Estimation of Growth and Yield of Stands

Scope of Forest Biometry…

1. Volume of forest crops at present

+

2. Forecast of future yields

1. <u>Volume of forest crops at present</u>

- Not always possible to calculate for whole forest

↓

Sample plots (Area + Point sampling)

↓

For obtaining forest inventory

2. Forecast of future yields…

Require tables which may give Yield of Stand on unit area basis

depends mainly on ↓

1. Stand structure
2. Stand growth
3. Stand density
4. Productive capacity of site, "site quality"

1. <u>Stand structure</u>

Definition :

- Distribution and representation of age and / or size classes of trees in a stand

↓

Keeps changing

↓ depends on

1. Factors of locality
2. Management practices

Stand structure…

- Classified in 2 groups :

  1. Even aged

  2. Un-even aged

Even aged Stand

- ✔ Trees approximately of same age
- ✔ Age variation less than 25% rotation age

- Though the trees are of nearly same age – class, competition for light & moisture results in crown differentiation
- Vigorous trees in dominant position, less vigorous in dominated position, left behind in the struggle occupy the suppressed position

Un-even aged stand

- ✔ Individual stem vary widely in age
- ✔ Age variation is more than 25% of rotation age

Uneven-aged: a stand with trees of three or more distinct age classes, either intimately mixed or in small groups.

Two-aged: a stand with trees of two distinct age classes separated in age by more than plus or minus 20% of the rotation age.

Even-aged: a stand composed of a single age class of trees in which the range of tree ages is usually plus or minus 20% of the rotation age.

Even aged and Un-Even aged forest

Even aged forest :

- Has stands of different ages to maturity but one stand has trees of one age

Un Even aged forest:

- Each stand has trees of all ages –**Selection Forest**

Silvicultural system

- Broadly classified in to 2 main groups :

I. **Even aged system**

   - Clear cutting
   - Shelterwood

   – Management based on **Age & Area**

II. **Un-Even aged system**

   - Selection

   – Management based on **Size**

✔ **Mathematically**

Even aged Stand

→ Normal distribution

- Peaking at mean BH size

Un-Even aged Stand

→ Inverse J curve

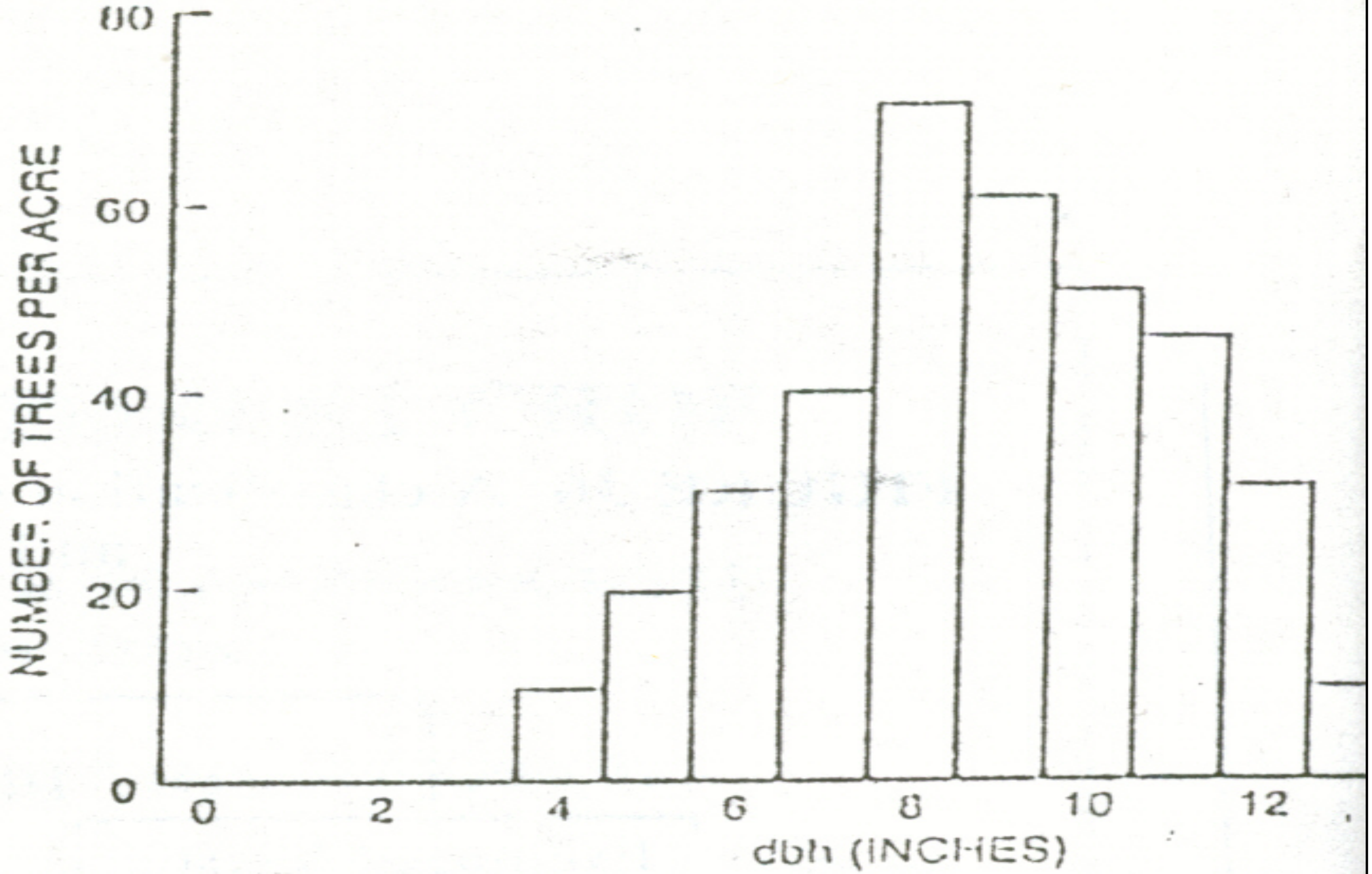


FIGURE 16-2
A typical dbh distribution for pure, even-aged stands.

A typical dbh distribution for pure, even-aged stands

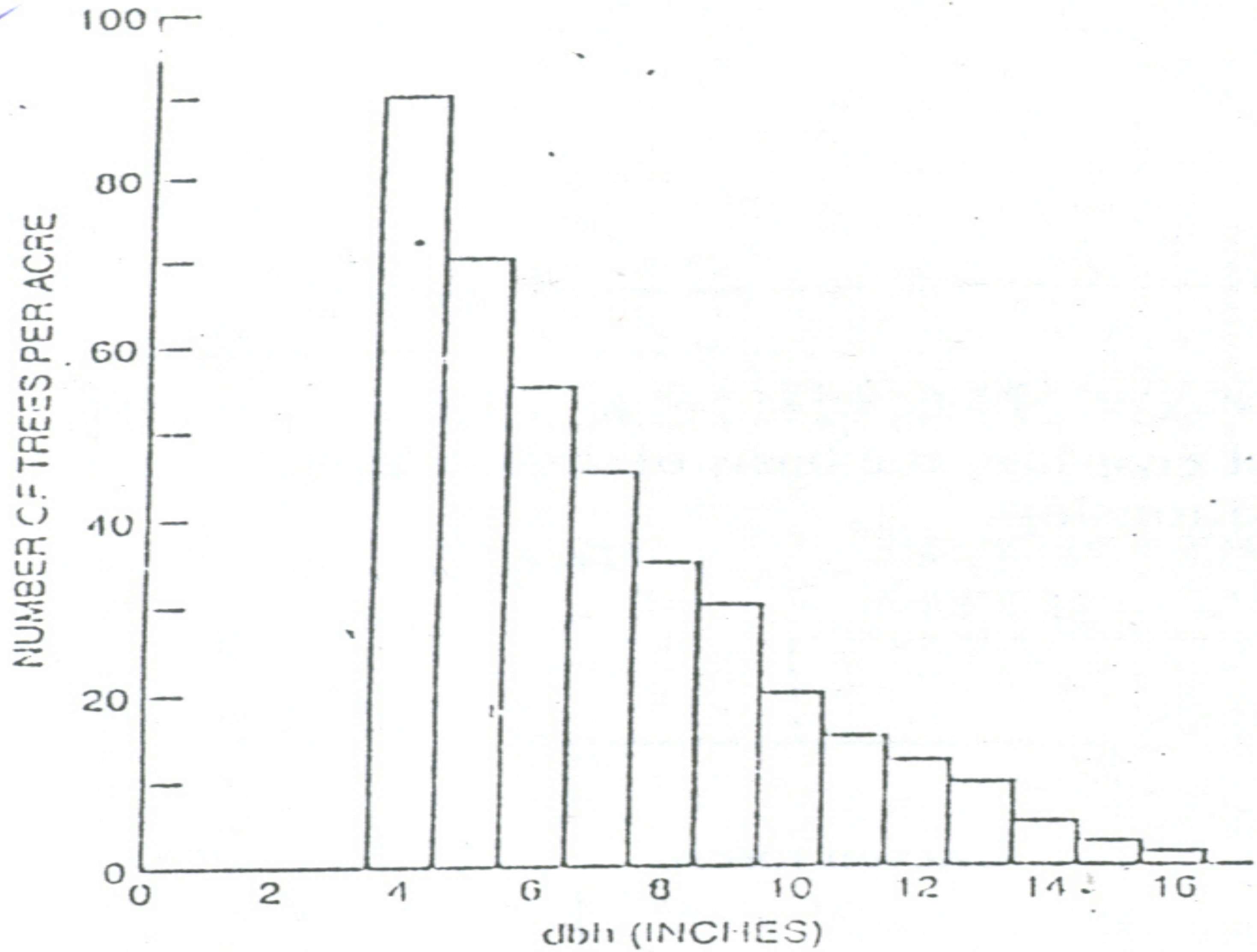
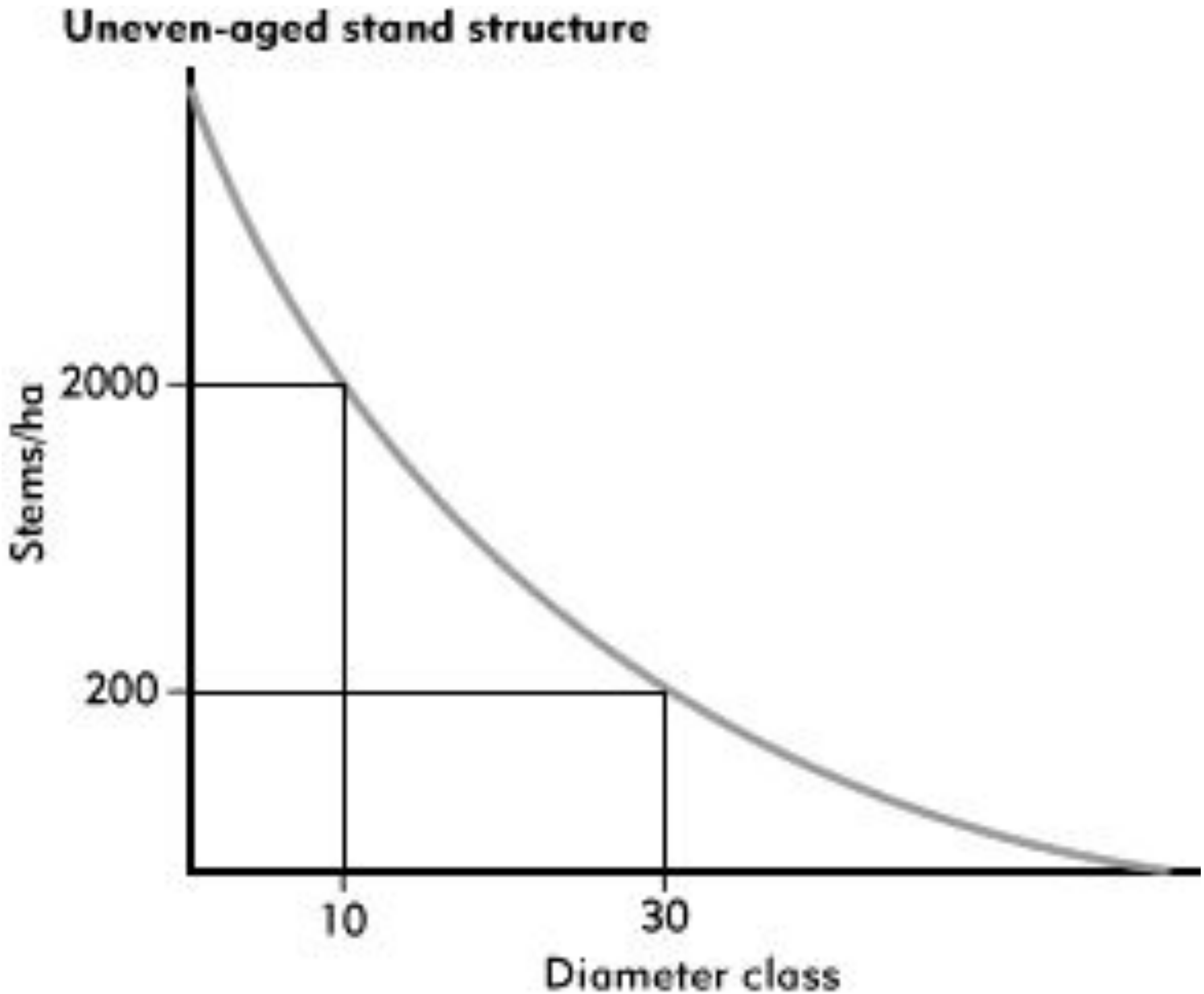
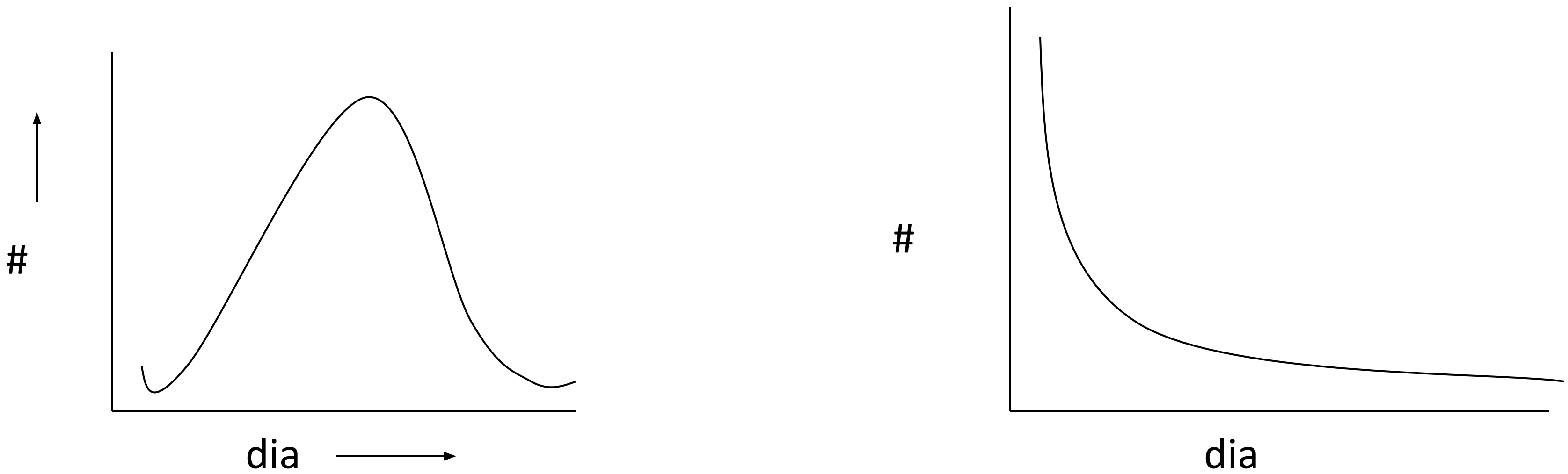


FIGURE 16-4
Typical dbh distribution for regular, une··-n-aged stands.

