Volume Table From
General Volume Table

- General Volume Table gives Volume by Dia and Ht. Based on large area (data of trees collected from wide range of distribution).
- Plot V-D for various Ht. classes no. of Curves equals no. ht. classes.
- No. Each Curve by mid height class.
- D & H for sufficiently large no. of trees of locality for which local volume table is wanted are measured and recorded.
- These Ds & Hs plotted on the set of Curves (2) above (Keeping D on same axis) H calculated (Interpolating Ht., against dia, in b/w the ht. Curves of the G.V.T.)
- Smooth Curve drawn.

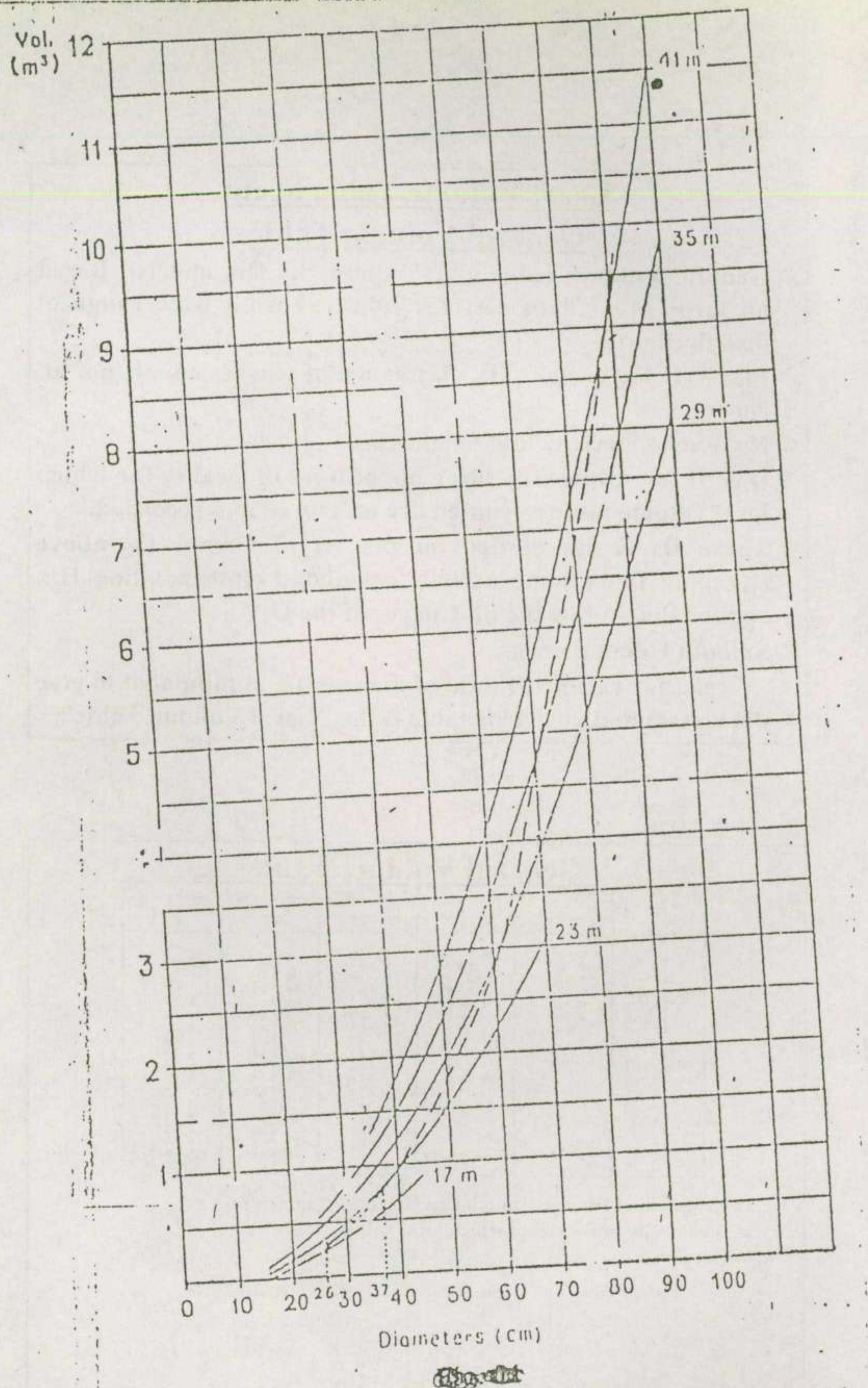
V read for various D (mid of dia class) and tabulated to give dia classes and vol. This table is the "Local Volume Table".

General Volume Table

d.b.h. (cm)	Volume (m³) Height (m)				
	17	23	29	35	41
15	0.030	0.068	0.106		
20	0.114	0.182	0.250		
25	0.222	0.329	0.435	0.541	
30	0.355	0.508	0.661	0.814	
35	0.512	0.720	0.929	1.137	1.345
40	0.692	0.965	1.237	1.509	1.782
45	0.897	1.242	1.586	1.931	2.276
50		1.552	1.977	2.403	2.828
55		1.894	2.409	2.924	3.438
60		2.269	2.882	3.494	4.107
65		2.677	3.396	4.115	4.834
70		3.117	3.951	4.785	5.619
75			4.547	5.504	6.462
80			5.185	6.274	7.363
85			5.863	7.092	8.322
90			6.583	7.961	9.339
95			7.343	8.879	10.415
100			8.145	9.847	11.549

Information of Diameter at b.h and Height for the trees of the locality in respect of which local volume table is to be prepared.

Diameter (cm)	Height (m)
26	18
37	22
42	24
50	26
58	28
68	34
85	40
90	41



Derivation of local volume table from general volume table

2/3/91

DIAGRAM

No. of Variables to be Used

The no. and choice of variables depends on

- **Extent of intended application**
- **Simplicity desired**
- **Desired accuracy**

It is not necessary that by increasing no. of variable the accuracy will greatly improve.

For marginal improvement great effort would be needed.

Moreover, in the increased fieldwork inevitable errors may crop up of greater magnitude.

Variable should be:

- **Easily measurable**
- **Highly correlated with the dependant variables**
- **Negligibly correlated with other independent variable (Dia, ht., age But age is highly correlated with Dia, ht. Moreover age is not easily measurable.)**

In a small area (local) for the same Dia, ht. variation may be negligible.

But on large area not applicable.

So on large area D & H both considered.

$V = \pi . r^2 . h . F$ $V = f(d, h, F)$

If we select d & h i.e. if d & h are fixed the variation in form to tree would not be great. It can be, only, an improvement.

Informations to Accompany Volume Table

The Table should include descriptive informations which will enable one to apply correctly.

To Accompany :

→ Species or species group and locality to which applicable.
→ Definition of dependent variable, vol, including unit in which vol. is expressed.
→ Definition of independent variable including stump height, top Dia (mechantable vol).
→ Author
→ Date of preparation
→ No. of trees on which based
→ Extent of basic data
→ Method of determining vol. of individual tree
→ Method of construction
→ 1 2 3 must be given Rest Desirable

Applicability of General Volume Table

To see whether a given table is applicable in a given locality or to a given coup:

- Select 4-5 trees of each ht. and Dia. class.
- Fell, record actual vol.
- Read from Curves/Tables also
- Find difference

Calculate Aggregate Difference and Average Deviation

- Average deviation (A D) of n test trees should be of the same order as that of the basic data of the Table.
- Aggregate difference should not exceed.

$2 \times AD/\sqrt{n}$

Exact height and necessary computations are given in the following table :-

Tree no.	D.b.h.	Total height	Commerical C..ft Actual	From the Curve	Difference
	Ins.	Ft.			
1	15.1.	98	25.8	33.0	7.2
2	19.6	80	51.0	45.8	5.2
3	22.2	93	65.1.	70.0	4.9
4	23.6	116	111.9	100.4	11.5
5	24.5	128	130.7	120.0	10.7
6	26.8	112	127.5	123.9	3.6
7	27.7	125	165.3	149.1	16.2
8	27.9	131	191.2	181.1	10.1
9	30.4	115	176.3	165.5	10.8
10	35.4	129	148.3	155.9	7.6
11	32.4	132	233.5	219.0	14.5
12	37.3	140	326.3	308.5	7.8
Total	--	--	1852.9	1772.2	120.1

Computations

Aggregate Difference

$= \frac{1852.9 - 1772.2}{1772.2}$

= 4.6 per cent

Average Deviation

$= \frac{120.1}{1772.2} \times 100$

= 6.8 per cent

Average deviation of basic data = 7 percent

$\frac{2 \times A.D.}{\sqrt{n}} = \frac{2 \times 7}{\sqrt{12}}$

= 4.0 per cent

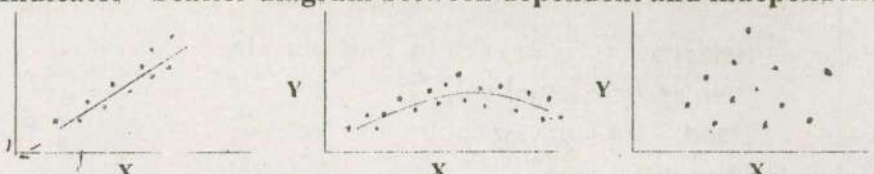
(This quantity, 4.0 per cent, measures the maximum permissible sampling error of the difference of the mean of the Table values and the test trees.

Given Average Deviation of basic data - 7%

Regression Equation Method

- **Quantification of the degree of association between two or more variables - Regression**
- **Degree of relationship - Correlation**

  Indicator - Scatter diagram between dependent and independent



Linear **Curvilinear** **No relationship**

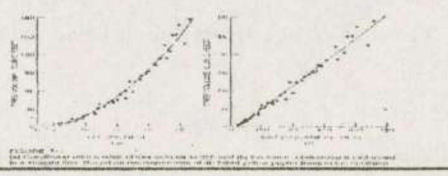
For curvilinear relationship - it is sometimes possible to make a simple transformation of one or both of the variables so that the relationship becomes linear in form.

Example:

st. line	$Y = a+bx$	$\Rightarrow Y = b_0 + b_1x$
parabola	$(Y-a) = k(x-b)^2$	$\Rightarrow Y = b_0 + b_1x+b_2x^2$
hyperbola	$(Y-a) = k/x$	$\Rightarrow Y = b_0 + b_1(1/x)$
	$(Y-a) = k/x + bx$	$\Rightarrow Y = b_0 + b_1(1/x) + b_2x$
	$Y = ax^b$	$\Rightarrow \log Y = b_0 + b_1\log x$
	$Y = ax^bc^x$	$\Rightarrow \log Y = b_0 + b_1\log x + b_2x$

TABLE 7-3
YELLOW-POPLAR DATA USED IN CONSTRUCTING A SINGLE ENTRY VOLUME TABLE

dbh, in.	Volume, cu ft	Total ht., ft	dbh, in.	Volume, cu ft	Total ht., ft
6.0	4.7	65	16.[illegible]	59.5	98
6.3	5.3	63	16.2	48.3	86
7.2	7.0	69	16.8	78.2	105
7.4	7.4	63	17.2	58.7	98
8.0	12.5	78	17.6	75.7	108
8.5	10.5	66	18.4	78.9	101
9.3	14.4	74	19.3	89.1	111
8.6	13.4	80	18.7	85.4	102
10.2	21.7	83	20.4	104.3	109
9.8	17.5	77	19.8	92.5	103
11.5	23.0	74	20.7	102.9	108
11.4	24.6	84	21.3	113.1	101
12.2	38.1	98	22.4	115.1	106
12.0	31.8	98	22.2	135.3	120
13.4	41.6	96	23.0	125.6	108
12.8	35.0	90	23.4	152.4	128
14.0	43.1	95	24.3	167.9	115
14.1	41.5	91	23.8	153.6	124
14.9	45.8	87	25.3	138.5	107
15.4	55.0	98	25.8	177.[illegible]	118



Exact height and necessary computations are given in the following table :-

Tree no.	D.b.h.	Total height	Actual	From the Curve	Difference	Computations
	Ins.	Ft.				Aggregate Difference = (1852.9-1772.2)/1772.2 = 4.6 per cent
1	15.1.	98	25.8	33.0	7.2	
2	19.6	80	51.0	45.8	5.2	
3	22.2	93	65.1	70.0	4.9	
4	23.6	116	111.9	100.4	11.5	Average Deviation = 120.1/1772.2 x 100 = 6.8 per cent
5	24.5	128	130.7	120.0	10.7	
6	26.8	112	127.5	123.9	3.6	
7	27.7	125	165.3	149.1.	16.2	
8	27.9	131	191.2	181.1.	10.1.	
9	30.4	115	176.3	165.5	10.8	Average deviation of basic data = 7 percent
10	35.4	129	148.3	255.9	7.6	
11	32.4	132	233.5	219.0	14.5	
12	37.3	140	326.3	308.5	7.8	$\frac{2 \times A.D.}{\sqrt{n}} = \frac{2 \times 7}{\sqrt{12}}$
Total	--	--	1852.9	1772.2	120.1	= 4.0 per cent (This quantity, 4.0 per cent, measures the maximum permissible sampling error of the difference of the mean of the Table values and the test trees.

Given Average Deviation of basic data - 7%

YELLOW-POPLAR DATA USED IN CONSTRUCTING A SINGLE-ENTRY VOLUME TABLE

dbh, in.	Volume, cu ft	Total ht., ft	dbh in.	Volume cu ft	Total ht., ft
6.0	4.7	65	16.[illegible]	59.5	98
6.3	5.3	63	16.2	48.3	86
7.2	7.0	69	16.8	78.2	105
7.4	7.4	63	17.2	58.7	98
8.0	12.5	78	17.6	75.7	106
8.5	10.5	66	18.4	78.9	101
9.3	14.4	74	19.3	89.1	111
8.6	13.4	80	18.7	85.4	102
10.2	21.7	83	20.4	104.3	109
9.8	17.5	77	19.8	92.5	103
11.5	23.0	74	20.7	102.9	108
11.4	24.6	84	21.3	113.1	101
12.2	38.1	98	22.4	115.1	106
12.0	31.8	98	22.2	135.3	120
13.4	41.6	96	23.0	125.6	108
12.8	35.0	90	23.4	152.4	128
14.0	43.1	95	24.3	167.9	115
14.1	41.5	91	23.8	153.6	124
14.9	45.8	87	25.3	138.5	107
15.4	55.0	98	25.8	177.3	118

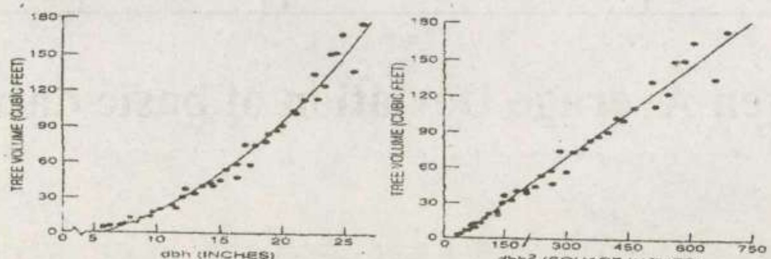


FIGURE 7-2
(a) Curvilinear relationship of tree volume to dbh and (b) the same relationship transformed to a straight line. Based on measurements of 40 felled yellow-poplar trees in the southern Annalanhiane

Typical mathematical models used for construction of volume tables :

$V = aD^b$ .... **Local Volume Table**

$V = bD^2H$

$V = a+bD^2H$ .... **general Volume Table**

$V = aD^bH^c$

$V = aD^bH^cF^d$ .... **Form Class vol. Table**

Where V : Volume in cubic units

D : dbh

H : Total height

F : a measure of form

a, b, c, d : constants

Constants are determined by finding out the

<u>'Line of Best Fit'</u> - Best fit regression equation

(i) Method of least squares — **sum of squares of deviations of various points along the ordinate or abscissa is the least.**

(ii) Graphical method

$Y = a+bx$ **Equation to the straight line**

In general the normal equations for a set of relations:

$\sum Y = na + b\sum X$

$\sum(XY) = a\sum(X) + b\sum X^2$

$$\Rightarrow b = \frac{\sum XY - (\sum X)(\sum Y)/n}{\sum X^2 - (\sum X)^2/n}$$

$$= \frac{\text{corrected sum of cross product}}{\text{corrected sum of squares for X.}}$$

$a = \sum Y/n - b(\sum X/n) = \bar{Y} - b\bar{X}$

$$Y = a + bX$$

Set of values of X & Y : X_1, X_2, X_3 .... Xn

Y_1, Y_2, Y_3.............. Yn

Sum of squares of distances :

$$S = (Y_1 - a - bX_1)^2 + (Y_2 - a - X_2)^2 + \ldots + (Y_n - a - bX_n)^2$$

$$= \sum (Y - a - bX)^2$$

For $\bar{S}$ to be least : $ds/da = 0$, $ds/db = 0$

$$ds/da = \sum Y - \sum a - b\sum X = 0$$

$$\Rightarrow \sum Y - na - b\sum X = 0$$

$$\Rightarrow \sum Y/n = a + b(\sum X/n)$$

$$\Rightarrow Y = a + b x$$

$$ds/db = \sum X(Y - a - bx) = 0$$

$$\Rightarrow \sum XY - a\sum X - b\sum X^2 = 0$$

$$\Rightarrow \sum XY - \sum X(Y - bX) - b\sum X^2 = 0$$

$$\Rightarrow \sum XY - \sum X[\sum Y/n - b(\sum X/n)] - b\sum x^2 = 0$$

$$\Rightarrow \sum XY - (\sum X)(\sum Y)/n = b\sum X^2 - b(\sum X)^2/n$$

$$\Rightarrow b = [\sum XY - (\sum X)(\sum Y)/n] / [\sum X^2 - (\sum X)^2/n]$$

Numerical example : X = 1 2 3 4 5

Y = 3 4 6 9 10

Equations : $3 = a + 1b$

$4 = a + 2b$

$6 = a + 3b$

$9 = a + 4b$

$10 = a + 5b$

Normal Equations : $32 = 5a + 15b$

$115 = 15a + 55b$

$\Rightarrow b = 1.9$

$a = 0.7$ $\Rightarrow Y = 0.7 + 1.9X$

Derivation of Regression Equation for Local Volume Table From The Regression Equation of the General Volume Table

Let the General Volume Equation for a sp. is

$$V = a + bD^2H$$

i.e. $V = f(D, H)$

For any locality, let the Ht. - Dia relationship be:

$$H = C + ed + ed^2$$

Then the local volume equation is:

$$V = a + bD^2(C + dD + eD^2)$$

$$= a + bcD^2 + cdD^3 + deD^4$$

$$\Rightarrow V = a + b_1D^2 + c_1D^3 + d_1D^4$$

$$V = f(D)$$

a = Regression constant

b_1, c_1 & d_1 = Regression co-efficient

N.B. : This equation should be used, within the range of observed data. Such equations don't give reliable results on extrapolation.