Typical dbh distribution for regular, uneven-aged stands


Uneven-aged stand structure
Stems/ha
2000
200
10
30
Diameter class

1. Dia Distribution Curve is different

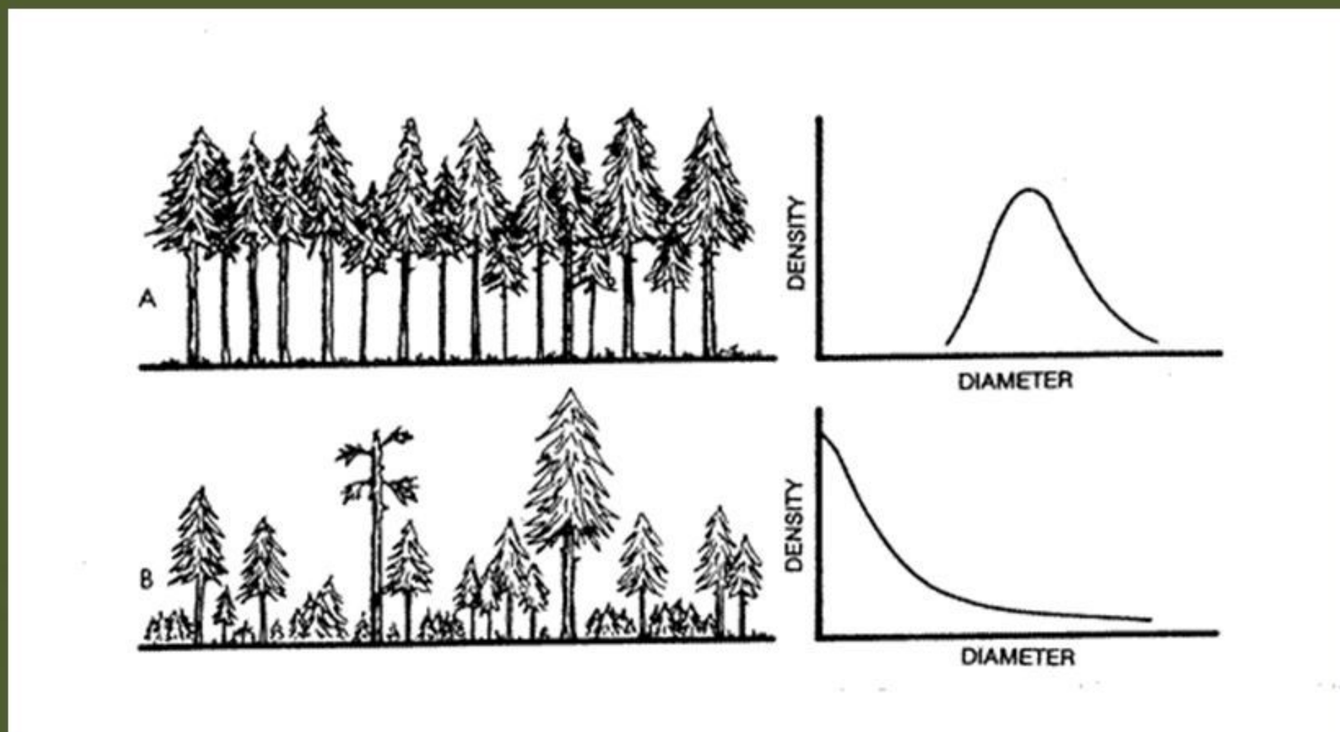


Even aged Stand

Uneven aged Stand

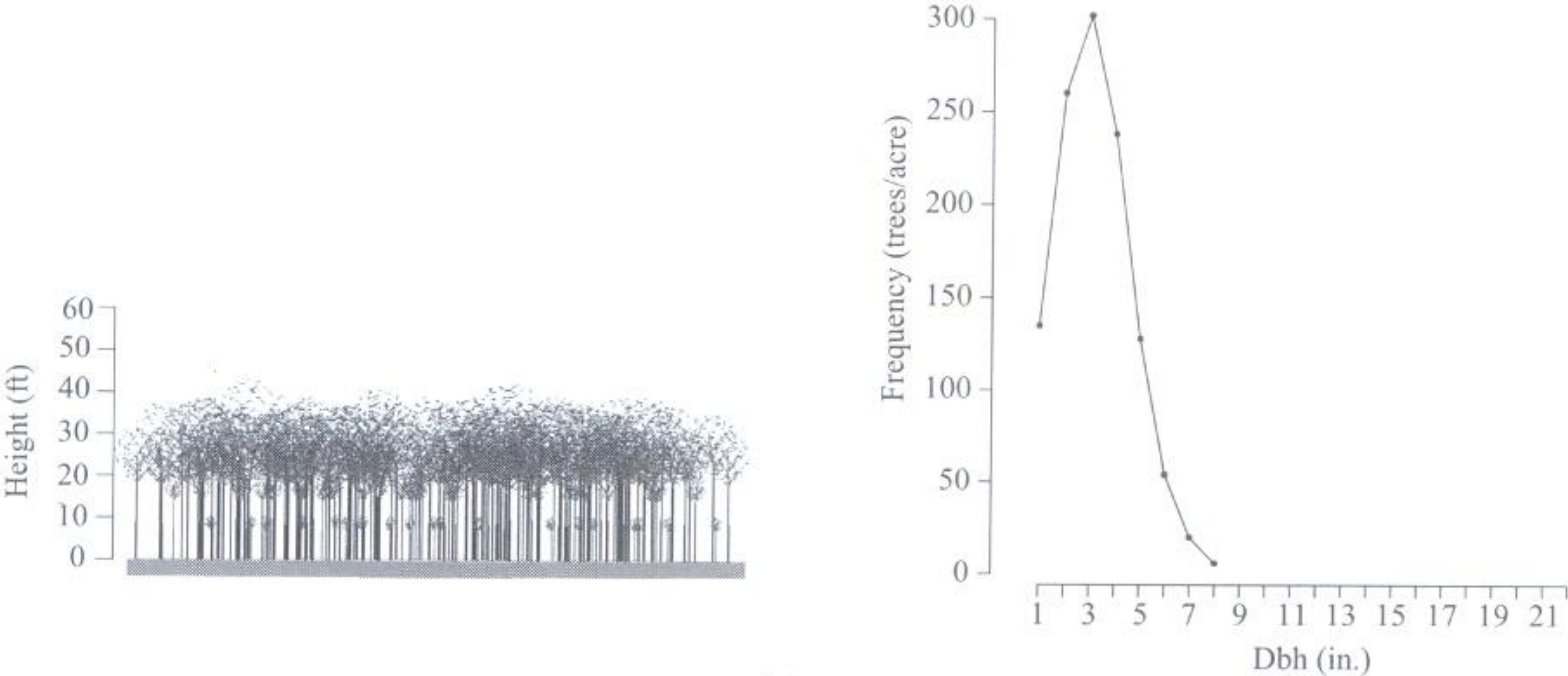
N-D Curves of Even aged & Uneven aged Stands

Even- and Uneven-aged Forest Stands



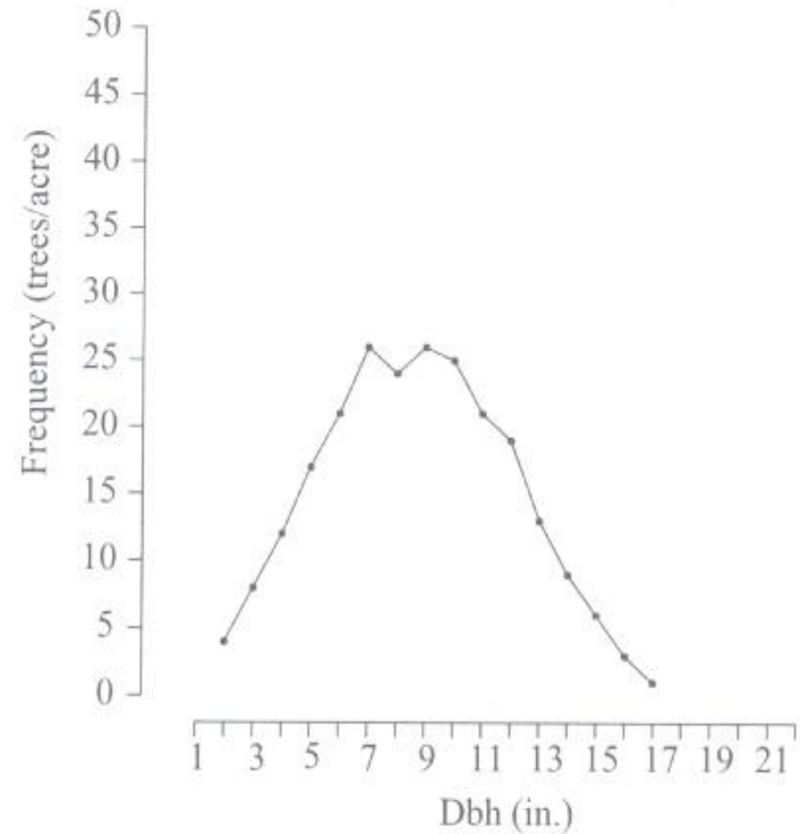
Distribution of tree sizes in an even-aged forest stand (A) and an uneven-aged forest stand (B)

Stand Profile of 20 yrs Oak - Even-aged

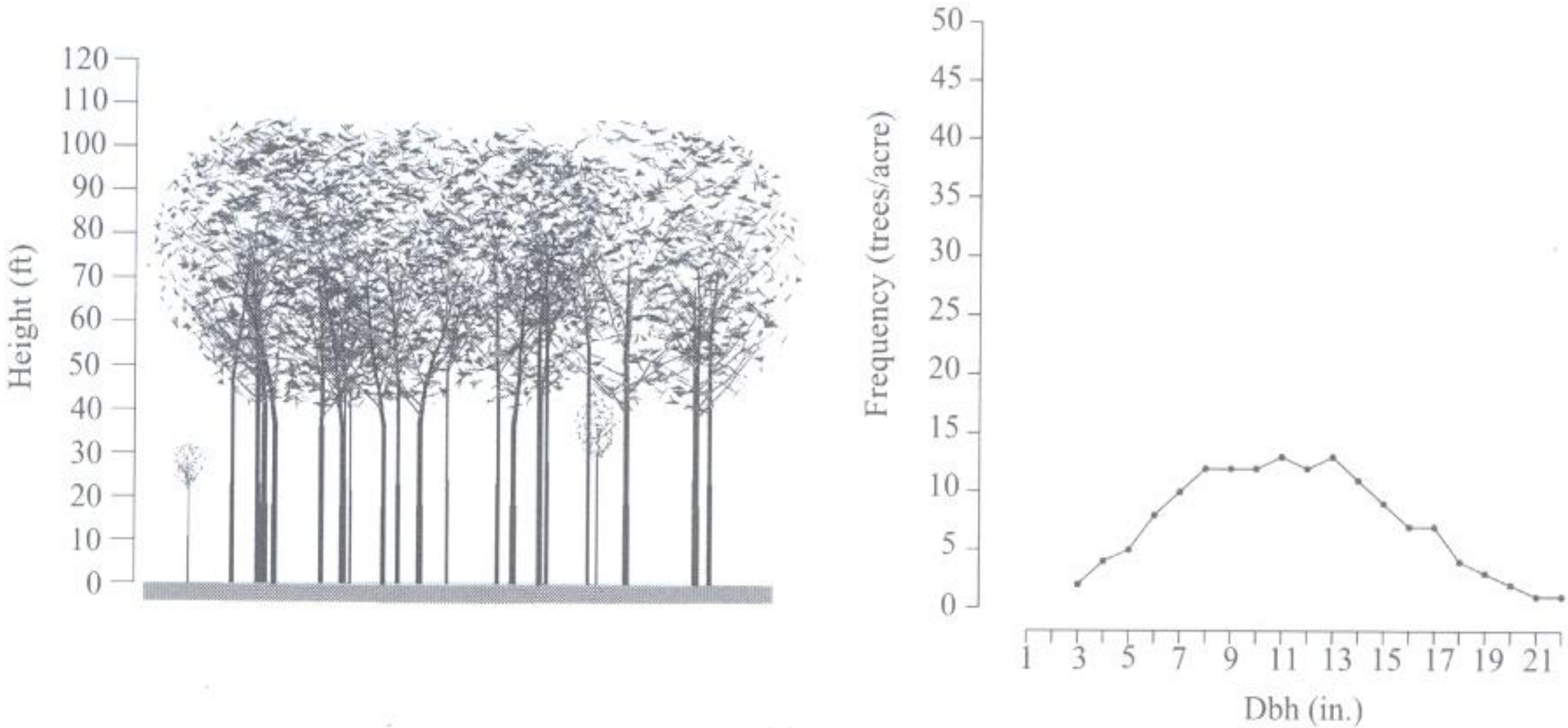


(*a*)

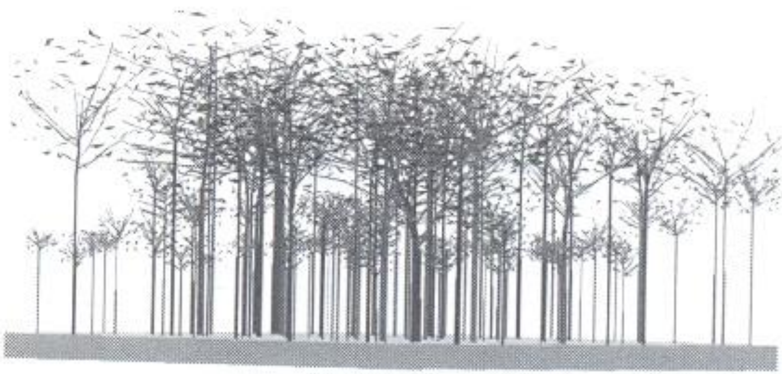
Stand Profile of 60 yrs Oak Stand
Even aged stand

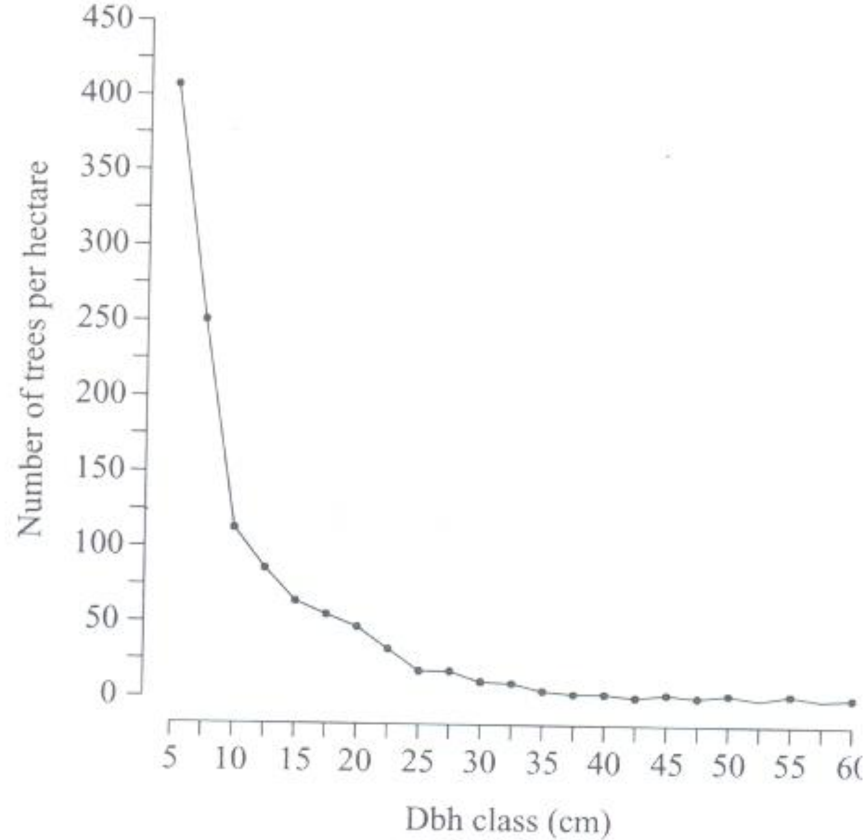


Stand Profile of 100 yrs Oak Even-Aged



(c)