Expl : For Sal (Orissa) G : $V/D^2H = -0.001775/D^2H + 0.338574$

($n = 77$, $R^2 = .56025$)

L : $\sqrt{V} = 0.1999 + 4.57179D - 1.56823\sqrt{D}$ (n = 599

Preparation of Volume Table

Earlier Methods

- Large scale data collection pertaining to dia & Ht. classes.
- Further processing by averaging.
- Tabulation and Graphic treatments

Present Trend

- To develop multiple Regression Volume Equations.

Preparation of Volume Equation by FSI

Data Collection

- Generally 30 or more trees measured for every spp. (covering the Dia ranges).
- Random tree selection
- Two Dbh (ob) measured at right angles to each other.
- Ht. measurement by altimeter.
- Trees felled.

Volume Computation:

- Volume of each section calculated by using "Huber's formula".

General Volume Equations:

Regressions Equations used.

- $V = a + bD^2H$
- $V = a + bD + CD^2H$
- $V = a + bD^2 + C(D^2H)^2$
- $V = a + bD + CD^2H + d(D^2H)^2$
- $V = a + bD + CH + CD^2H$
- $V = a + bD + CD^2 + dD^2H$
- $Log_e V = a + b \log_e D + C\, Log_e H$
- $V/D^2 H = a + bD^2 H$
- $V/D^2 H = a + bD^2 H + C/D^2H$

Local Volume Equations:

Regressions Equations :

- $V = a + bD^2$
- $V = a + bD + CD^2$
- $V = a + bD + CD^2 + dD^3$
- $V = a + b\sqrt{D} + CD^2$
- $\sqrt{V} = a + bD$
- $\sqrt{V} = a + bD + C\sqrt{D}$
- $V/D^2 = a + b/D^2$
- $V/D^2 = a + b/D + C/D^2$
- $V/D^2 = a + b/D^2 + C/D + dD$
- $Log_e V = a + \log_e D$

Where :

AGE OF TREES

Why

- To study time required for production of wood.
- Rate of capital growth.
- Returns from plantations/forestry.

Methods (Standing Trees)

- Ocular estimate
- From records
- Whorls of branches -counting
- Successive measurement
- Annual rings counting

Ocular Estimation

Size and relative taper of stem

Young ones have more tapering.

Size and shape of crown

Chir pine crown is conical when young rounded as old.

Colour and Condition of bark

Young, rough, light

Limitations

From Records :

- Year of plantation (Artificial regeneration)
- Seeding felling (Natural regeneration)

Limitations

- If plantation continues for more years
- No specific year

Counting of whorls of branches

Branches in whorls every year (growing season).

Branches fall (self pruning) (Semal example)

Age upto branches estimated. A very few species ; in old trees difficult; Approximate.

Method : Successive Measurement

Dia. measured periodically at least three times.

d_1 ------- initial Diameter

d_2, d_3 ---- at 2nd and 3rd time

P_1 -- dia. growth between 1st and 2nd per unit Dia per year

P_2 -- dia. growth between 2nd and 3rd per unit Dia per year

Age at 1st measurement given by :

$$Age = 1 / P_1 S$$

$$S = \frac{\log P_1 - \log P_2}{\log d_2 - \log d_1}$$

Used for trees without rings.

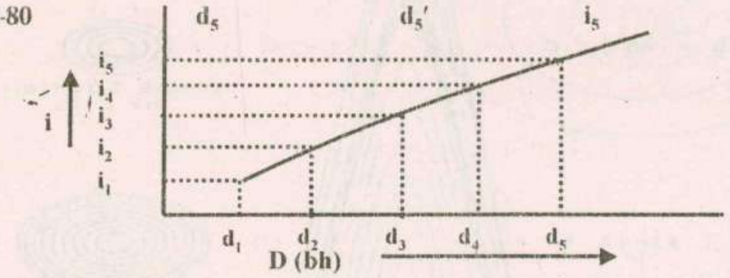
Can also be used for trees with rings.

Dia. - Age Curve Prepared by Successive Measurements

- dbh of several trees measured dia. class wise, all dia. classes to be covered.
- Dbh of Same trees measured after a gap of some years (5 or 10).
- Difference between two average dias. gives dia. Increment.
- Dia. increment plotted against dia.
- Smoothened

- Increment read against lowest Dia. Added to give new dia. at the end of the period increment again read against this and added.
- Repeat
- this gives Dia attained by lowest dia. at various successive years.
- Plot dia. vs. interval (time).

Dia class	Av. D at t_1	Av. D at t_2	Increment
30-40	d_1	d_1'	i_1
41-50	d_2	d_2'	i_2
51-60	d_3	d_3'	i_3
61-70	d_4	d_4'	i_4
70-80	d_5	d_5'	i_5



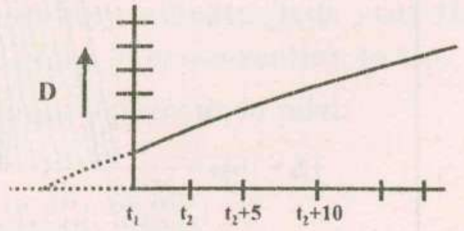
Start Lowest D

D_1 ---- $d_1 + i_1$

D_2 ---- $d_1 + i_1 + i_1'$

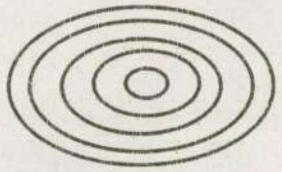
D_3 ---- $d_1 + i_1 + i_1' + i_2' = D_2 + i_2'$

D_4 ---- $D_3 + i_3'$



Rings :

- Trees grow by adding a new layer outside trunk under bark.
- Process starts in the beginning of new year stops in winter.
- Wood formed in the beginning more porous light in colour.
- This appears as rings on a cross section.



Count number of rings - gives age - time required to grow from tip to stump height.

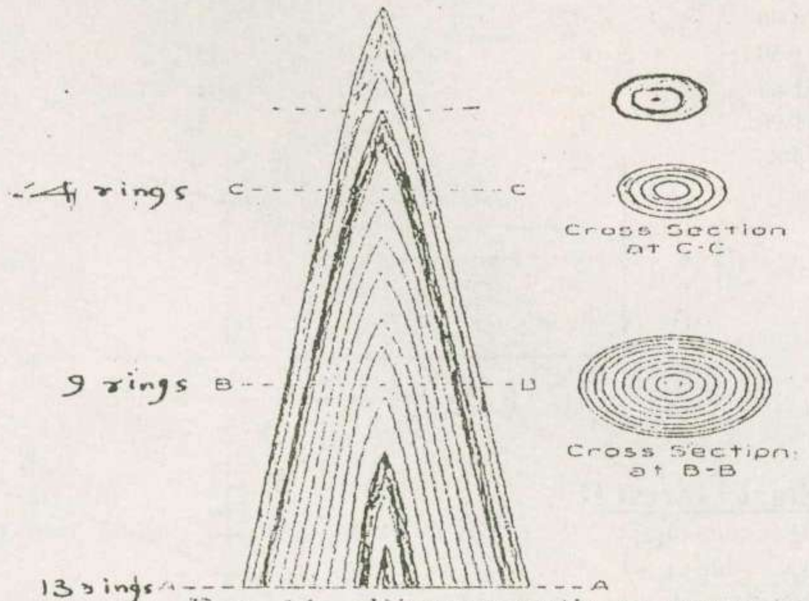


Fig. 11.—Diagrammatic representation of the appearance of annual rings on the longitudinal section of a tree trunk.

Example

A tree has 67 annual rings on stump. It is cut into 16′ long logs. The number of rings at the top of the logs is 53, 37, 19. The top log is 18′. When was it growing most rapidly in height? What was its rate of growth in ft. per year during this period of growth?

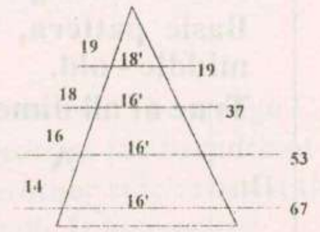
What additional information is required to determine its total age?

18′ in 19 yr. 18/19′ per year

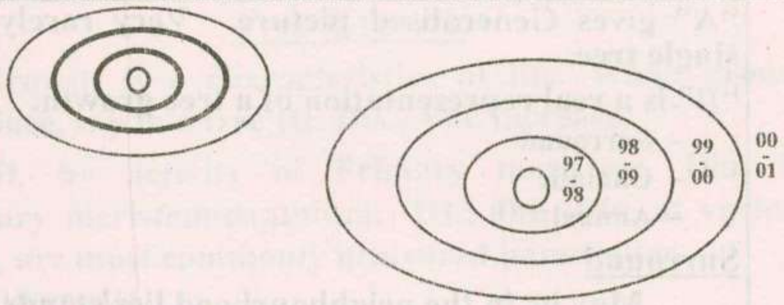
16′ in 18 yr. 16/18′ per year

16′ in 16 yr. 1′ per year

16′ in 14 yr. 16/14′ per year



Time taken to reach stump ht.



No. of rings on any cross-section indicates/tells year the tree has taken to reach the place of cross-section to tip.

Count in reverse outer to inner - present to past.

Ring Width

Hard summer wood - porous spring wood

Together constitute ring width.

Ring width indicates growth.

Wider - Faster growth

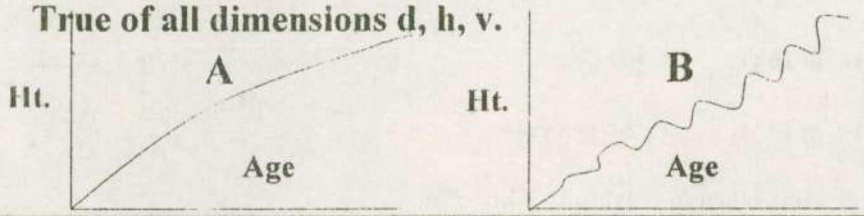
Narrow - Slow

Counting to the pith we can make out when - which year it grew faster/slower. Relate to "influencing" factors.

- **Climatic**
- **Surrounding**

Basic pattern, besides, slow - fast - slow in young - middle - old.

True of all dimensions d, h, v.



"A" gives Generalised picture. Very rarely given by a single tree.

"B" is a real representation of a tree growth.

- **Surround**
- **Climatic**
- **Annual**

<u>Surround</u> -

May be in the neighbourhood lies/stands another one competing for soil, moisture, light, slow : One such may die, giving open space a little spurt.

<u>Climatic</u> -

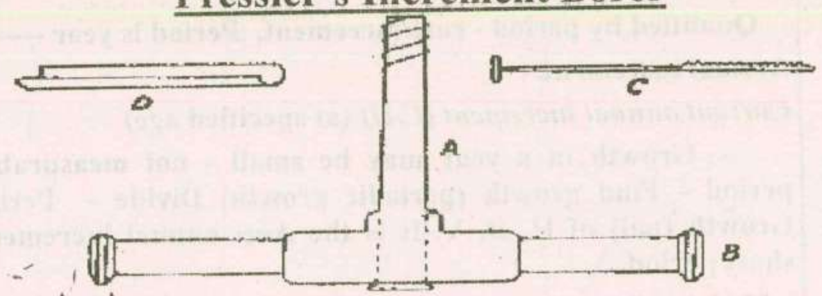
Climatic cycles : Wet years dry years (Fast - Slow ⇔ Wide - Narrow rings).

Annual Spring Fast:

Winter - dead. Height/Dia. - age graph is not smooth but a series of steps.

Diurnal Variation : during certain period of day.

Pressler's Increment Borer



A : Auger

B : Hollow handle

C : Wedge

D : Cradle

A narrow cylinder of wood is extracted. The wedge C has scale marked on it on one side to measure the breadth of rings and a roughly toothed edge on the other side to assist the extraction of cylinder of wood and a cradle D to keep the cylinder of wood after extraction so that it does not break.

Tree Growth

Growth is a characteristics of life. When growth takes place, say in a tree Ht. Dia., Vol. increase.

Ht. by activity of Primary meristem, Dia. by Secondary meristem-cambium. Ht., dbh, Dia. at various heights, are most commonly measured parameters.

Influenced by

Growth → Genetic make up ←

Environment

soil, moisture, climate

topographic factors competition

(Site Quality - Sum of All)

Species Specific

Arjun Boswellia serrata

Growth is increase

Qualified by period - rate/increment. Period is year ------ annual.

Annual increment.

Current annual increment (CAI) (at specified age)

Growth in a year may be small - not measurable- take a period - Find growth (periodic growth) Divide - Period annual Growth (pai) of H, D, V.-It is the Ave. annual increment for any short period.

MAI (mai) Average annual increase upto any age.

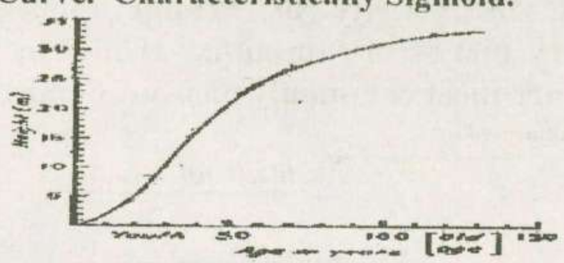
The vol. Of a Eucalyptus tree in 10 year is 1 cum. MAI=(35 ft) ÷ 10 = 3.5 cft/year

AGE yr	2	4	6	8	10	12	14
Vol unit	1	3	5	9	10	11	12
MAI unit/yr	0.5	0.75	0.83	0.12	1.	0.9	0.8

To find out cai mai

GROWTH Curves

If (H, D, V) is plotted against age, the Curve obtained is 'Growth' Curve. Characteristically Sigmoid.

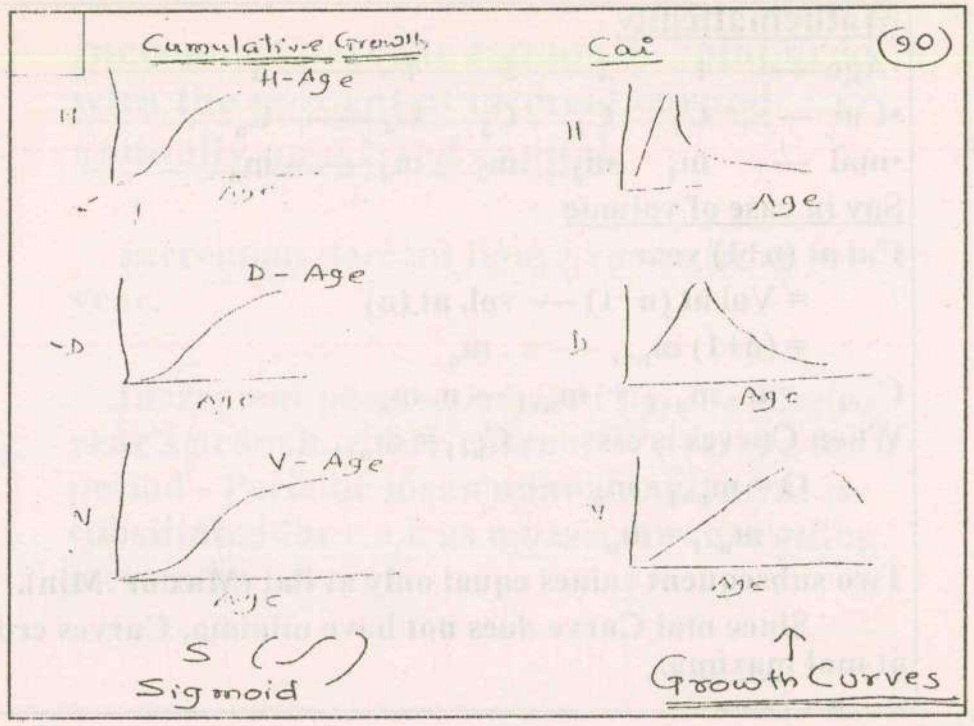


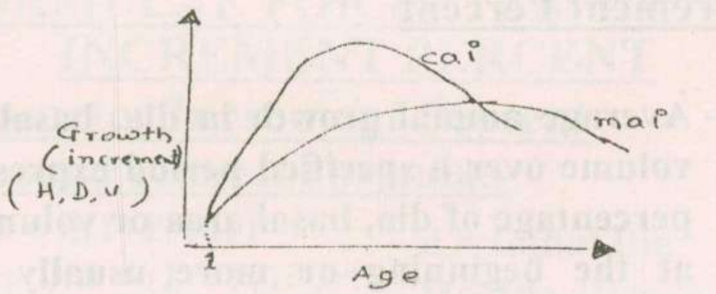
Applicable to most life forms.