Stand Profile of un-even aged stand

Even aged and Un-even aged forest

- Even aged forest :
  - Has stands of different ages till maturity but one stand has trees of one age
- Un Even aged forest:
  - Each stand has trees of all ages –**Selection Forest** or all aged forest

ND curve for Even aged and Un-even aged forest

Silvicultural system

- Broadly classified in to 2 main groups :

I. **Even aged system**

- Clear cutting
- Shelterwood

System of Concentrated Regeneration

◦ Management based on

– **Age**

II. **Un-Even aged system**

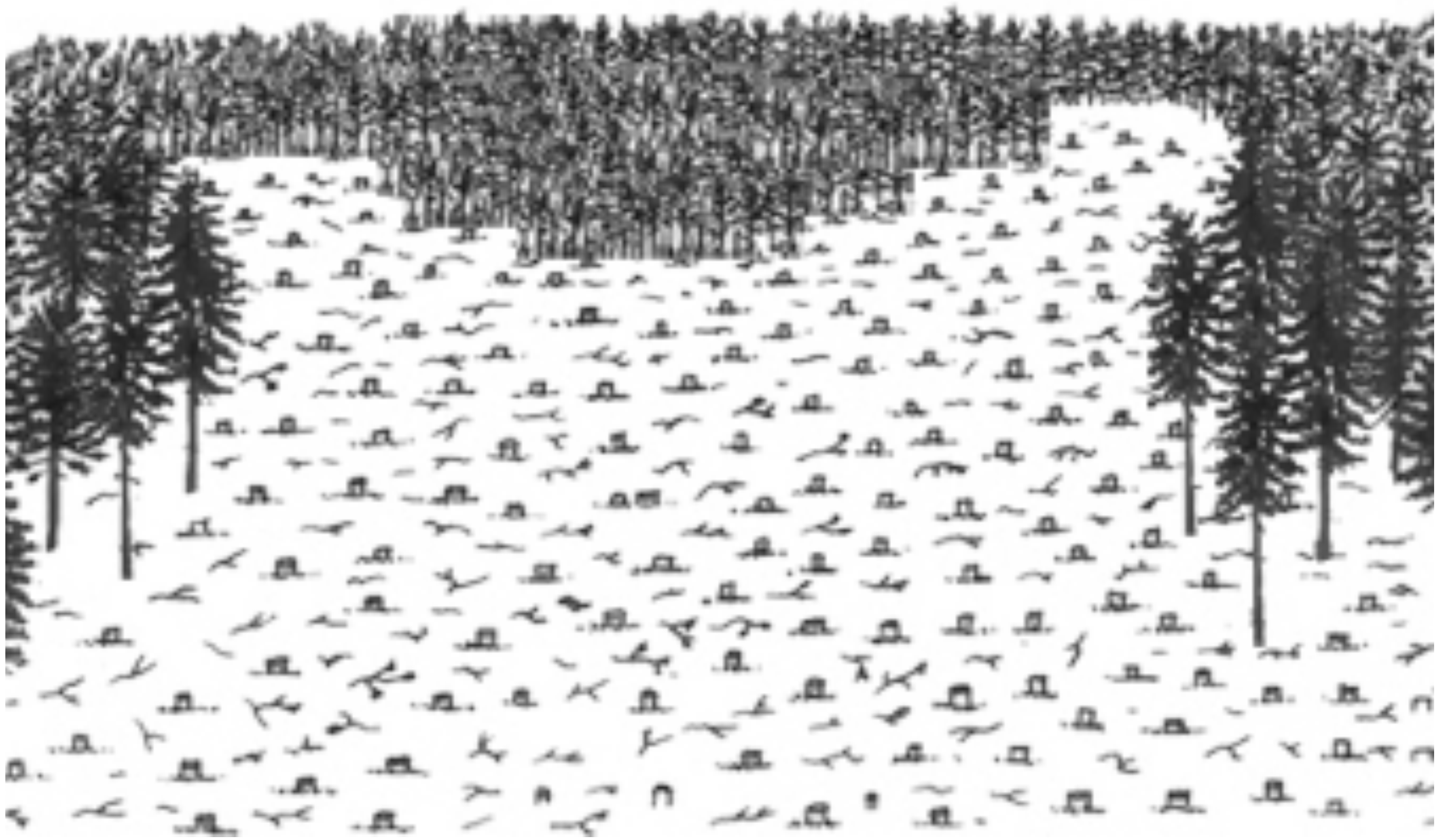
- Selection - System of Diffused Regeneration

◦ Management based on

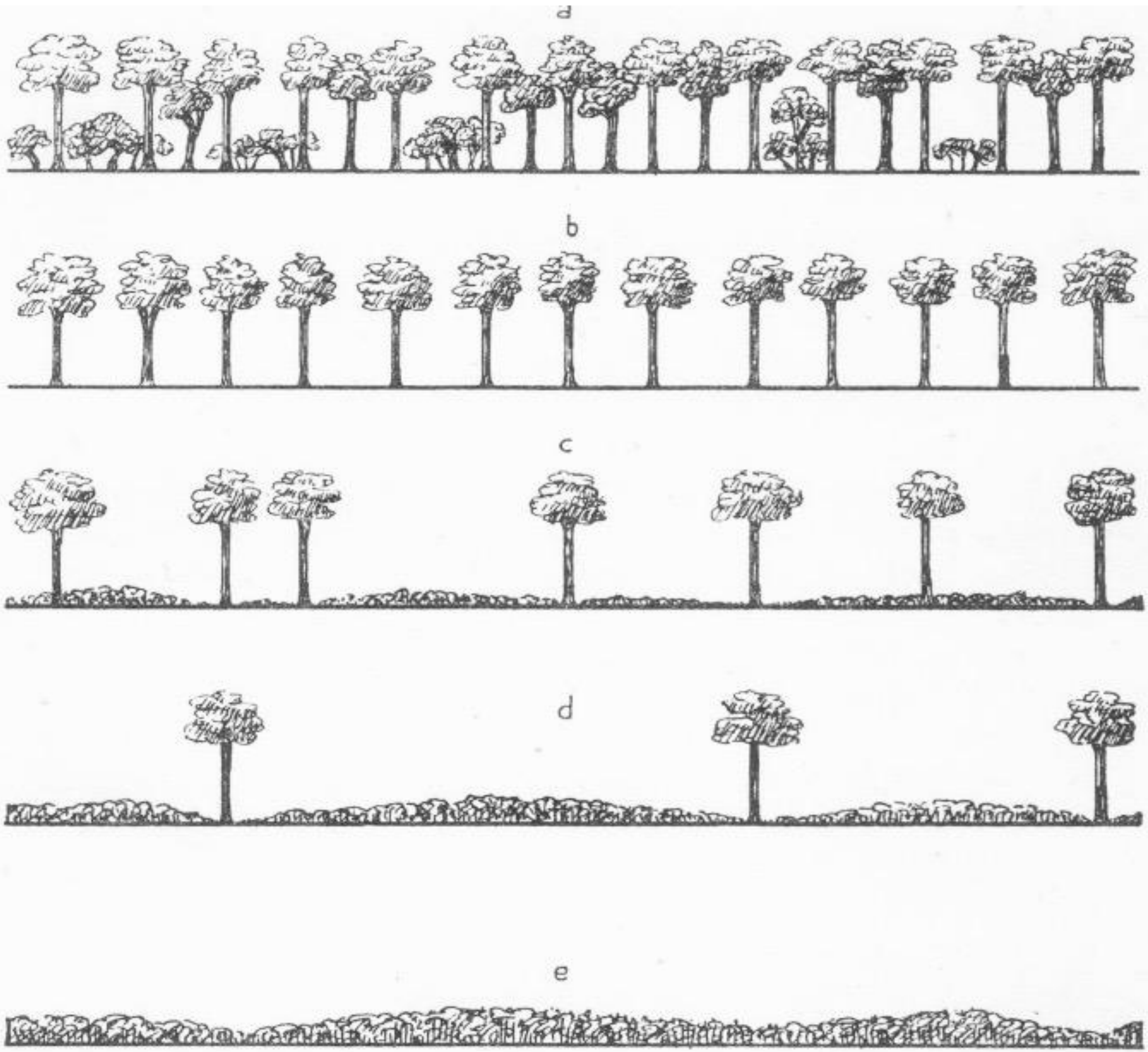
– **Size**

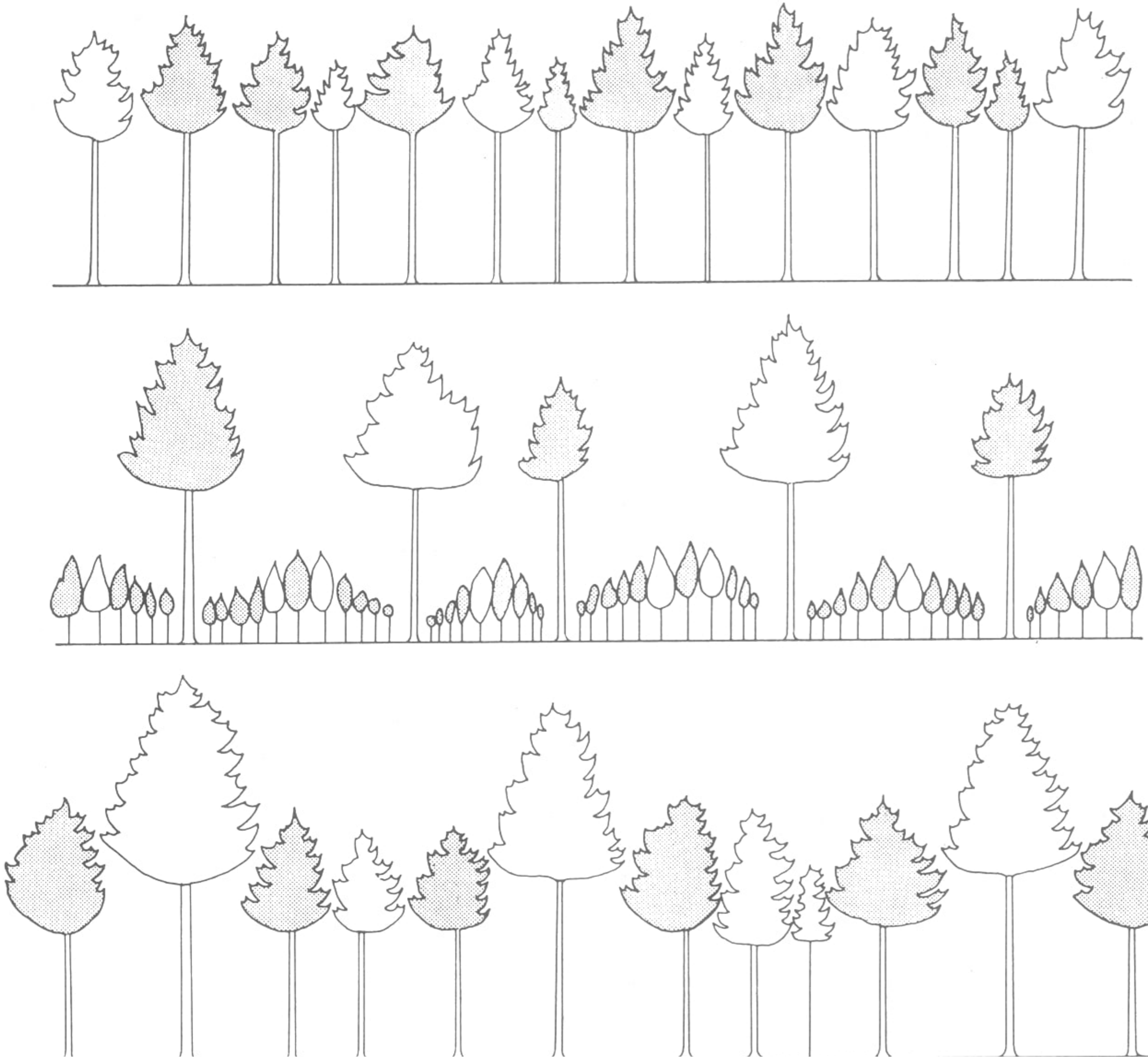
Even aged system

Clear cutting



Even aged System: Shelterwood


a
b
c
d
e



Selection System

FIG. 60. Forest worked under the selection system.

Un-even aged System: selection

- After rotation period **Even aged forest** needs regeneration
- **Uneven aged forests**: new recruits continuously coming

  - ✔ Productivity (Timber) (Quantity) wise even aged is better than uneven aged.
  - ✔ Quality wise uneven aged may be better.

Uneven aged stand

De Liocourt diameter distribution:

– Stem numbers in successive diameter classes had a fixed ratio within a stand

$$\frac{N1}{N2} = \frac{N2}{N3} = \frac{N3}{N4} = q$$

(Di Liocourt quotient)

Where, N1, N2, N3 etc. are # of stems in successive dia class.

– Geometric series

Even aged & Un-Even aged Forest structure

- Reverse J shaped curve
  - Even aged Forest
    - Curve applies to the whole forest
  - Un-Even aged Forest
    - Curve applies to each small unit of area throughout the forest

Even Aged Stand (of one species) are Characterized by:

1. # of Stems /ha
2. Basal Area
3. Crop dia
4. Height
5. Age
6. Form
7. Crown size and Canopy

Un-even Aged Stands are Characterized by:

1. Diameter and # of stem distribution

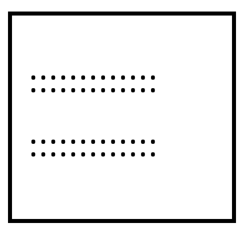
Number of Stems per ha:

- A useful description

- Alone it is not sufficient

(Along with **ht, Age** or **dia** it gives picture of crop)

Example:



Young crop
#200/ha may be quite open or light stocked

Mature crop
200/ha near rotation age may be densely stocked

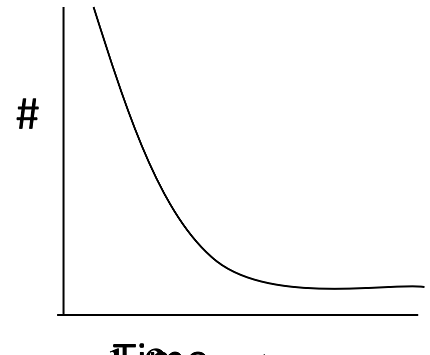
>Plantation usually done at 2.5x2.5m or 3.3x 3.3m

→ 1600 or 1000 plants /ha

at Maturity ↓

200 – 500 trees /ha

- In natural forests



  - Even in even aged well managed forest
    - # decrease due to

      - Natural Mortality

      - Thinning

<u>Estimate # of Trees/ha:-</u>

Method 1:

- Lay out small plot of known area, a

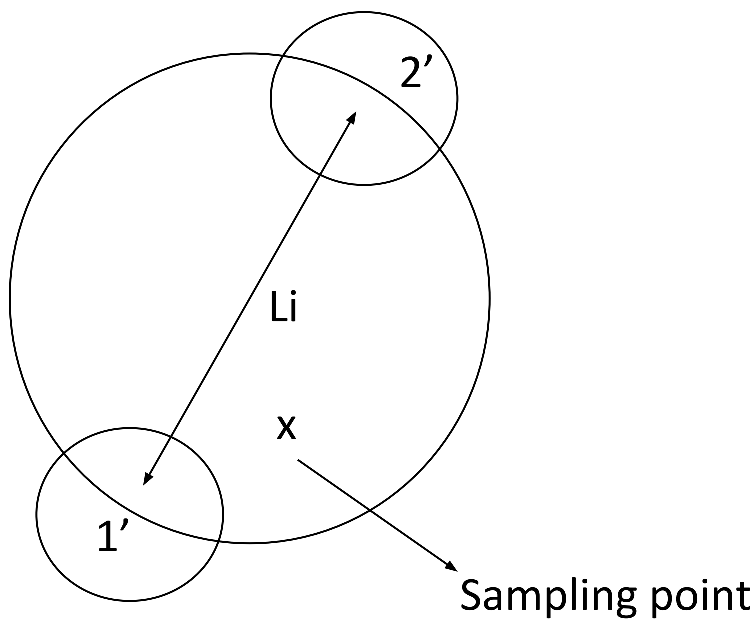
- Count the # of trees in each plot, n

- Calculate

No of trees per Ha,	**N=n/a**

Method 2:

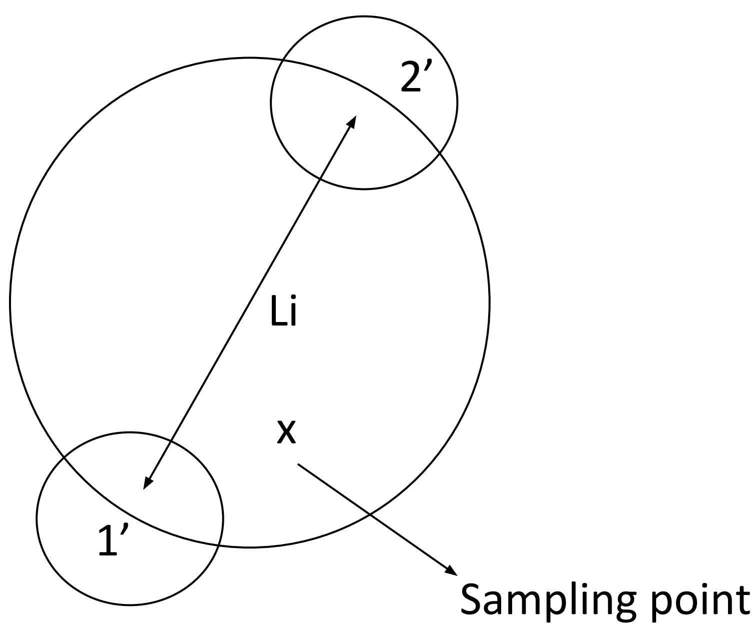
a) At representative points measure the length Li



1’ = closest neighbour
2’ = second closest neighbour

Method 2:

- measuring the closest neighbour, there is **one tree** within the plot made up of **one-half of each** of the two trees lying on the plot perimeter.



1’ = closet neighbour
2’ = second closet neighbour

b) No of trees per Ha,

$$\mathbf{Ni = A/a_i}$$

where,

$\mathbf{A}$ = 1 ha = 10,000 m^2 = $\mathbf{10^4}$ m^2

$\mathbf{a_i}$ = area of circle with **'Li'** as diameter

i.e. $\mathbf{a_i} = \pi \times (Li/2)^2$

$$= \frac{\pi \times Li^2}{4}$$

$$\Longrightarrow \mathbf{Ni = A/a_i = [(4/\pi) * 10^4] * \left[\frac{1}{Li^2}\right]}$$

$$\mathbf{= K * (1/Li^2)}$$

c) This is for one sample point if we take sample at ‘m’ points, then

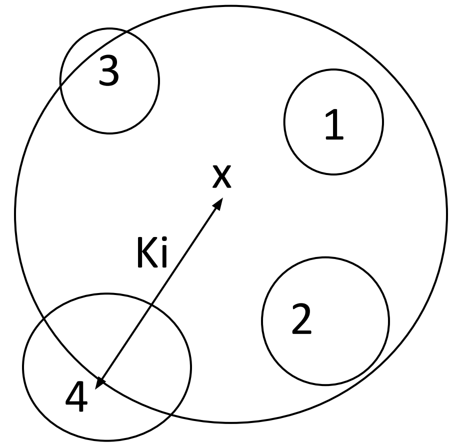
$$\Rightarrow \quad \mathbf{N = \frac{\sum Ni}{m}}$$

$$N = \frac{[(4/\lambda) * 10^4] * \sum (1/Li^2)}{m}$$

$$= \mathbf{K * \frac{\sum (1/Li^2)}{m}}$$

Method 3 :

-Extension of method 2.



$$N= \frac{[(n-1/2) * 10^4]}{\wedge \quad m} * \sum^{m} (1/ki^2)$$

1,2,3,4 = nearest, 2^{nd},3^{rd} & 4^{th} nearest neighbour

n = n^{th} nearest neighbouring tree.

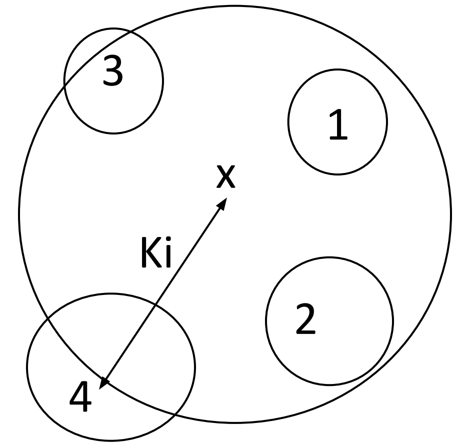
ki = distance from the sampling point to the n^{th} nearest tree.

m = # of sampling points.

Method 3 :

-Extension of method 2.

$$N = \frac{[(n-1/2) * 10^4]}{\pi * m} \sum^{m} (1/ki^2)$$



1,2,3,4 = nearest, 2nd,3rd & 4th nearest neighbour

n = nth nearest neighbouring tree.

- Measuring from the sampling point to the nth(4th) nearest neighbour, there are **3 complete trees** in the plot and **one half tree** lying on plot perimeter
- (n-1/2)

Example of number of trees /ha Calculation

- **Problem 1:**

At 10 points in a plantation chosen systematically, the following data were collected on the number of trees –n- in circular plots of area 0.01 ha. Calculate number of trees per Ha.

Data: n=16,14,18,13,12,9,17,15,16,14

- **Solution:-**

$$\sum^{10} n_i = 144 \qquad n = 14.4$$

$$N = n/a \qquad = 14.4/0.01$$

$$= 1440 \text{ stems ha}^{-1}$$

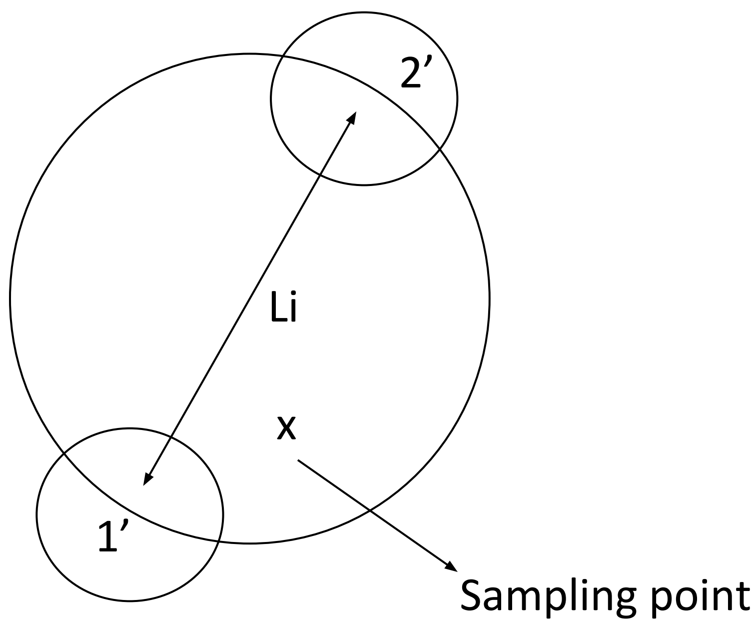
- **Problem 2:**

In a similar plantation and at a similar ten points chosen systematically, the distance-L,- between the nearest two trees (n=1) was measured and recorded in m.

Data: Li= 2.25, 3.75, 1.95, 3.65, 2.75, 2.90, 3.10, 3.45, 3.60, 2.85.

Method 2:

a) At representative points measure the length Li



1’ = closest neighbour
2’ = second closest neighbour

b) No of trees per Ha,

$$\mathbf{Ni = A/a_i}$$

where,

$\mathbf{A}$ = 1 ha = 10,000 m^2 = $\mathbf{10^4}$ m^2

$\mathbf{a_i}$ = area of circle with **'Li'** as diameter

i.e. $\mathbf{a_i} = \pi \times (Li/2)^2$

$$= \frac{\pi \times Li^2}{4}$$

$$\Rightarrow \mathbf{Ni = A/a_i = [(4/\pi) * 10^4] * \left[\frac{1}{Li^2}\right]}$$

$$\mathbf{= K * (1/Li^2)}$$

c) This is for one sample point if we take sample at 'm' points, then

$$\Rightarrow \quad \mathbf{N} = \frac{\sum \mathbf{Ni}}{\mathbf{m}}$$

$$N = [(4/\pi) * 10^4] * \frac{\sum (1/Li^2)}{m}$$

$$= \mathbf{K} * \frac{\sum (\mathbf{1/Li^2})}{\mathbf{m}}$$

- **Solution:-**

$$\sum^{10} (1/Li^2) = 1.246$$

$$N = \frac{(1.273)10^4}{10} \quad (1.246)$$

$$= \quad 1586 \text{ stems ha}^{-1} \qquad \text{Where } n=1$$

- **Problem 3:**

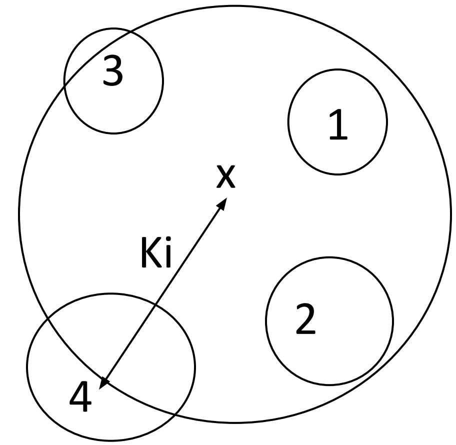
  In a similar manner but in another older plantation the distance from the sampling to the 4^{th} nearest tree (n=4) was measured and recorded to the nearest 0.1 m.

  Data: 4.8, 6.2, 5.4, 6.1, 5.7, 6.0, 5.8, 5.6, 6.2, 6.0

Method 3 :

-Extension of method 2.

$$N = \frac{[(n-1/2) * 10^4] *}{\pi \quad m} \sum^{m} (1/ki^2)$$



1,2,3,4 = nearest, 2nd,3rd & 4th nearest neighbour

n = nth nearest neighbouring tree.

ki = distance from the sampling point to the nth nearest tree.

m = # of sampling points.

- **Solution:-**

$$\sum^{10} (1/Ki^2) = 0.3045$$

$$N = \frac{(3.5)10^4}{10\,(3.14)}\,(0.3045)$$

$$= \;339 \text{ stems ha}^{-1}$$

Forecast of future yields…

1. Stand structure

2. Stand growth

↓

3. ***Stand density***

4. Productive capacity of site, “site quality”

Normal forest

“Ideal state of perfection”

↓

Complete , ideal stocking of all stands

- satisfy the purpose of management to the full
- Serves as standard for comparison of an actual forest estate so as to bring out the deficiencies

Normal Forest

- "Normal" – ***doesn't*** denote the usual meaning of *usual, common or regular* and it means ***ideal condition*** in the context of forestry

- On a given site and given object of management, it is a forest which has
    - Ideal growing stock
    - Ideal distribution of age class
    - Ideal increment

- Annual or periodic yields equal to the increment can be realised in perpetuity, without endangering the future yields and without detriment to the site

Basic factors of Normality

General attributes :

1. Species grown & methods of silviculture adopted must fully suit all peculiarities of site
2. Growing stock of trees must be so constituted that it provides regularly the greatest possible quantity
3. General organization of forest must appropriate for its purpose
   - Road network, extraction method, sales organization
4. General administration must be the best possible

<u>Historical background of the Normal forest</u>

- Late 18th and earlier 19th century, when the principle of **<u>sustained yield</u>** took root

↓

'Forest should be capable of continuous, regular yields'

↓

Even aged stands & Even aged forestry – Essence of good forestry

2 main types of Normal Forest

1. Normal Even aged forest

2. Normal Un-Even aged forest

1. <u>Normal Even aged forest</u>

3 Attributes/Norms :

1. <u>Normal series of age gradation/ age classes:</u>

   - Presence of as many uniform aged stands as there are years in the rotation
   - Appropriate quantity, trees of all ages from one to rotation age
     - Ages of stand differs by one year up to rotation age
     - Each yield capacity is equal

(When trees of each age occur on separate areas – **<u>age gradations</u>**

Trees within certain age limit occur mixed together on a same area form **<u>age-class</u>**)

2. Normal increment

- Best or maximum increment attainable by a given species per unit area, for a given rotation and on a given site

3. Normal growing stock (NGS) ↓

- Volume of a stand with normal age- class & normal increment.
- Volume indicated in yield table for each age-class
- NGS follows as a matter of course if 2 conditions are satisfied- (1)Normal series of age-class & (2)Normal Increment
- Presence of NGS- not necessarily a Normal Forest.
- Eg. Sal forest – low density with mature & over mature trees- but volume greater than Yield Table – forest is abnormal – absence of younger age- class – Cannot produce sustained yield

All 3 norms must be present for the forest to be normal as a whole

<u>Trinity of norms</u>

1.Normal series of age gradation

(presence in forest, in appropriate quantity, trees of all ages from one year old to rotation age)

2. Normal increment.

(best increment attainable for a given species, for a given rotation, per unit area on a given site)

3. Normal growing stock

(volume of stands with normal age class and a normal increment; *<u>in practice</u>* volume indicated in Yield Table for each age class)

2. Normal Un-Even aged forest

- Un-Even aged forest
  - Trees of all ages(& sizes) are intermingled on every small unit of area
  - Age & rotation – meaningless
  - Normality is judged by
    - No. of trees in each size class
    - Must have normal series of size gradation instead of age gradation

3 Norms :

1. Normal growing stock
2. Normal increment
3. Normal series of **size gradation**

Normal Un-Even aged forest

- Difficult to devise a simple model to :
  - represent either the no. or volumes of trees in several size classes
- No Yield tables
- Normal growing stock – which produces permanently the most valuable increment
- Ideal state can only be found by long experience of working – Method of control inventory

3 ways to know Normality in un-even aged forest :

1. **Inverse J curve (N-D curve)**

   - Normal Un-Even aged forest
   - Normal Even aged forest

 Derive inverse J curve for un-even aged forest from yield table for even aged forest

 Get Coefficient of diminution

SIZE- FREQUENCIES AND COEFFICIENT OF DIMINUTION ON 1 HA

Dia. Class	No of Stems	Coefficient of diminution
0-10	185	1.54
10-20	120	1.41
20-30	85	1.36
30-40	62	1.25
40-50	50	1.25
50-60	40	1.22
>60	34	1.15

Ways to know Normality in un-even aged forest :

De Liocourt diameter distribution:

– Stem numbers in successive diameter classes had a fixed ratio within a stand

$$\frac{N1}{N2} = \frac{N2}{N3} = \frac{N3}{N4} = q \text{ (Di Liocourt quotient)}$$

Where, N1, N2, N3 etc. are # of stems in successive dia class.

Or, Geometric series/regression

$N_1, N_1.\ q^{-}1, N_1.q^{-2}, N_1.q^{-3}$.............

Meyer's exponential expression

- Simplified De Liocourt's law
- Used exponential form :

$$y = K e^{-a\chi}$$

Where,

Y = no. of stems in dia interval

χ = mid of dia class

'K' =relative stand density which is dependent on site conditions

and ' a' = percentage reduction in no of stems for each dia. class.