But not true growth - Cumulative Growth Curve.

It establishes relation H-Age.

From this, such, increment/growth information is derived. Plot this against Age. If one year difference not measurable say at 10 year 5-15 difference divided by 10 cai at 10 year.





Invariable relation : The two Curves cross at the crest of mai separation starts at the begin of 2nd year.

Mai is average. So long as cai is increasing / above mai, mai increases. Mai increases so long as cai is above mai, the moment it touches mai, mai starts falling cai goes below mai.

Mai rises slowly because it is an average and higher cai gets distributed over past.

Mathematically

•Age --- 1 2 3 4 -----------n

•Cai --- C_1 C_2 C_3 C_4 ---------C_n

•mai --- m_1 m_2 m_3 m_4 ------- m_n

Say in case of volume

Cai at (n+1) year

= Vol at (n+1) ---- vol. at (n)

= $(n+1)\ m_{n+1}$ ---- $n\ .\ m_n$

$C_{n+1} = n\ .\ m_{n+1} + m_{n+1} - n.\ m_n$

When Curves cross $C_{n+1} = m_{n+1}$

$O = m_{n+1} - m_n$

$\Rightarrow m_{n+1} = m_n$

Two subsequent values equal only at flat (Max or Min).

Since mai Curve does not have minima, Curves cross at mai maxima.

Increment Percent

- Average annual growth in dia, basal area or volume over a specified period expressed as a percentage of dia, basal area or volume either at the beginning or more usually halfway between the beginning and end of the periods.

- Analogy of interest and principal. Increment percent is not separable from the wood capital - causing the capital or base volume to increase annually, in a cumulative manner.

Increment percent cannot be compared with the percent of interest earned annually on a fixed capital.

Increment percent figure varies from year to year.

Increment percent is based upon a single year's growth, either current or average for a period - Periodic mean annual increment is substituted for c.a.i. as a basis for computing increment percent.

FORMULAE FOR DETERMINING INCREMENT PERCENT

1. Diameter Increment Percent

Compound Interest Formula:-

$D = d(1+P/100)^n$

$\Rightarrow D/d = (1 + P/100)^n$

$\Rightarrow 1 + P/100 = \sqrt[n]{D/d}$

$\Rightarrow P = 100\ (\sqrt[n]{D/d} - 1)$

d = Initial Dia

D = Dia after 'n' yrs

P = Rate of increment Percent

Pressler's Formula

Mean of two Diameter : (D+d)/2

Ave. Annual Increase in dia : (D-d)/n on D+d/2

$\Rightarrow P = 200\ (D-d)/n(D+d)$

(P, calculated by S.I. rate on mean of Dias.)

2. Volume Increment percent

Compound Interest Formula :

$$P = 100\,(n\sqrt{V/v} - 1)$$

Pressler's Formula

$$P = 200/n[(V-v)/(V+v)]$$

Height remains constant after certain age and assuming form factor to remain constant. Then volume varies as the basal area or square of Diameter. Then Pressler's Formula is modified as :

$$P = 200/n[(D^2-d^2)/(D^2+d^2)]$$

Schneider's Formula (For Spp. With Annual rings)

$P = 400/nD$ D : Present Diameter (u.b.) at the point of boring & n : no. of rings in the outermost centimeter of the radius

MENSURATION EXERCISES

Stump Analysis,

Increment Boring,

&

Stem Analysis

STUMP ANALYSIS EXERCISE

Object

1. To determine the progress of dia. increment, on the average stump throughout the life of the trees or over any desired period.
2. Correlate dia. increment with external influences.

Equipments (Per party)

(1)	Callipers	1
(2)	Measuring scale	1
(3)	Tape (30 m)	1
(4)	Pocket lens	1
(5)	Haga altimeter or Abney's level	1
(6)	Cross cut saw	1
(7)	Sharp axe	1
(8)	Pins	1 pkt
(9)	Water bottle with water	1
(10)	Forms and Graph papers	
(11)	Pencil	
(12)	Khukri	

FIELD WORK

*1. **Selection of trees***

(i) Typical and representative trees/stumps to be selected.
(ii) Trees should be free from defects and abnormalities.
(iii) Suppressed trees should be avoided
(iv) Trees should be of rotation size and above.

*2. **Dressing of Stump***

(i) Dress the stump horizontal, if necessary by slicing off.
(ii) Keep the stump height as low as practicable (20 to 30 cm).
(iii) Remove a ring of bark at the top of the stump for girth measurement.
(iv) Apply water on the stump surface for better visibility of the rings.

*3. **Measurements on Stump***

A. **Stump**

(i) Stump height : to be measured
(ii) Girth (u.b.) : to be measured with the tape
(iii) Corresponding average radius calculated

B. **Ring Count and Radial Measurements**

(i) Select four radii on the stump such that

- They are as widely apart as possible – ideal being at right angles.
- Their average length to be approximately equal to the radius calculated from the girth.

(ii) Fix the pins at the pith and on the rings at the end of every decade, pith outwards (1st, 2nd …………… last decade) along the four radii.

(iii) Measure the radial lengths of the decades by a single setting of the scale on any radius.

(iv) Count the total number of rings upto the circumference (avoid false rings).

C. **Tabulation of Measurement**

(i) The measurements of stump radii should be tabulated in Form no. 1.

(ii) Prepare an abstract of Form no. 1 and tabulate the same in Form no. 1A for the purpose of drawing of the curve showing stump diameter (u.b.) / stump age (no. of rings at stump).

D. **Stump diameter (u.b.) / Stump Age Curve**

(i) This curve is plotted from the readings of Form no. 1A (CURVE NO.I).

(ii) This curve needs two corrections

- Stump age converted to actual age.
- Stump diameter (u.b.) to be converted to Dbh (o.b.)

4. ***Seedling Height Data (Correction from stump age to total age)***

(i) About 10 freely growing seedlings (2 to 3 mts. high) are cut flush to the ground.

(ii) The number of rings at the ground level, and at 10 cm, 20 cm, 30 cm ……. upto 150 cm height are counted (this seedling height data can also be used for stem analysis).

(iii) This data is recorded in the seedling height form (Form no. 2).

(iv) A curve is drawn between seedling age and height (Seedling Age-Height Curve) from the data of Form no. 2 (CURVE NO. II).

(v) From this curve the age corresponding to the average stump height is read, which is used to obtain the total age from the stump age.

5. ***Conversion of Stump Diameter (u.b.) to Dbh (o.b.)***

(i) About 10 trees are selected in each diameter class.

(ii) For each tree the under bark dia. is measured at three heights, two preferably equi-distant from the average stump height and third at a higher place but less than the breast height.

(iii) Dbh (o.b.) is also measured for each tree.

(iv) This data (TAPER DATA) is recorded in Form no. 3.

(v) Average Dbh (o.b.) is plotted against the average diameters (u.b.) at different heights. This gives the diameter (u.b.) / Dbh (o.b.) Curve (CURVE NO. III). The Curve no. III will be a set of three curves, all straight lines.

(vi) In between these curves a curve (straight line) corresponding to the average stump height is interpolated.

(vii) From this interpolated curve Dbh (o.b.) can be read against the stump diameter (u.b.) at various decades at the average stump height.

6. ***Final Corrected Curve***

(i) The Curve no. I between stump dia (u.b.) and stump age is corrected for age correction by shifting the age axis. This corrected axis gives the true age of the tree.

(ii) For each stump diameter (u.b.) the corresponding Dbh (o.b.) can be read from the Taper Data Curve and this can be incorporated in Curve no. I. Hence the corrected curve will be between Dbh (o.b.) and the true age.

(iii) This curve represents the progress of Dbh (o.b.) against age.

INCREMENT BORING

Object

(a) To determine the current increment of trees with annual rings, for different dia classes – an indication of need for thinning or regeneration.
(b) To find out the average time required for trees to pass through successive dia classes – to fix yield or rotation.
(c) To determine the diameter increment of matured trees – allowance to be made for increment during regeneration period in regulating the yield.
(d) To determine the effect of adverse or favourable factors.
(e) To determine the current growth percent of a given dia class.

Equipments (Per group)

(i)	Pressler's Borer	1
(ii)	Pocket Lens	1
(iii)	Callipers	1
(iv)	Measuring Scale	1
(v)	Cotton wool	
(vi)	Graph paper	
(vii)	Pencil	

FIELD WORK

1. *Selection of trees*

(i) About 10 trees in each dia class should be selected.
(ii) Trees should be typical of the locality.
(iii) Abnormal trees should be rejected.

2. *Measurements of Dbh*

(i) Dbh (o.b.) to be measured – 2 diameters at right angles.
(ii) Bark removed and Dbh (u.b.) measured – 2 diameters at right angles.
(iii) The tree is bored at two ends of the dia at right angles to the axis of the tree to a depth of 4 to 5 cms so as to get at least 15 to 20 rings.
(iv) Length of the outermost five rings are recorded
(v) The data collected to be tabulated in Table I.