K & a are constants vary with site & species

e = 2.71828 , the base of Napierian Logarithm

3. **Stand density** or **Crop density**

- Measure of relative completeness of tree stocking
- Expressed as a decimal coefficient
  - Taking Normal no. of trees, basal area or volume as unity

 Overstocked

 Full stocked

 Understocked

Tree density illustrates the horizontal distribution of trees. The top photo shows a dense forest with many trees (or stems) per acre. The lower photo is less dense, with fewer trees per acre.

$$\text{Stand density (SD)} = \frac{\text{Actual stand vol.}}{\text{Normal stand vol.}}$$

Over stocked , SD > 1

Under stocked, SD < 1

Normal stocking, SD = 1

Growth Prediction for Normal Even Aged Stand using Yield Tables

$$Iv = p\,(Y_f - Y_p)$$

Iv : Volume growth /ha

p : $\left[\dfrac{\text{Actual stand vol.}}{\text{Normal stand vol.}}\right]$

Y_f = future vol/ha from yield table

Y_p = present vol/ha from Yield table

- **Ex**

Year	Age	Vol.(according to YT)
1980	70	11,900
1990	80	13,360

In 1980 inventory data showed avg. vol. of stand 7” dia and above to be 8920 ft^3. What is stocking in 1980 ?

$$\Rightarrow \text{stocking in 1980} = \frac{8920}{11900} = 75\%$$

Cont…

1. Assuming constant stocking for next 10 yrs :

   → Iv = (13,360 - 11,900) x 0.75

   = 1095 ft^3

2. Suppose 4% increase in stocking in next 10 years: '**p**' in year 1990 = 0.79

   → Iv = (13,360) x 0.79 - (11,900) x 0.75

   = 1629 ft^3

CROWN CLASS

- **Crown class** is a term used to describe the position of an individual tree in the forest canopy.
- In the definitions below, “general layer of the canopy” refers to the bulk of the tree crowns in the size class or cohort being examined.
- Crown classes are most easily determined in even-aged stands
- In an un-evenaged stand, a tree’s crown would be compared to other trees in the same layer.

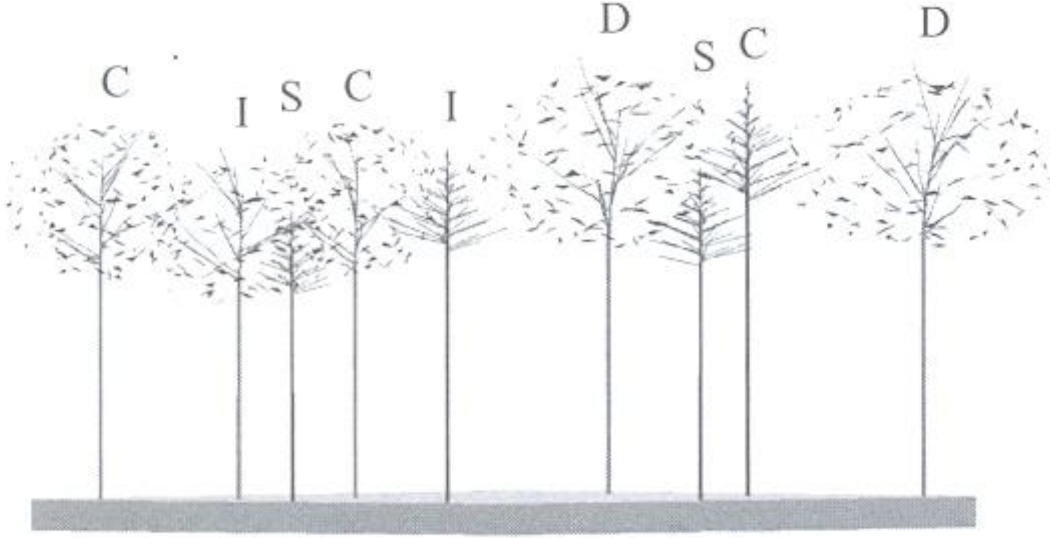
- Kraft's Crown Classes are defined as follows (Smith et al. 1997 and Helms 1998 modified for clarity):

- **Dominant trees** These crowns extend above the general level of the canopy. They receive full light from above and some light from the sides. Generally, they have the largest, fullest crowns in the stand

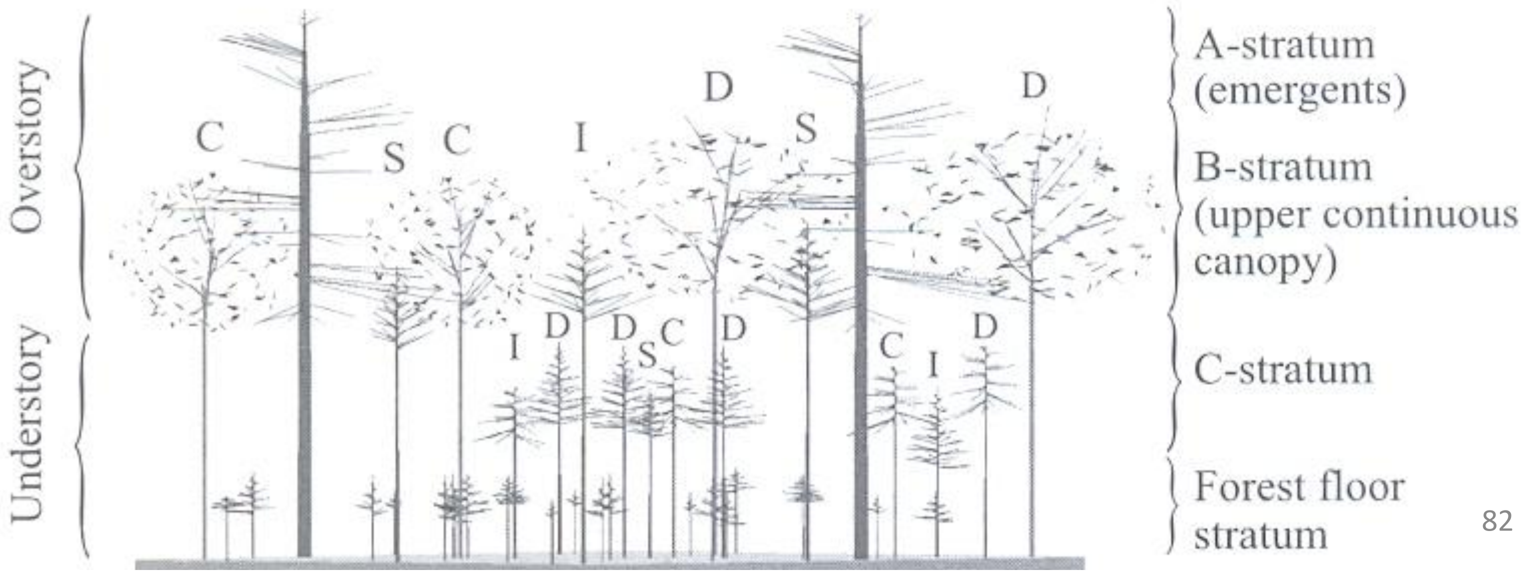
- **Codominant trees** These crowns make up the general level of the canopy. They receive direct light from above, but little or no light from the sides. Generally they are shorter than the dominant trees.

- **Intermediate trees** These crowns occupy a subordinate position in the canopy. They receive some direct light from above, but no direct light from the sides. Crowns are generally narrow and/or one-sided, and shorter than the dominant and codominant trees.

- **Suppressed trees (Overtopped trees)** These crowns are below the general level of the canopy. They receive no direct light. Crowns are generally short, sparse, and narrow


C
I
S
C
I
D
S
C
D

(*a*)


Overstory
Understory
A-stratum
(emergents)
B-stratum
(upper continuous
canopy)
C-stratum
Forest floor
stratum
C
S
C
I
D
S
D
I
D
D
S
C
D
C
I
D


C D I D S C I S C D

- Crown classes are a function of tree vigor, tree growing space, and access to sunlight. These in turn are influenced by stand density and species shade tolerance.

- A shade tolerant “suppressed” western hemlock on the other hand, may survive very nicely and be able to take advantage of increased sunlight if a neighboring tree were to fall over.

- Crown class distribution can also infer overall vigor of an evenaged stand.

- If most trees are in the intermediate crown class, then the stand is likely too crowded and the trees are stagnated.

- A stand with nearly every tree in the dominant category is either very young, with all of the trees receiving plenty of sun, or very sparse and may be considered “understocked.”

- A typical evenaged stand has the majority of trees in the codominant class, and the fewest trees in the suppressed class.

Canopy density

- Measure of relative completeness of canopy
- Expressed as decimal coefficient (closed canopy as 1)
- No bearing with crop volume, basal area or no. of trees
- Important for forests which do not have yield tables
  - Gives indication of stand density

Classification of canopy density

i. **Closed** - density 1

ii. **Very Dense** - density between 0.7 and 1

iii. **Moderately dense** - density between 0.4 and 0.7

iv. **Open** - density between 0.1 and 0.4

Calculation of canopy density for Pure Even Aged Crops :

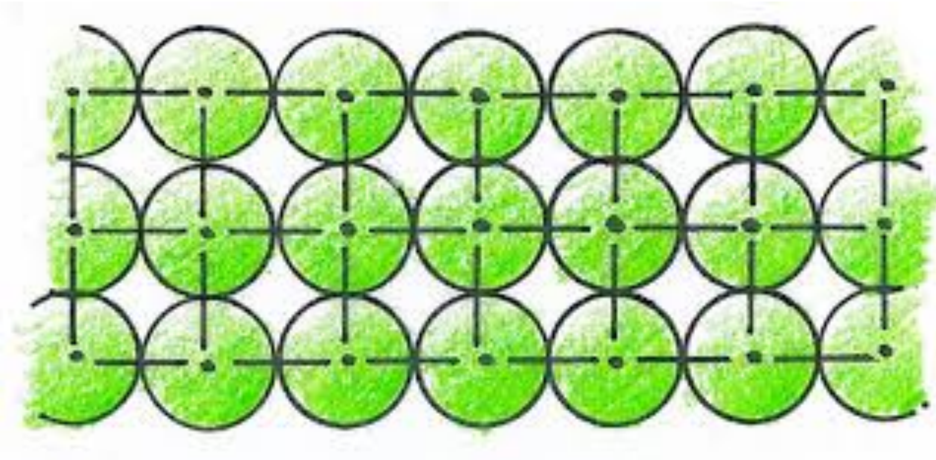
Assumption :

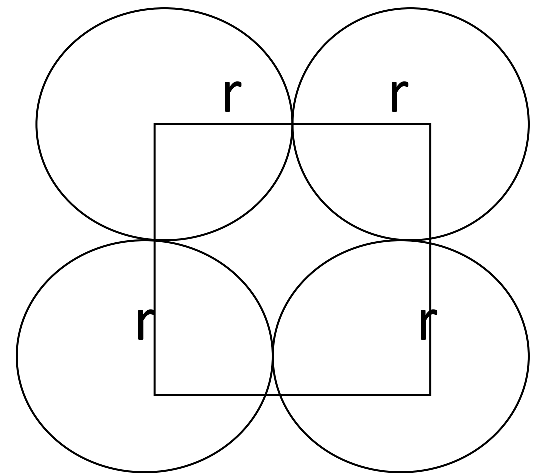
Canopy as - non overlapping circles of same size

2 methods :

1. For square spacing
2. For triangular spacing

1. **<u>For Square Spacing</u>**

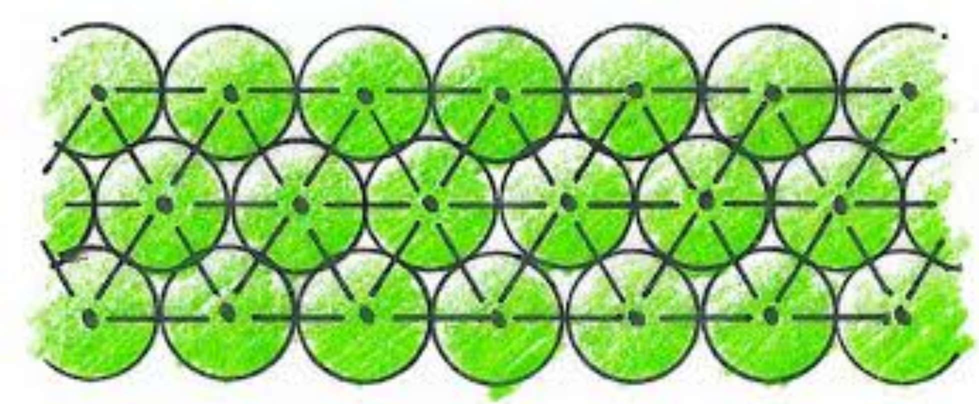


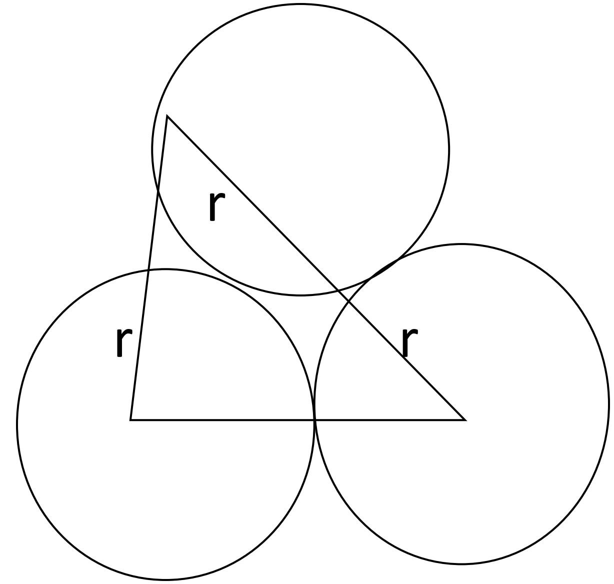


Maximum canopy closer is

$$= \frac{.\pi r^2}{4\ r^2} x100\% \quad = \quad \left(\frac{\pi}{4}\right) x100\% \ = \ 78.54\ \%$$

2. <u>For triangular spacing</u>





Maximum canopy closer is

$$= \frac{3 \times \frac{1}{6} \times \pi r^2}{\frac{1}{2}\,(2r)^2 \sin 60^0} \times 100\%$$

Cont…..

$$= \frac{1}{2} \cdot \frac{\pi}{2} \cdot \frac{2}{\sqrt{3}} \times 100\%$$

$$= \frac{\pi}{2\sqrt{3}} \times 100\% = 0.9068 \times 100\%$$

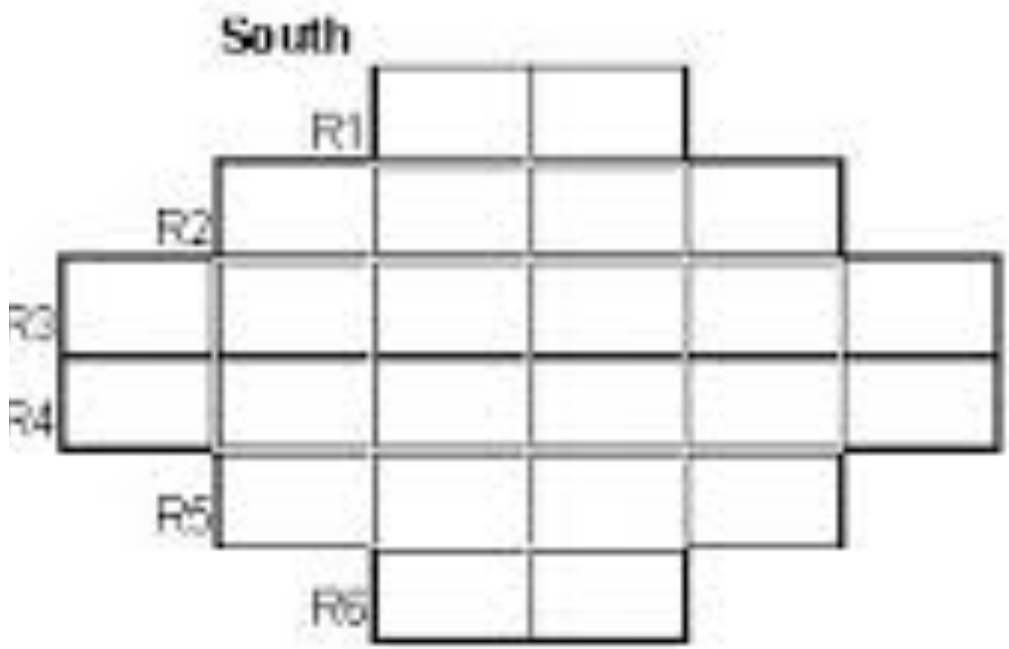
$$= 90\%$$

Measurement of canopy density in field

- Instrument - Spherical Densiometer

Properties :

- Spherical surface
- 24 square blocks



- Each square block has 4 equi spaced dots
- Total dots = 24 * 4 = 96

Procedure

1. Open the densiometer
2. Hold it about 12” in front of you with both the hands and at elbow height
3. Press the elbows against the sides of the body for more rigid support.
4. The top of your forehead should be visible in the mirror but not the grid area

6. Close one eye and get your sighting eye in line with the grid centerline

7. Make sure the densiometer is level by getting the bubble inside of the circle

8. You will have a view of canopy cover

9. Maintain this position while you count

Calculation

1. There are four dots in each square of the grid
2. Count either the dots that are more than half shaded or less than half shaded, depending on which is easier to count.
3. Count systematically, from top row to bottom row, left to right.
4. Record the number of shaded dots on your data sheet
5. If you counted unshaded dots, subtract that number from 96 to get shaded dots.

6. Multiply the count by 1.04
7. This is the percentage of area covered by canopy

- Canopy Closure/density is used a variable to predict stand volume from Aerial Photographs

- **<u>For pure crops with same size crowns</u>**, a constant ratio(K/d), of crown diameter(K) and bole diameter(d), implies a maximum basal area per Ha for complete crown cover

Estimating maximum basal area per hectare for known spacing and K/d ratio.

Where: N – number of stems per hectare at full stocking

K- crown diameter, m

d- stem diameter, m

$$z = \frac{K}{d}$$, the crown/bole diameter ratio

The maximum number of stems per hectare N, assuming **square spacing** , for trees of a given diameter is given by:

$$N = \frac{100 * 100}{K * K} = \frac{10^4}{K^2}$$

$$G_{max} = \frac{N * \pi d^2}{4} = \frac{10^4}{K^2}\left[\frac{\pi d^2}{4}\right] = \frac{\pi}{4}\left[\frac{10^4}{z^2}\right] = \mathbf{0.7854\ x}\left[\frac{\mathbf{10^4}}{\mathbf{z^2}}\right]$$

Q: For a crown/bole diameter ratio of 10, crown diameter and bole diameter in m, **<u>the maximum feasible basal area per hectare,</u>** G_{max}, with square spacing is :

$$G_{max} = \frac{(0.7854) * 10^4}{10^2} = 78.5\ m^2\ ha^{-1}$$

or, for a **K/d** ratio of 15 of square spacing;

$$G_{max} = \frac{(0.7854)\ 10^4}{15^2} = 34.9\ m^2\ ha^{-1}$$

2. **<u>Forecast of future yields…</u>**

1. Stand structure
2. Stand growth
3. Stand density

↓

4. ***<u>Productive capacity of site, “site quality”</u>***

Forest Site Quality Determination

Forest Site

- An area
  - considered in terms of its environment – determine the type and quality of the vegetation it can carry
  - Affected by the Factors like
    - Rock
    - Soil
    - Climate
    - Topography
    - Vegetation

Site Quality

- Forest site quality – "Relative Productive Capacity"
- Site productivity :
  - Site quality + management inputs
  - Management inputs like
    - Growing stock manipulation
    - Site treatment
    - Fertilizer/irrigation inputs
    - Soil compaction (grazing)
    - Biomass and nutrient cycling

Measurement of Site quality

- Using Multiple variables
  - Forest productivity depends on various parameters
  - Attempts are made to quantify forest productivity in terms of these parameters.

– 2 methods

1. Site Factor - CVP Index
2. Using vegetative characteristics

Measurement of Site quality

1**. CVP (climate, vegetative & productivity)**

Index

– Tries to quantify Climatic , edaphic and biotic factors

– Given by Paterson - Weck

CVP Index

$$I = \left[\frac{T_v}{T_a}\right] (P) \left[\frac{G}{12}\right] (E)$$

I = CVP Index. Varies from 0 – 30,000. Forest growth possible in I > 25

T_v = Mean monthly temp. of the hottest month in ^{0}c

Ta = Difference between the mean monthly temp ^{0}c of the hottest and coldest month

P = mean annual precipitation in mm

G = Length of growing season in Months

E = Evapo-transpiration defined as = Rp/Rs

Rp = Radiation at pole, 10^3 g cal $cm^{-2}min^{-1}$

Rs = Radiation at site, 10^3 g cal $cm^{-2}min^{-1}$

- Potential Productivity $Y = 5.2 \log I - 7.25$

Contd.

  - Y has units m^3/ha/year
- For Dehradun
  - $I = (28.4/15.6)\ (2160)\ (6/12)(47/100) = 924.09$
  - $Y = 5.2 \log 924.09 - 7.25 = 8.17\ m^3$/ha/year
- <u>Short comings:</u>
  - Too broad based
  - Soil conditions, aspects, topography, slopes not considered
  - Biotic factors not considered
  - Applicable only over very large forest areas

Measurement of Site quality

2. **Using vegetative characteristics**
   i. Plant indicators
   ii. Trees characteristics
      - BA, Volume, Height etc.

ii. Plant indicators

- Match species to different sites
  - *Casia tora* indicator of degraded forest
  - Lantana & Teak - Verbenaceae
- Applicable to simple compositions of forest
- Requires considerable knowledge of ecology

ii. <u>Trees characteristics</u>

- Important characteristics of tree which reflect productivity:
  - ***Vol.***, Dia or BA, Height,
- Volume best indicator but –
  - Prior calculation of volume, difficult to apply in practice

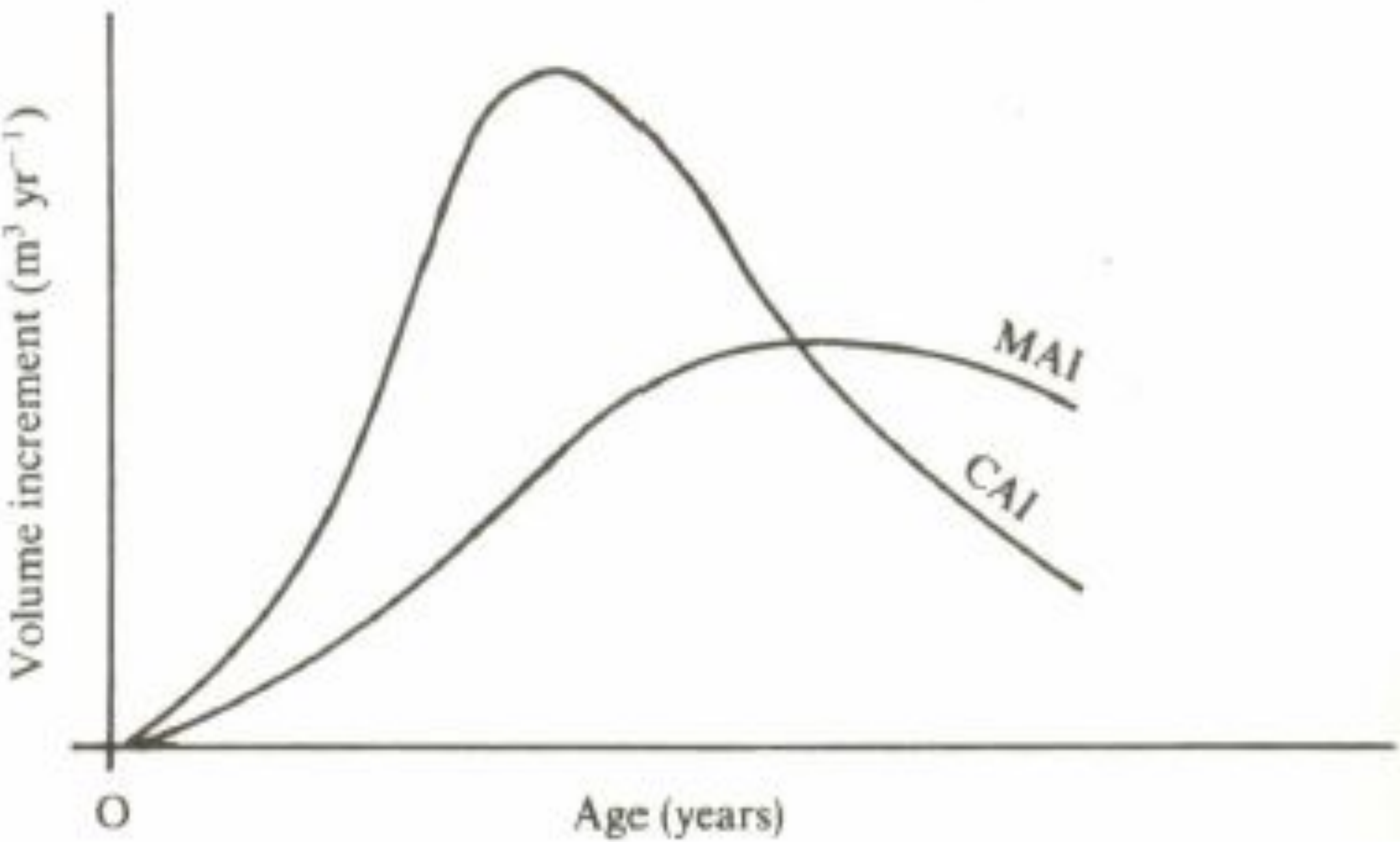
Yield class system of classifying growth potential

MAI & CAI curve intersection

↓

Maximum average rate of volume increment(MAI) which a particular species can achieve on a particular site

FIGURE Current and mean annual increments; single trees



- Yield Class : based on maximum MAI
  - 'Yield class 12' means it has maximum MAI of 12m³/ ha
- But for preparing yield class for a site , one has to wait for the period till the crop reaches its maximum MAI
- Practiced in Europe

Other tree characteristics…

Diameter or basal area	Height
• Reflects the effects of site quality • Affected by stand density and management practices	• Reflects the effects of site quality • Least affected by stand density and management practices

Tree Height

- Height is the best tree characteristic for measuring the site quality
- Height reflects the effect of Site Quality
- Least affected by density except in extreme situations
- Ht. growth of a species – same in different densities
- <u>Advantage</u>: variations in ht. growth due to variation in SQ are closely and +ly related with variation in growth volume

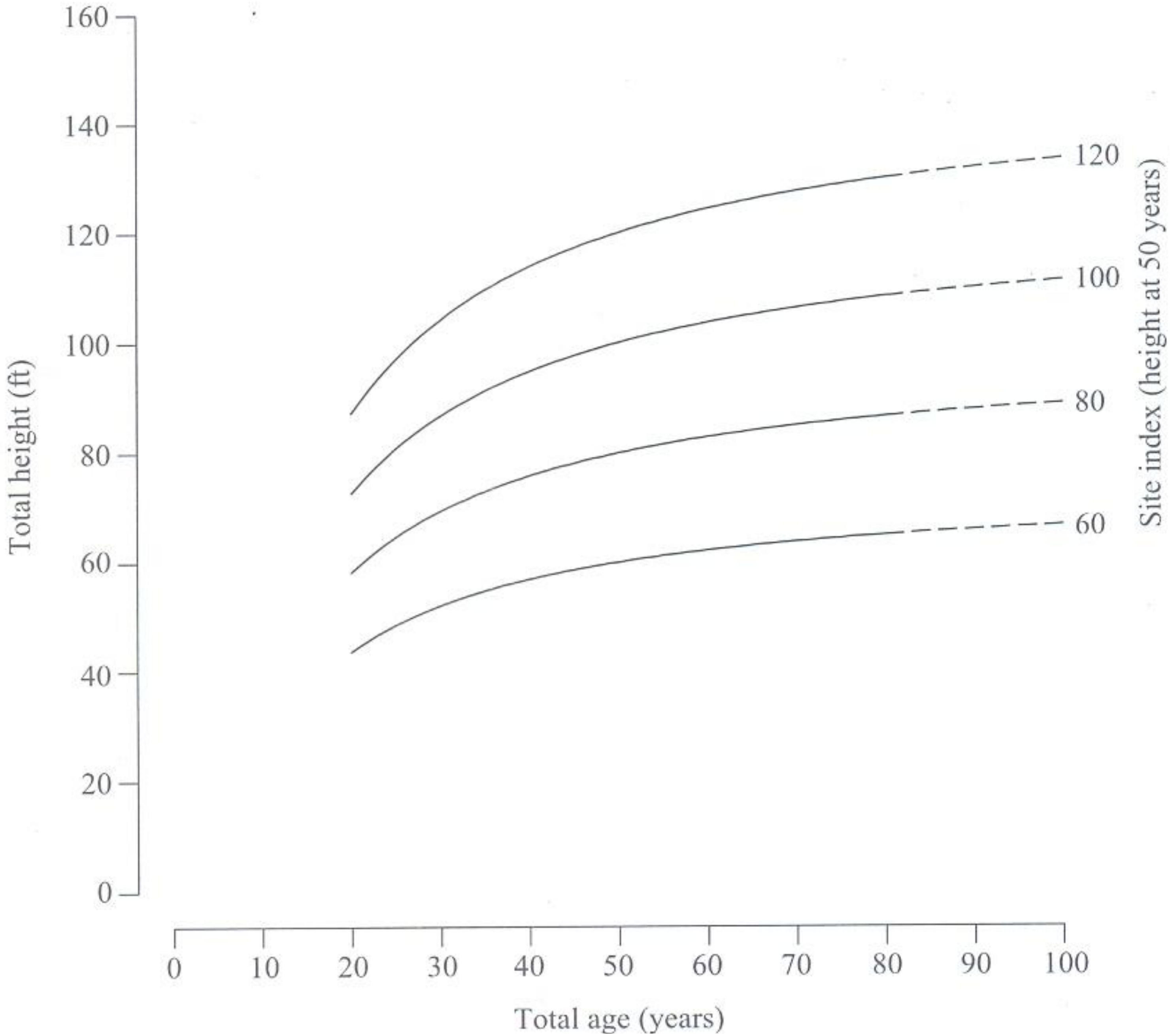
- Relationship of tree ht and age - used in most countries as a measure of site quality

   - In America – relationship between tree ht and age is called “ **site index**”

↓

Avg ht that a dominant and co-dominant trees will attain at key ages, such as 50 or 100 years

Ex : site index 70 on a 50 yr basis means ?


Total height (ft)
160
140
120
100
80
60
40
20
0
Total age (years)
0
10
20
30
40
50
60
70
80
90
100
120
100
80
60
Site index (height at 50 years)

In India….