3. *Computation*

(i) Abstract of Table I is recorded in Table II. In this Table corresponding increment is given against the average initial Dbh (u.b.) and corresponding twice bark thickness is given against average observed Dbh (u.b.).

(ii) **Dia Increment Curve (Curve 1):** From Table II average width of five rings plotted against the average initial Dbh (u.b.) of that dia class (i.e. average Dbh u.b. before 5 years.)

(iii) **Growth Curve (Curve 2):** Increment for the lowest dia is read from the Increment Curve – Added to the original dia – final dia after 5 years obtained – increment is again read against this final dia – added and next dia obtained and so on till the maximum dia is reached. This data is tabulated in Table III. The final dia is plotted against age (5 years succession), the lowest dia i.e. the first entry being considered to be against age "0". This gives the growth curve – age / Dbh (u.b.) graph.

(iv) **Age correction:** The age axis is shifted to the left by necessary number of units, corresponding to the estimated time required to reach the calculated lowest dia. This is obtained from the negative intercept on the age axis made by the growth curve when extrapolated in the backward direction.

(v) **Twice Bark Thickness Curve (Curve 3) :** In this curve twice bark thickness is plotted against the average observed Dbh (u.b.) (from Table no. II)

(vi) **Conversion of Dbh (u.b.) to Dbh (o.b.):** Twice Bark Thickness is read from the bark thickness curve for all the Dbh (u.b.) given in column no. 1 of Table III. This data is tabulated in Table IV. From this the Dbh (o.b.) can be calculated for each Dbh (u.b.) and this correction can be incorporated in the growth curve. This final curve so obtained gives Dbh (o.b.) against the actual age.

STEM ANALYSIS EXERCISE

Object

Analysis of a complete stem to determine the average rate of diameter, height and volume increment throughout the life of a tree species having annual growth rings i.e. to determine the following graphs:

(i) Diameter – Age Curve
(ii) Height – Age Curve
(iii) Volume – Age Curve

Equipments (Per party)

1.	Callipers	1
2.	Measuring scale	1
3.	Tape (30 m)	1
4.	Pocket lens	1
5.	Haga altimeter or Abney's level	1
6.	Cross cut saw	1
7.	Sharp axe	1
8.	Pins	1 pkt
9.	Water bottle with water	1
10.	Forms and Graph papers	
11.	Pencil	
12.	Khukri	

FIELD WORK

1. ***Selection of trees***

(i) Tree should be of rotation age and over.
(ii) Trees should be typical shape and development.
(iii) Typical and representative trees to be selected.
(iv) Suppressed, markedly dominant and free standing trees should be avoided.
(v) Trees should be free from defects and abnormalities.

2. ***Measurements on Standing Tree***

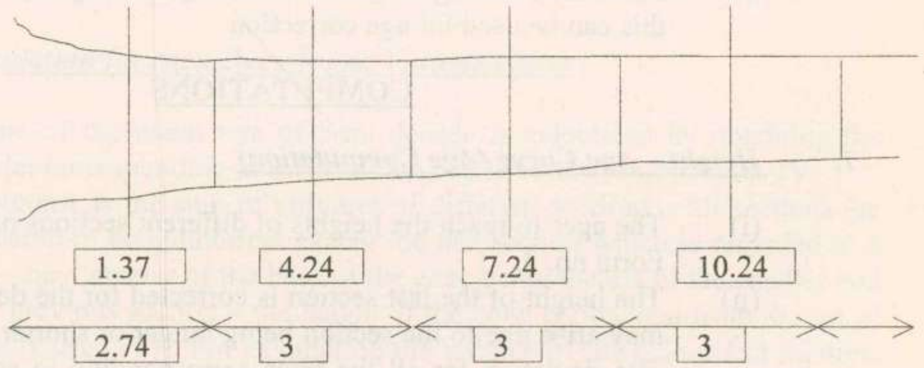
(i) Before felling the tree Dbh (o.b.) is measured and recorded
(ii) B.H. point is marked all around the bole.
(iii) Total height and crown width also measured and recorded.

3. ***Measurement on the Felled Tree***

A. Over Bark and Under Bark Dia Measurements

(i) Height of the first green branch and the lowest point of full crown i.e. clear bole and crown length to be measured.
(ii) Total height of the tree to be measured.
(iii) Heights of points with Dia (o.b.) 20 cms and 5 cms and the Dia (u.b.) at these points are measured.
(iv) The tree is then considered to be divided into sections from base (including stump) to the top.
- Lowest section = 2.74 m (twice B.H.)
- Successive upper sections = 3 m
- Last section or top section is considered separately if it exceeds 1.5 m. If it is less than 1.5 m then it is included in the previous section.

(v) The mid points of these imaginary sections (1.37m, 4.24m, 7.24m, 10.24m .... so on) are marked on the felled tree.
(vi) Two Dia (o.b.) and two Dia (u.b.) at right angles to each other, at these mid points are measured, their mean recorded and bark thickness calculated.



B. Ring Counting for Age Measurements

(i) Tree is then cut at these mid points by cross cut saw.
(ii) On each section the total number of complete rings are counted (avoiding any incomplete false rings).
(iii) The time required (age in years) to reach each section mid point height from the B.H. point are worked out by subtracting the total number of rings on that section from the number of rings at the B.H. section.

C. **Radial Measurements by Decades**

(i) Two radii angularly as far apart as possible and the average of which is nearly equal to the average radii calculated earlier are marked on the surface of the section.
(ii) The surface is made clear by moistening or chiseling.
(iii) On the first section (1.37 m) rings are counted from pith outwards. Pins are inserted at each decade on each radii. Incomplete decade at the circumference is left. The radii of each decade are measured from the pith outwards with a single setting of the scale.
(iv) On the other sections the outer most incomplete decade is marked off first and the rings are counted from cambium inwards. The decades are counted from circumference inwards. Pins are inserted at each decade on each radii. The radii of each decade are measured from pith outwards with a single setting of the scale.
(v) All this data are recorded in Form no. 1.

4. ***Seedling Height Data***

(i) The seedling height data obtained for the stump analysis can be used for stem analysis. (Curve II, Stump Analysis).
(ii) From the seedling height curve the age corresponding to the B.H. read and this can be used for age correction.

COMPUTATIONS

1. ***Height – Age Curve (Age Computation)***

(i) The ages to reach the heights of different sections of the tree are entered in Form no. 3.
(ii) The height of the last section is corrected for the deviation. This deviation may arise due to the section being longer or shorter than standard i.e. 3 m. The deviation for all the trees corresponding to any height are averaged and the height is corrected accordingly.
(iii) Height – Average Age Curve is plotted.
(iv) The age correction for the breast height age is applied to this Curve (Curve I).

2. ***Mean Diameter (u.b)/ Height Curves by Decades (Dia Curves)***

(i) Diameter (u.b.) at different heights corresponding to successive decades are abstracted from Form 1 and are entered in Form 3A for all the trees, separately for each decade – low decades will have lesser entries – these entries are totalled and averaged. In working out the averages, the number by which the total is to be divided should be the number of trees which reach the decade concerned irrespective of whether they reach the height of the section or not.
(ii) Deviation is incorporated for the upper most section.
(iii) For each decade average diameters (u.b.) are plotted against heights – the curves are smoothened and harmonized. This is done by three steps giving three sets of curves.

- Average diameters are plotted against the heights of the section, decade wise smoothened and harmonized (Curve II) – from these set of curves values of diameters are read against the sections of 1.37 m, 4.24 m, 7.24 m etc. for each decade and tabulated – these are used for plotting the next set of curves.
- The dia values obtained from the previous set of curves are plotted against decades separately for each section, (i.e. height of the section) (Curve III). These curves are smoothened and harmonized – from these set of curves, again the value of diameters are read against the section heights for each decade – these values are tabulated which are used for plotting the next set of curves.
- The dia values obtained from the previous curve are re-plotted against height of the sections for decades and the final dia (u.b.) – height set of curves is obtained (Curve IV), for each decade.

In harmonizing, the higher decades should be given most weightage.

3. ***Volume Calculation for each Decade and Volume Curve***

(i) Volume of the mean tree of each decade is calculated by obtaining the diameter corresponding to different heights from the set of Curves IV.
(ii) The volume is the sum of volumes of different sections – all sections are considered to be cylindrical except the last section which is regarded as a cone – the diameter of the base of the cone being the dia of the smaller end of the previous section – the height of the cone is obtained from the set of graphs (Curve IV). For calculating the volume of the cylindrical sections it is necessary to know the mid point dia of that section and its height. These diameters can be read from the set of Curves IV. The entries are made in Form 3B.
(iii) Thus volumes of mean tree of each decade are calculated.
(iv) The tree volumes for each decade are then plotted against age above breast height and a smooth curve drawn. This is the Volume – Age Curve at breast height age. (Curve V).
(v) This curve is corrected for age, i.e. to bring it to the total age from the breast height age. This is done by shifting the age axis by the age correction in years obtained from the seedling height curve.