- Before 1930,
  - Average ht of all trees used
- Since 1930,
  - Site quality assessed based on top ht
  - Top hts of all sample plots – plotted against age
  - Then site classes are delimited by following methods :
    1. **Baur’s method**
    2. **British Forestry Commission(BFC) method**

$$M.B.A. = \pi * \left(\frac{\text{crop diameter}}{2} \right)^2$$

$$= \frac{\pi}{4} \times (\text{crop dia.})^2$$

$$\text{Crop dia.} = \sqrt{\frac{(4 \times M.B.A.)}{\pi}}$$

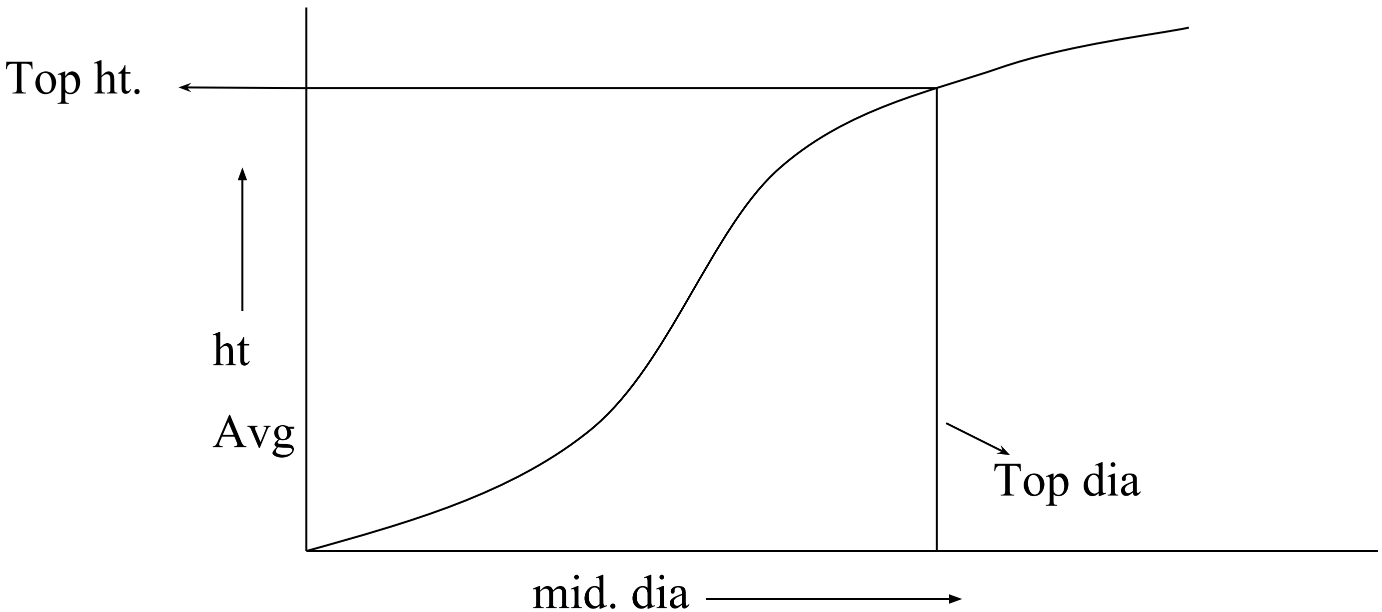
$$\text{Crop dia.} = 2 \times \sqrt{\frac{M.B.A}{\pi}} \quad \text{——} \quad (1)$$

Top diameter :-

- diameter corresponding to the M.B.A. of 250 biggest diameters per ha

- Used in determining the top height of the crop assessing the site quality.

Plot mid point of dia class Vs Avg. ht.



c) Calculate M.B.A. for stand

d) Then calculate crop diameter

e) Read height from graph → mean height

Top height

'Height corresponding to the Top Diameter (calculated from basal area of 250 biggest diameters per ha) as read from height diameter curve'

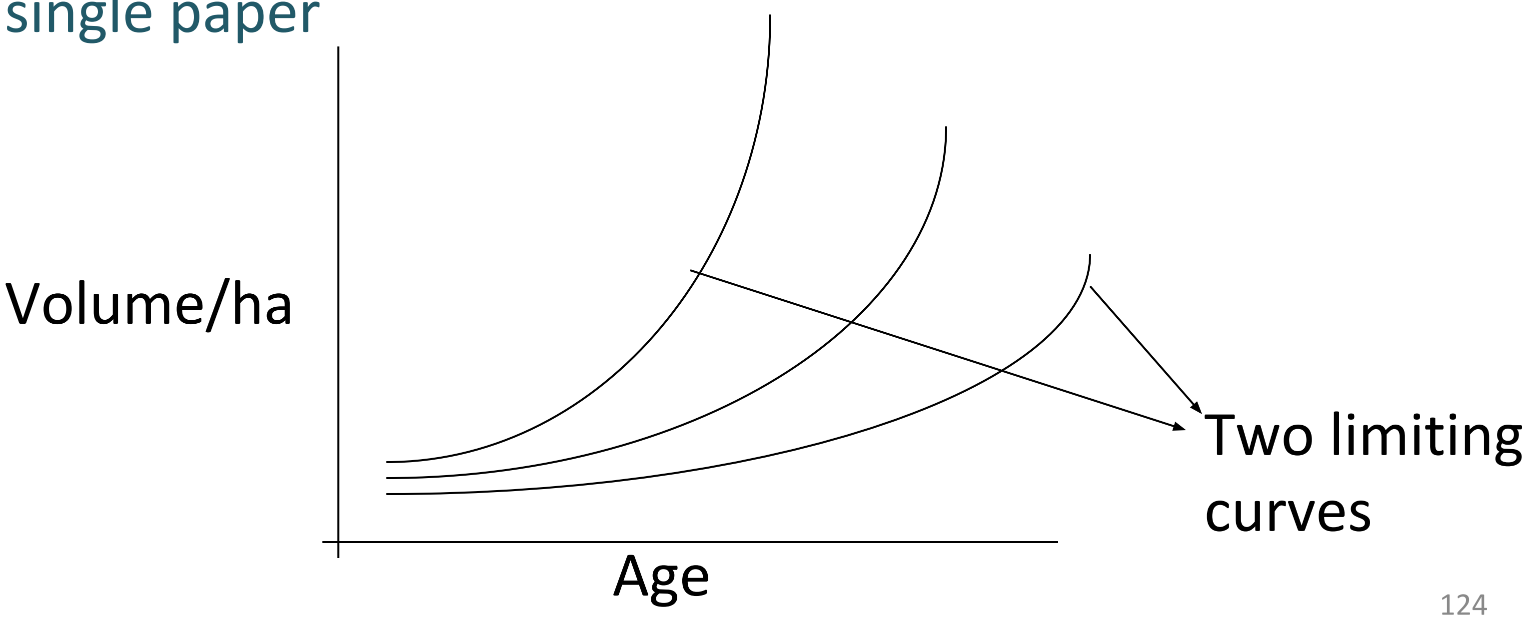
- To assess the quality of the locality
- This relates only 250 biggest dia. (or about 125 trees)

Measurement of Site quality

1. Strip – Height Method (Baur's Method)

- Steps

1. Identify various plots
2. Plot volume/ha Vs age curve for each of the plot on a single paper



Contd.

3. Two limiting curves are drawn

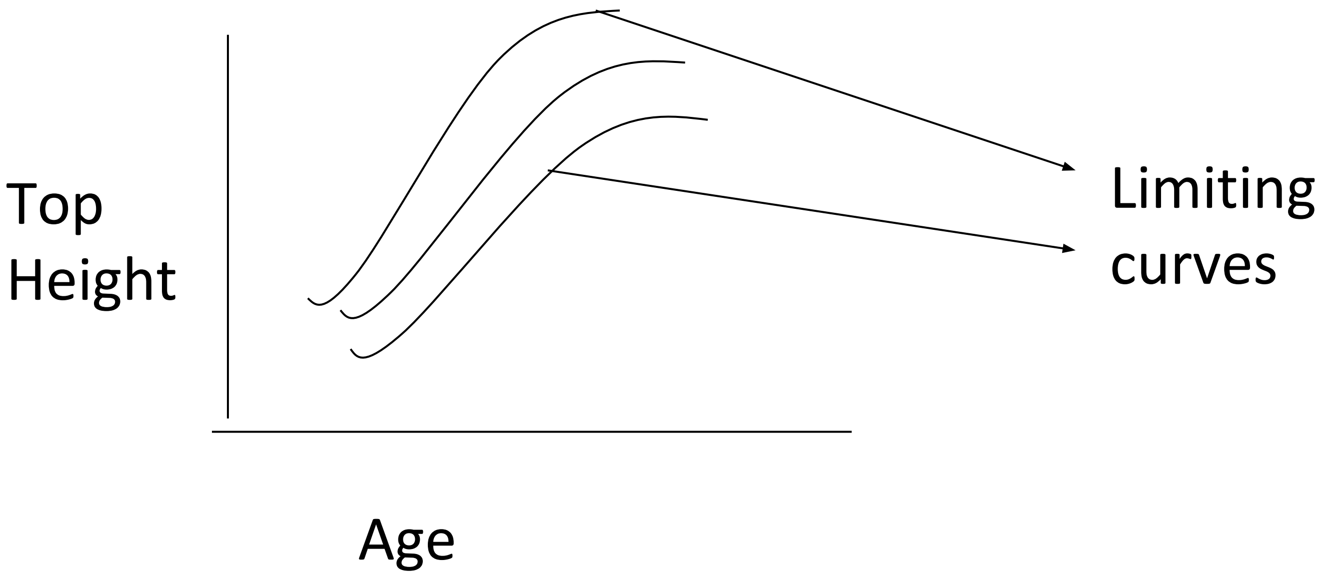
4. Space between the two limiting curves is divided into strips of equal width
5. These strips represent different site quality classes

- **In India -** Volume is replaced by Height

Baur's method with height

- Steps

1. Identify various plots
2. Draw 'top height Vs age' curve for each of the plots



Contd.

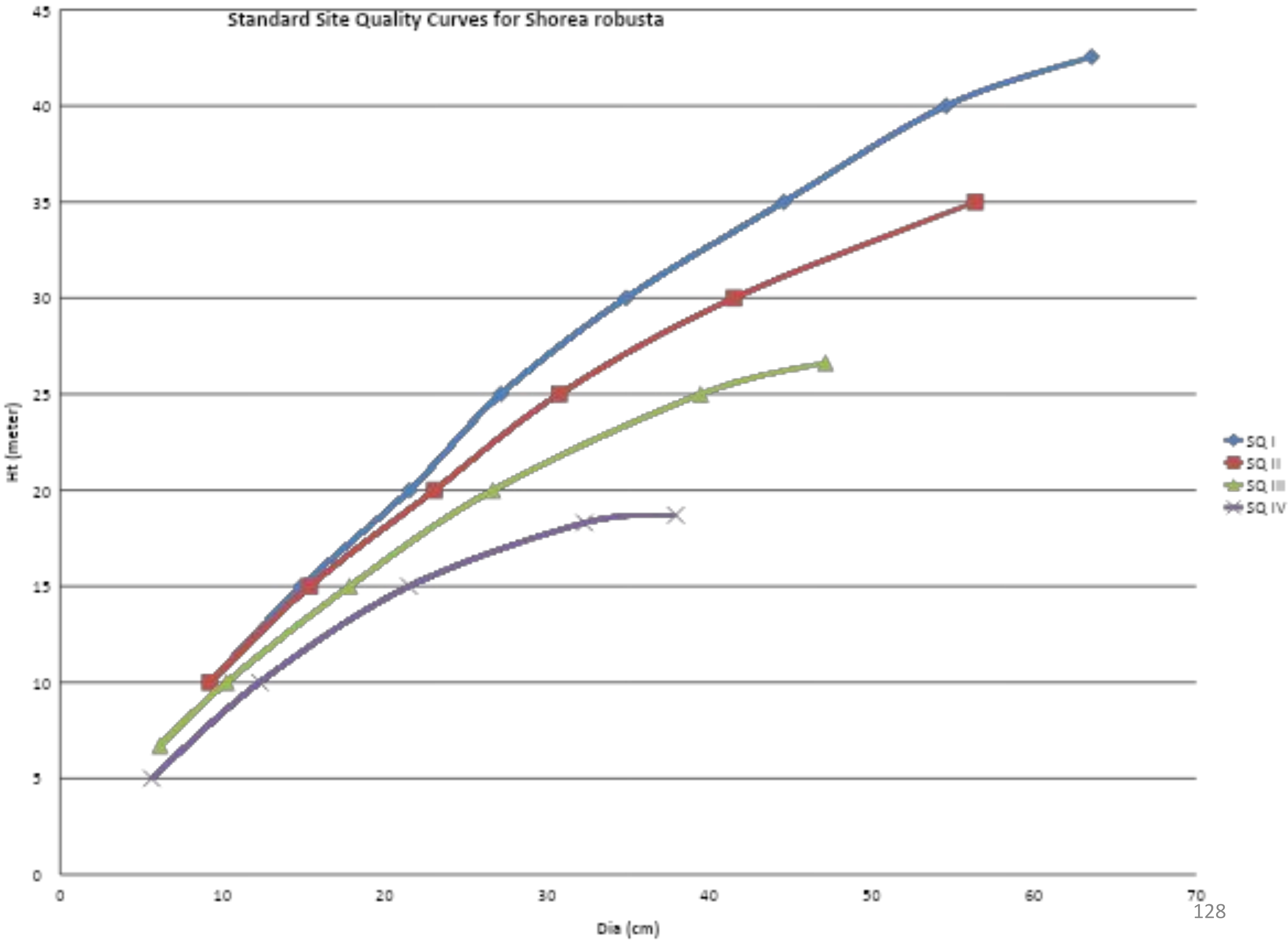
3. After neglecting the abnormal points limiting curves are plotted through the guiding points

4. No. of qualities to be differentiated are decided by considering:-

   - ✔ Difference between the limiting curves
   - ✔ Practical limits of accuracy in ht determination

5. Space between limiting curves divided symmetrically

   1. For sal Four quality classes : divided by three curves
   2. For teak five quality classes : divided by four curves


Standard Site Quality Curves for Shorea robusta
Ht (meter)
Dia (cm)
0
5
10
15
20
25
30
35
40
45
0
10
20
30
40
50
60
70
SQ I
SQ II
SQ III
SQ IV

2. British Forestry Commission method

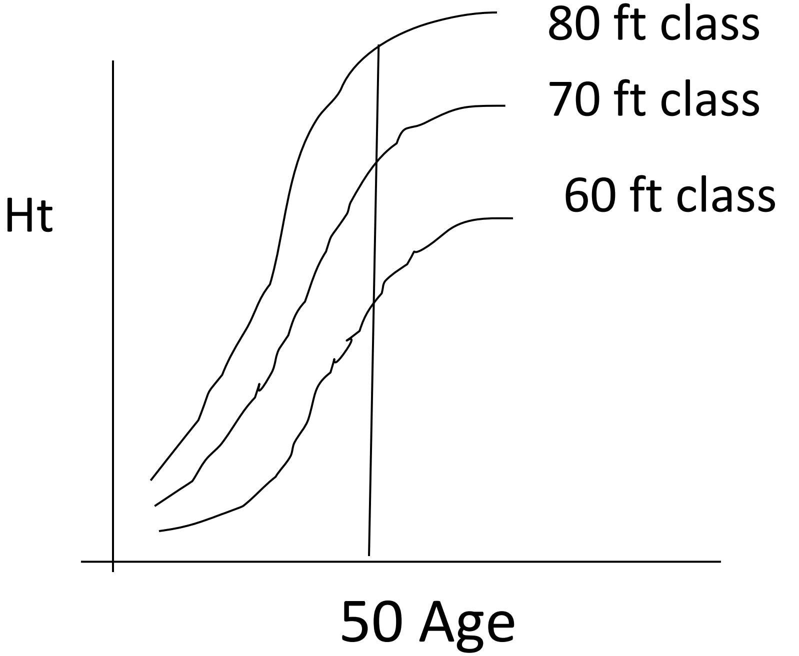
- Here also height taken as index
- Site trees
  - Dominant or co-dominant
  - Even aged
  - No evidence of crown damage, disease, crook, or forking etc.
- Measurement taken of site trees only
- Data on height development obtained from both temporary and permanent sample plots

Contd.

Steps

1. Index age fixed (25,50 or 100 years) fixed on the basis of estimation of age of site*
2. From each plot over index age three stems of approx. mean heights are selected.
3. Selected trees are subjected to stem analysis; age Vs ht curve from stem analysis prepared for each plot on a single paper.