4. ***Dbh (o.b.) – Age Curve***

(i) **Twice bark thickness / Dia (u.b.) Curve:** From Form no. 1, Dia (u.b.) of all the sections and all trees are arranged in 10 cm dia classes, and entered in Form no. 4 along with their respective twice bark thicknesses – the Dia (u.b.) and the twice bark thickness are totaled and averaged. A smooth curve is drawn between twice bark thickness and Dia (u.b.). (Curve VI).

(ii) **Seedling Height – Age Curve:** The seedling height curve drawn during stump analysis can be used – age corresponding to breast height is obtained from this curve, which is used for age correction.

(iii) **Age – Dbh (o.b.) Curve:** Average Dbh (u.b.) at different ages i.e. by decades is directly read from the set of graphs of curve IV. These readings are read against 1.37 m height. The twice bark thickness corresponding to each such Dbh (u.b.) is read from the twice bark thickness curve and tabulated. From this Dbh (o.b.) corresponding to each Dbh (u.b.) by decades are obtained. From this Dbh (o.b.) – Age Curve can be plotted and finally the age axis can be shifted for the age correction. (Curve VII)

Species :- Stump Analysis Form No. 1.

Quality :- Division :-

Block and Compartment :-

Radii of Different Decades

S.No	Stump height cm.	Girth at stump height u.b. cm.	Radius at stump height u.b. cm. (from girth)	Four radii	Radii of decades in cms. 1	2	3	4	5	6	7	8	9	10	11	12	Total radial length cm	Total number of rings	Remarks
				R_1 R_2 R_3 R_4															

Summary of Data Collected
Radii of Different Decades

Species :-

Stump Analysis Form No. 1 A

Quality :-

Division :-

Block and Compartment :-

S. No.	Ave. Stump height cm.	Four radii	Average Radii of decades in cms.												Remarks
			1	2	3	4	5	6	7	8	9	10	11	12	
		R_1													
		R_2													
		R_3													
		R_4													
Total															
Average Dia.															

Stump Analysis Form No. 2

SEEDLING HEIGHT

Species :-

Division : -

Quality of Locality :-

Block and Compartment :-

S.No.	Height (in cm.)	A	B	C	D	E	F	G	H	Average Age
		Age	Age	Age	Age	Age	Age	Age	Age	
	0									
	10									
	20									
	30									
	…									
	…									
	…									
	…									
	…									
	…									
	…									
	…									
	…									
	…									
	…									

INCREMENT BORING
WIDTH OF OUTERMOST .... RINGS

Species :

Division :

Block & Compartment :

TABLE - I

Tree No.	DBH Over-bark			DBH Under-bark			2 x Bark thick-ness	Width of ...... rings at two diametrically opposite points (in cm.)			Dia. ub before 5 years
	D1	D2	Avg.	D1	D2	Avg.	Col. 4-7	W1	W2	W1+W2	
1	2	3	4	5	6	7	8	9	10	11	12
Diameter Class											
A											
A											
B											
B											
C											
C											
D											
D											
E											
E											
F											
F											
G											
G											
Total											
Average											
Diameter Class											
A											
A											
B											
B											
C											
C											
D											
D											
E											
E											
F											
F											
G											
G											
Total											
Average											

INCREMENT BORING
WIDTH OF OUTERMOST .... RINGS

Species :

Division :

Block & Compartment :

TABLE - I

Tree No.	DBH Over-bark			DBH Under-bark			2 x Bark thick-ness	Width of ...... rings at two diametrically opposite points (in cm.)			Dia. ub before 5 years
	D1	D2	Avg.	D1	D2	Avg.	Col. 4-7	W1	W2	W1+W2	
1	2	3	4	5	6	7	8	9	10	11	12
Diameter Class											
A											
A											
B											
B											
C											
C											
D											
D											
E											
E											
F											
F											
G											
G											
Total											
Average											
Diameter Class											
A											
A											
B											
B											
C											
C											
D											
D											
E											
E											
F											
F											
G											
G											
Total											
Average											

Stump Analysis Form No. 3

TAPER DATA

Species :- Division : -

Quality of Locality :- Block and Compartment :-

	D.b.h. Class				D.b.h. Class				D.b.h. Class				D.b.h. Class			
	Dia. ub			D.b.h. over bark	Dia. ub			D.b.h. over bark	Dia. ub			D.b.h. over bark	Dia. ub			D.b.h. over bark
	At ___ cm	At ___ cm	At ___ cm		At ___ cm	At ___ cm	At ___ cm		At ___ cm	At ___ cm	At ___ cm		At ___ cm	At ___ cm	At ___ cm	
A	...	...	...													
	...	...	...													
B	...	...	...													
	...	...	...													
C																
...																
...																
...																
Total																
Avr.																
Dia																

INCREMENT BORING
WIDTH OF OUTERMOST .... RINGS

Species :

Division :

Block & Compartment :

TABLE - I

Tree No.	DBH Over-bark			DBH Under-bark			2 x Bark thick-ness	Width of ...... rings at two diametrically opposite points (in cm.)			Dia. ub before 5 years
	D1	D2	Avg.	D1	D2	Avg.	Col. 4-7	W1	W2	W1+W2	
1	2	3	4	5	6	7	8	9	10	11	12
Diameter Class											
A											
A											
B											
B											
C											
C											
D											
D											
E											
E											
F											
F											
G											
G											
Total											
Average											
Diameter Class											
A											
A											
B											
B											
C											
C											
D											
D											
E											
E											
F											
F											
G											
G											
Total											
Average											

INCREMENT BORING

TABLE - II

TABLE SHOWING AVE. DBH (UB) - AVE. INCREMENT IN ____YEARS AND AVE. 2 x BT (FROM TABLE 1)

Sr. No.	Ave. initial DBH (u.b.) in cm.	Increment in ______ Years in cm.	Ave. observed DBH (u.b.)	2 x Bark thickness in cm.
1	2	3		4

* Serial number shall be the same as the number of diameter classes covered.

INCREMENT BORING

TABLE - III

Table showing D.B.H. (u.b) at an interval of _________ Years

Age	Initial diameter (u.b) in cm.	Increment in Cm. as seen from DBH (u.b) - increment curve drawn as per Table II	Final diameter (u.b) in Cm. Column 1 + column 2
	1	2	3

*** First reading of column 1 shall be the same as the first reading of column 2 of table II.

INCREMENT BORING

TABLE - IV

Computation of DBH (o.b.)

DBH (u.b.) in cm. to be reproduced as per Col. (1) of Table III	Twice Bark thickness in cm.	DBH (o.b.) in Cm. Col. (1) + Col. (2)
1	2	3

** Corresponding value of 2 x B.T. as seen from DBH (u.b.)-2 x B.T. curve drawn as per data in table II.

RADIAL MEASUREMENTS

Species :- | **TREE No.** ____________ | **Stem Analysis Form No. 1.**

Quality :- | **Division :-**

Crown class :- | **Block and Compartment :-**

S. No. of section	Height of section in metre	Age to section in years	Rings on section	Diameter		Twice bark thickness	Avg. radius under bark cm	Length of section	Radius at successive decade marks cm and mm												Additional measurements
				Over bark cm	Under bark cm				120	110	100	90	80	70	60	50	40	30	20	10	
																					1 Total height………
																					2 Ht. to 1st green branch …… Ht. to full crown ……. Average clear bole ……. Average crown length …..
																					3 Ht. to 20 cm d. over bark D.u.b. at 20 cm d.o.b.
																					4 Ht. to 5 cm d, over bark … D.u.b.at 5 cm d.o.b. ….. Length of stem smallwood ………………………………………
																					5 Ht. frm b.h. half way to top (F.Q.) ……………… D.u.b. at this point …………

Species :-

Division :-

MEAN DIAMETER COMPUTATION FOR DECADE 1

Quality :-

Block and Compartment :-

Tree No.	HEIGHT OF SECTION (METRES)																																	
	1.37		4.24		7.24		10.24		13.24		16.24		19.24		22.24		25.24		28.24		31.24		34.24		37.24		40.24		43.24		46.24		49.24	
	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.
Total																																		
No. of trees																																		
Avg.																																		

MEAN DIAMETER COMPUTATION FOR DECADE 2

Tree No.	HEIGHT OF SECTION (METRES)																																	
	1.37		4.24		7.24		10.24		13.24		16.24		19.24		22.24		25.24		28.24		31.24		34.24		37.24		40.24		43.24		46.24		49.24	
	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.
Total																																		
No. of trees																																		
Avg.																																		

Division :-

Species :-

AGE COMPUTATION

Block and Compartment :-

Quality :-

Tree No.	HEIGHT OF SECTION (METRES)																																	
	1.37		4.24		7.24		10.24		13.24		16.24		19.24		22.24		25.24		28.24		31.24		34.24		37.24		40.24		43.24		46.24		49.24	
	Age	Dev.	Age	Dev.	Age	Dev.	Age	Dev.	Age	Dev.	Age	Dev.	Age	Dev.	Age	Dev.	Age	Dev.	Age	Dev.	Age	Dev.	Age	Dev.	Age	Dev.	Age	Dev.	Age	Dev.	Age	Dev.	Age	Dev.
Total																																		
No. of trees																																		
Avg.																																		

Species :- Division :-

MEAN DIAMETER COMPUTATION FOR DECADE 5

Quality :- Block and Compartment :-

Tree No.	HEIGHT OF SECTION (METRES)																																	
	1.37		4.24		7.24		10.24		13.24		16.24		19.24		22.24		25.24		28.24		31.24		34.24		37.24		40.24		43.24		46.24		49.24	
	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.
Total																																		
No. of trees																																		
Avg.																																		

MEAN DIAMETER COMPUTATION FOR DECADE 6

Tree No.	HEIGHT OF SECTION (METRES)																																	
	1.37		4.24		7.24		10.24		13.24		16.24		19.24		22.24		25.24		28.24		31.24		34.24		37.24		40.24		43.24		46.24		49.24	
	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.
Total																																		
No. of trees																																		
Avg.																																		

Species :- Division :-

MEAN DIAMETER COMPUTATION FOR DECADE 3

Quality :- Block and Compartment :-

Tree No.	HEIGHT OF SECTION (METRES)																																	
	1.37		4.24		7.24		10.24		13.24		16.24		19.24		22.24		25.24		28.24		31.24		34.24		37.24		40.24		43.24		46.24		49.24	
	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.
Total																																		
No. of trees																																		
Avg.																																		

MEAN DIAMETER COMPUTATION FOR DECADE 4

Tree No.	HEIGHT OF SECTION (METRES)																																	
	1.37		4.24		7.24		10.24		13.24		16.24		19.24		22.24		25.24		28.24		31.24		34.24		37.24		40.24		43.24		46.24		49.24	
	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.
Total																																		
No. of trees																																		
Avg.																																		

Species :- Division :-

MEAN DIAMETER COMPUTATION FOR DECADE 9

Quality :- Block and Compartment :-

Tree No.	HEIGHT OF SECTION (METRES)																																	
	1.37		4.24		7.24		10.24		13.24		16.24		19.24		22.24		25.24		28.24		31.24		34.24		37.24		40.24		43.24		46.24		49.24	
	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.
Total																																		
No. of trees																																		
Avg.																																		

MEAN DIAMETER COMPUTATION FOR DECADE 10

Tree No.	HEIGHT OF SECTION (METRES)																																	
	1.37		4.24		7.24		10.24		13.24		16.24		19.24		22.24		25.24		28.24		31.24		34.24		37.24		40.24		43.24		46.24		49.24	
	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.
Total																																		
No. of trees																																		
Avg.																																		

Species :- Division :-

MEAN DIAMETER COMPUTATION FOR DECADE 7

Quality :- Block and Compartment :-

Tree No.	HEIGHT OF SECTION (METRES)																																	
	1.37		4.24		7.24		10.24		13.24		16.24		19.24		22.24		25.24		28.24		31.24		34.24		37.24		40.24		43.24		46.24		49.24	
	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.
Total																																		
No. of trees																																		
Avg.																																		

MEAN DIAMETER COMPUTATION FOR DECADE 8

Tree No.	HEIGHT OF SECTION (METRES)																																	
	1.37		4.24		7.24		10.24		13.24		16.24		19.24		22.24		25.24		28.24		31.24		34.24		37.24		40.24		43.24		46.24		49.24	
	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.
Total																																		
No. of trees																																		
Avg.																																		

Species :-

MEAN TREE VOLUME COMPUTATION FOR DECADES (1-3)

Quality :-

Division :-

Block and Compartment :-

Tree No.	HEIGHT OF SECTION (METRES)																																
	1.37		4.24		7.24		10.24		13.24		16.24		19.24		22.24		25.24		28.24		31.24		34.24		37.24		40.24		43.24		46.24		Total vol. In m^3
		Dev.		Dev.		Dev.		Dev.		Dev.		Dev.		Dev.		Dev.		Dev.		Dev.		Dev.		Dev.		Dev.		Dev.		Dev.		Dev.	
10 YEARS																																	
Ht. Of cone																																	
Diameter (cm)																																	
Basal Area (m_3)																																	
Volume (m_3)																																	
20 YEARS																																	
Ht. Of cone																																	
Diameter (cm)																																	
Basal Area (m_3)																																	
Volume (m_3)																																	
30 YEARS																																	
Ht. Of cone																																	
Diameter (cm)																																	
Basal Area (m_3)																																	
Volume (m_3)																																	

Species :-

Division :-

MEAN DIAMETER COMPUTATION FOR DECADE 11

Block and Compartment :-

Quality :-

Tree No.	HEIGHT OF SECTION (METRES)																																	
	1.37		4.24		7.24		10.24		13.24		16.24		19.24		22.24		25.24		28.24		31.24		34.24		37.24		40.24		43.24		46.24		49.24	
	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.
Total																																		
No. of trees																																		
Avg.																																		

MEAN DIAMETER COMPUTATION FOR DECADE 12

Tree No.	HEIGHT OF SECTION (METRES)																																	
	1.37		4.24		7.24		10.24		13.24		16.24		19.24		22.24		25.24		28.24		31.24		34.24		37.24		40.24		43.24		46.24		49.24	
	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.	Dia.	Dev.
Total																																		
No. of trees																																		
Avg.																																		

Species :-

MEAN TREE VOLUME COMPUTATION FOR DECADES (7-9)

Quality :-

Division :-

Block and Compartment :-

Tree No.	HEIGHT OF SECTION (METRES) 1.37	Dev.	4.24	Dev.	7.24	Dev.	10.24	Dev.	13.24	Dev.	16.24	Dev.	19.24	Dev.	22.24	Dev.	25.24	Dev.	28.24	Dev.	31.24	Dev.	34.24	Dev.	37.24	Dev.	40.24	Dev.	43.24	Dev.	46.24	Dev.	Total vol. In m^3
70 YEARS																																	
Ht. Of cone																																	
Diameter (cm)																																	
Basal Area (m_3)																																	
Volume (m_3)																																	
80 YEARS																																	
Ht. Of cone																																	
Diameter (cm)																																	
Basal Area (m_3)																																	
Volume (m_3)																																	
90 YEARS																																	
Ht. Of cone																																	
Diameter (cm)																																	
Basal Area (m_3)																																	
Volume (m_3)																																	

Species :-

MEAN TREE VOLUME COMPUTATION FOR DECADES (4-6)

Quality :-

Division :-

Block and Compartment :-

Tree No.	HEIGHT OF SECTION (METRES) 1.37	Dev.	4.24	Dev.	7.24	Dev.	10.24	Dev.	13.24	Dev.	16.24	Dev.	19.24	Dev.	22.24	Dev.	25.24	Dev.	28.24	Dev.	31.24	Dev.	34.24	Dev.	37.24	Dev.	40.24	Dev.	43.24	Dev.	46.24	Dev.	Total vol. In m^3
40 YEARS																																	
Ht. Of cone																																	
Diameter (cm)																																	
Basal Area (m_3)																																	
Volume (m_3)																																	
50 YEARS																																	
Ht. Of cone																																	
Diameter (cm)																																	
Basal Area (m_3)																																	
Volume (m_3)																																	
60 YEARS																																	
Ht. Of cone																																	
Diameter (cm)																																	
Basal Area (m_3)																																	
Volume (m_3)																																	

MEAN TREE VOLUME COMPUTATION FOR DECADES (10-12)

Species :- Division :-

Quality :- Block and Compartment :-

Tree No.	HEIGHT OF SECTION (METRES) 1.37	4.24	7.24	10.24	13.24	16.24	19.24	22.24	25.24	28.24	31.24	34.24	37.24	40.24	43.24	46.24	Total vol. In m^3
	Dev.	Dev.	Dev.	Dev.	Dev.	Dev.	Dev.	Dev.	Dev.	Dev.	Dev.	Dev.	Dev.	Dev.	Dev.	Dev.	
100 YEARS																	
Ht. Of cone																	
Diameter (cm)																	
Basal Area (m_2)																	
Volume (m_3)																	
110 YEARS																	
Ht. Of cone																	
Diameter (cm)																	
Basal Area (m_2)																	
Volume (m_3)																	
120 YEARS																	
Ht. Of cone																	
Diameter (cm)																	
Basal Area (m_2)																	
Volume (m_3)																	

COMPUTATION FOR BARK THICKNESS

Species :- Division :-

Quality :- Block and Compartment :-

	Diameter-Classes													
	0-10 cm		10-20 cm		20-30 cm.		30-40 cm.		40-50 cm.		60-80 cm.		80-100 cm	
Tree no.	D.u.b.	2 x bark thickness	D.u.b.	2 x bark thickness	D.u.b.	2 x bark thickness	D.u.b.	2 x bark thickness	D.u.b.	2 x bark thickness	D.u.b.	2 x bark thickness	D.u.b.	2 x bark thickness
Total														
No. of observations														
Average														