4. Heights at index age are observed. And divided into 10 feet divisions representing Quality classes.



5. In this way number and range of quality classes is determined

6. All the plots over the age of index age are then allotted to a site quality.

Fractional site qualities

- Quality classes has high range of heights
- According to YT, plantation teak at 60 years has top Ht. ranging from
    - 44 to 65 ft. in IV site quality
    - 65 to 85 ft in III site quality
    - 85 to 106 in II site quality
    - 106 to 127 in I site quality
- Too big gaps
- Exact measurement of productive capacity of a site for a particular for comparison, is lacking

Fractional site qualities

- Lauri evolved the FSQ
- Each quality class has a mean curve, an upper curve and a lower limiting curve
- Lower limiting curve of one quality is the upper limiting curve of next quality class below
- Curves are perfectly harmonized, the mean curve is at equidistant from the upper and lower curves
  - Lower limiting curve: 0.0
  - Mean curve: 1.0
  - Upper limiting curve:2.0

Fractional site qualities

- If age and top height are known fractional site qualities can be calculated
- A teak plantation at the age of 60 years has a top height of 75 ft.
- This falls on the mean curve of III quality and therefore said to be 1.0 III

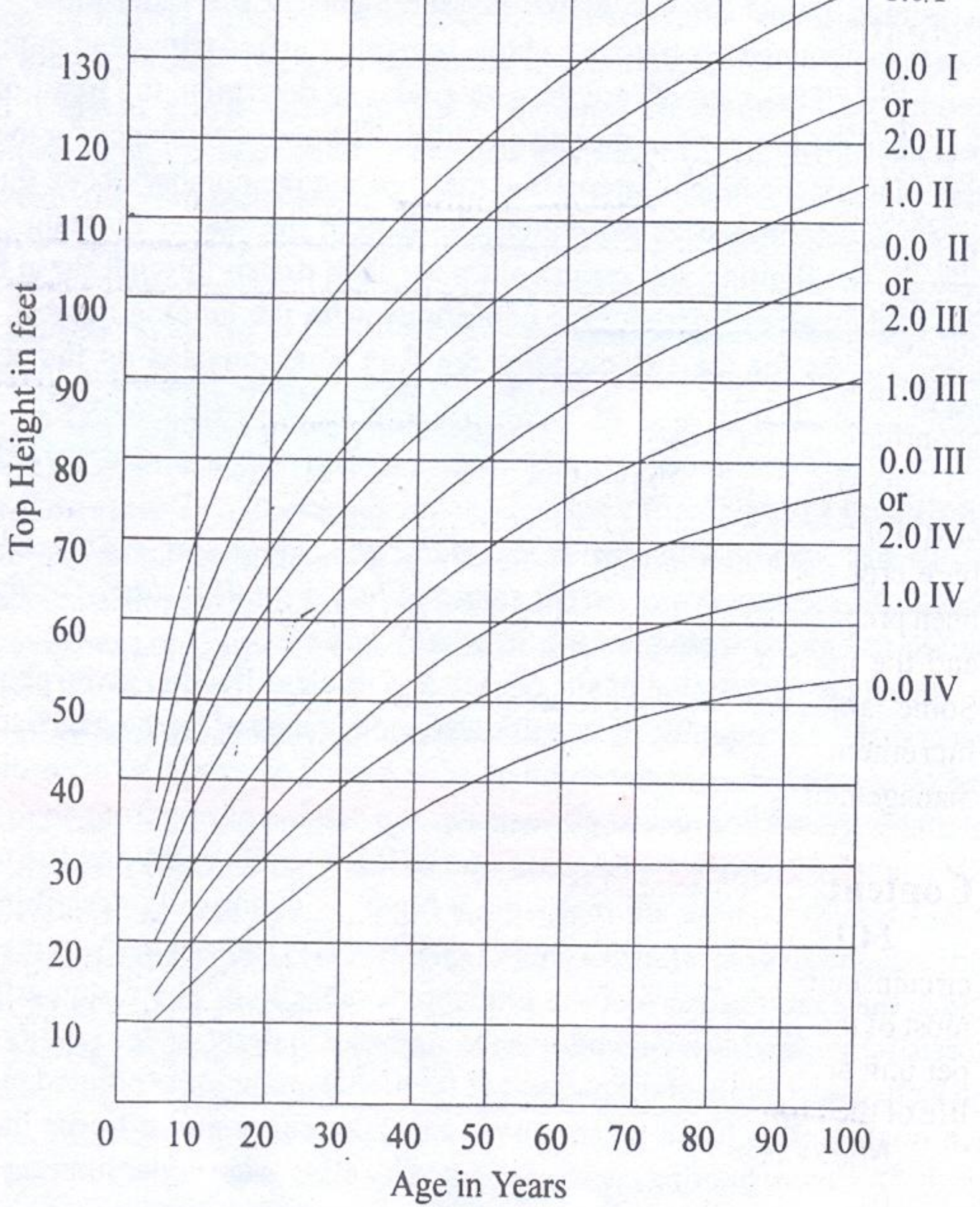


Fig. 118 Age-top height curves for plantation trees

... This falls on ... quality and therefore can be said to be 1.0 III. If the

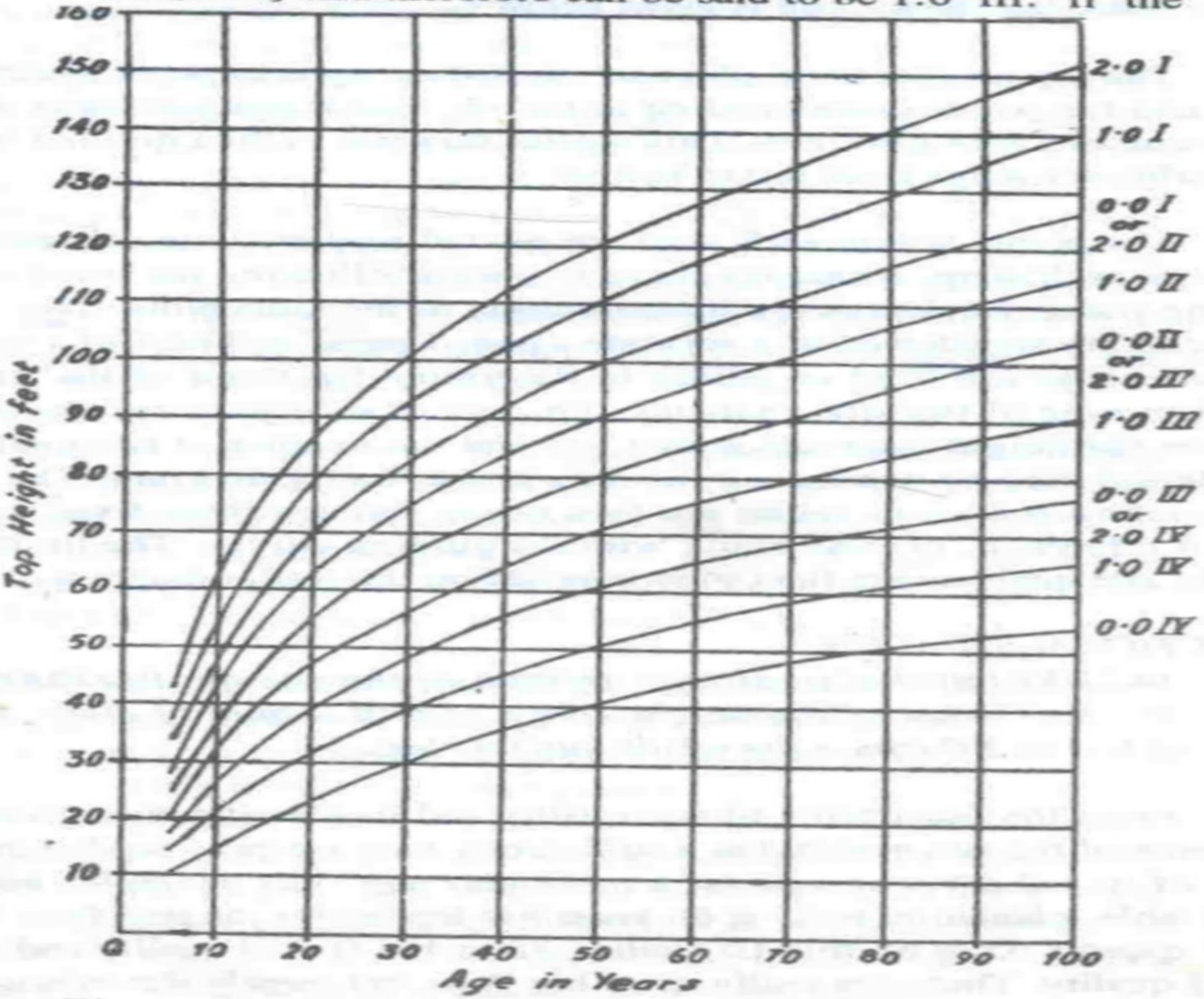
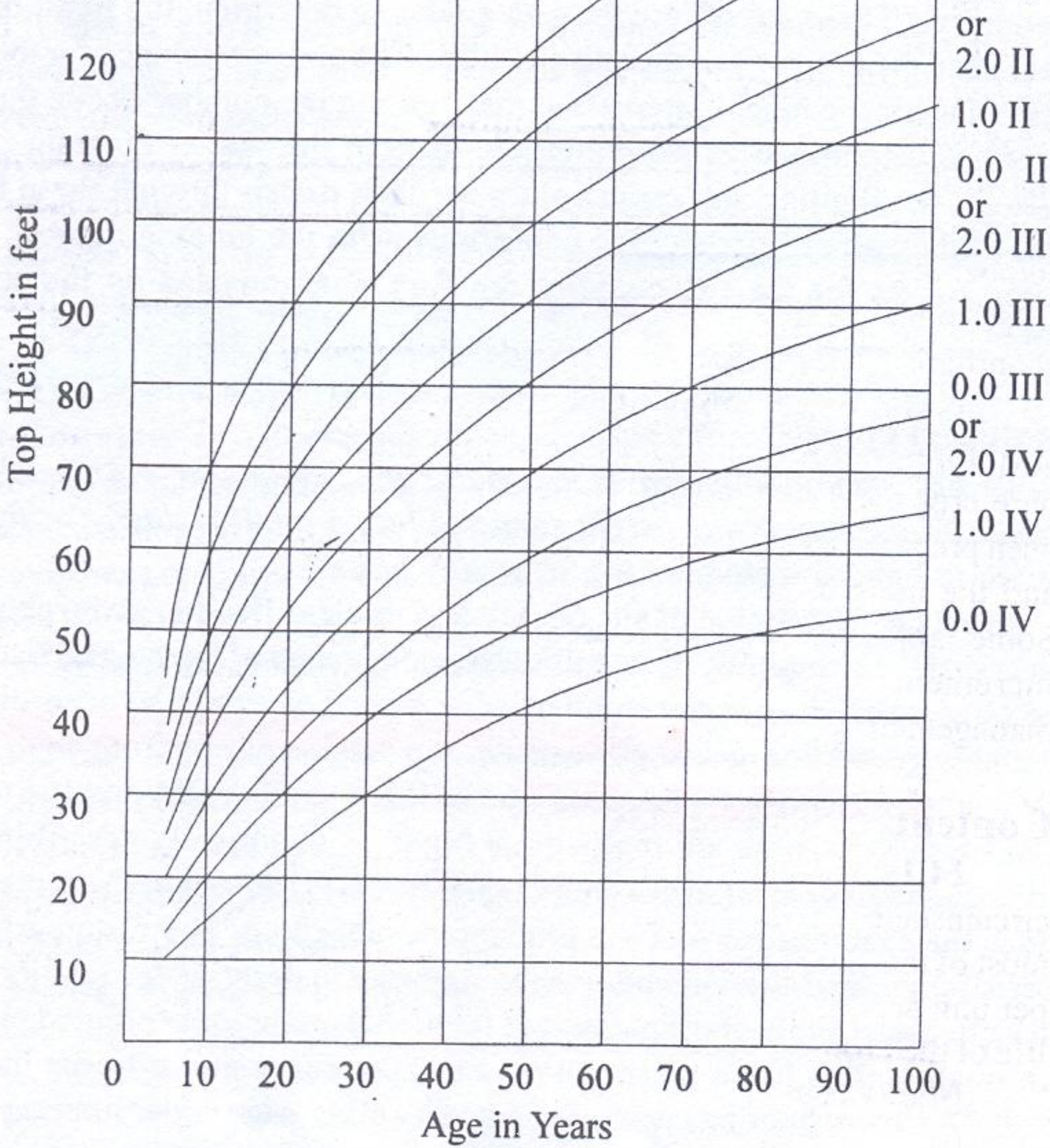


Fig. 117 Age-top height curves for plantation teak

Fractional site qualities

- Teak Plantation of 60 years age, top ht 65 ft. Find it's quality class??

- It falls on the lower limiting curve of the quality
- 0.0 III or 2.0 IV quality



Top Height in feet
120
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
Age in Years
or
2.0 II
1.0 II
0.0 II
or
2.0 III
1.0 III
0.0 III
or
2.0 IV
1.0 IV
0.0 IV

... This falls on ... quality and therefore can be said to be 1.0 III. If the

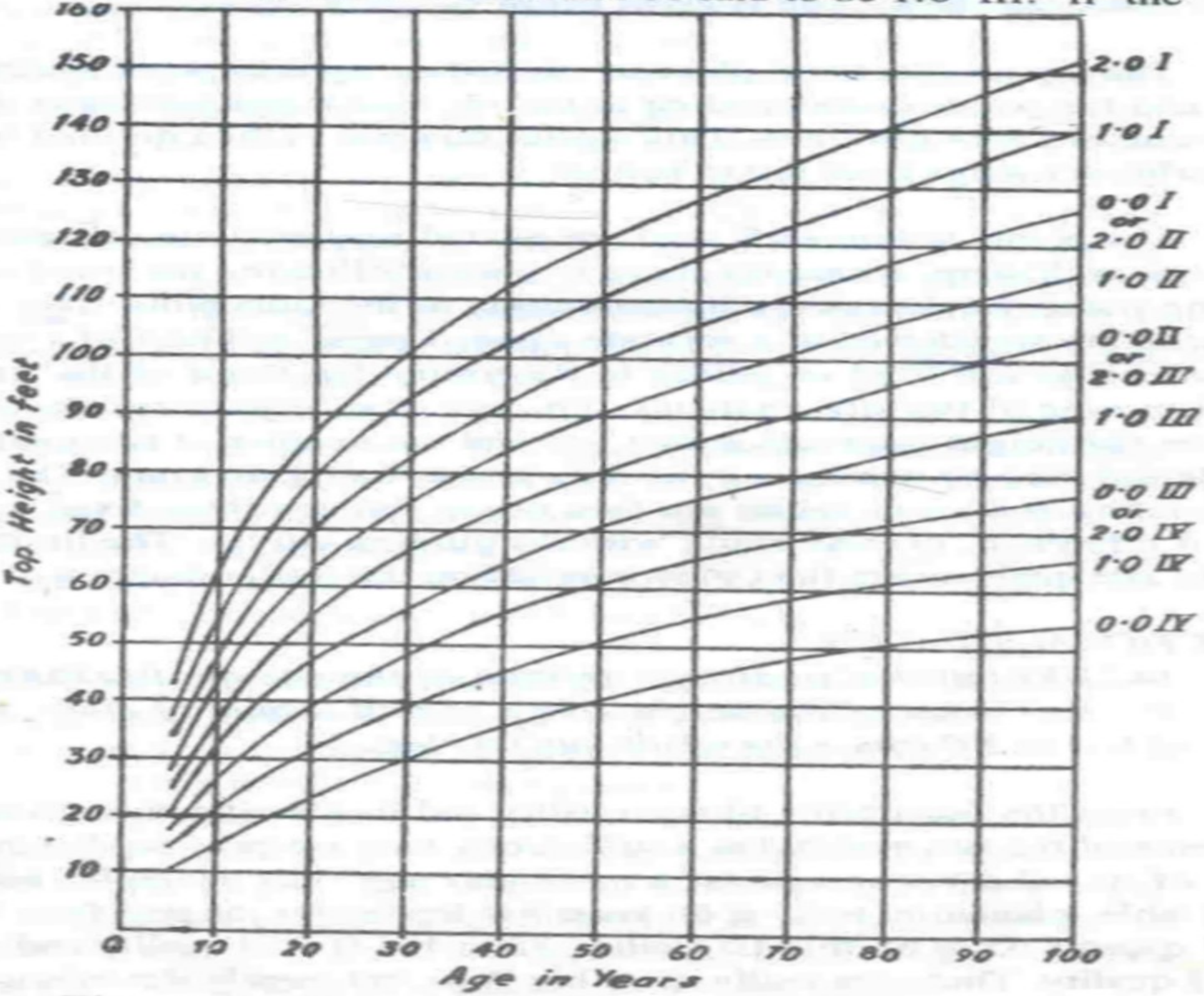
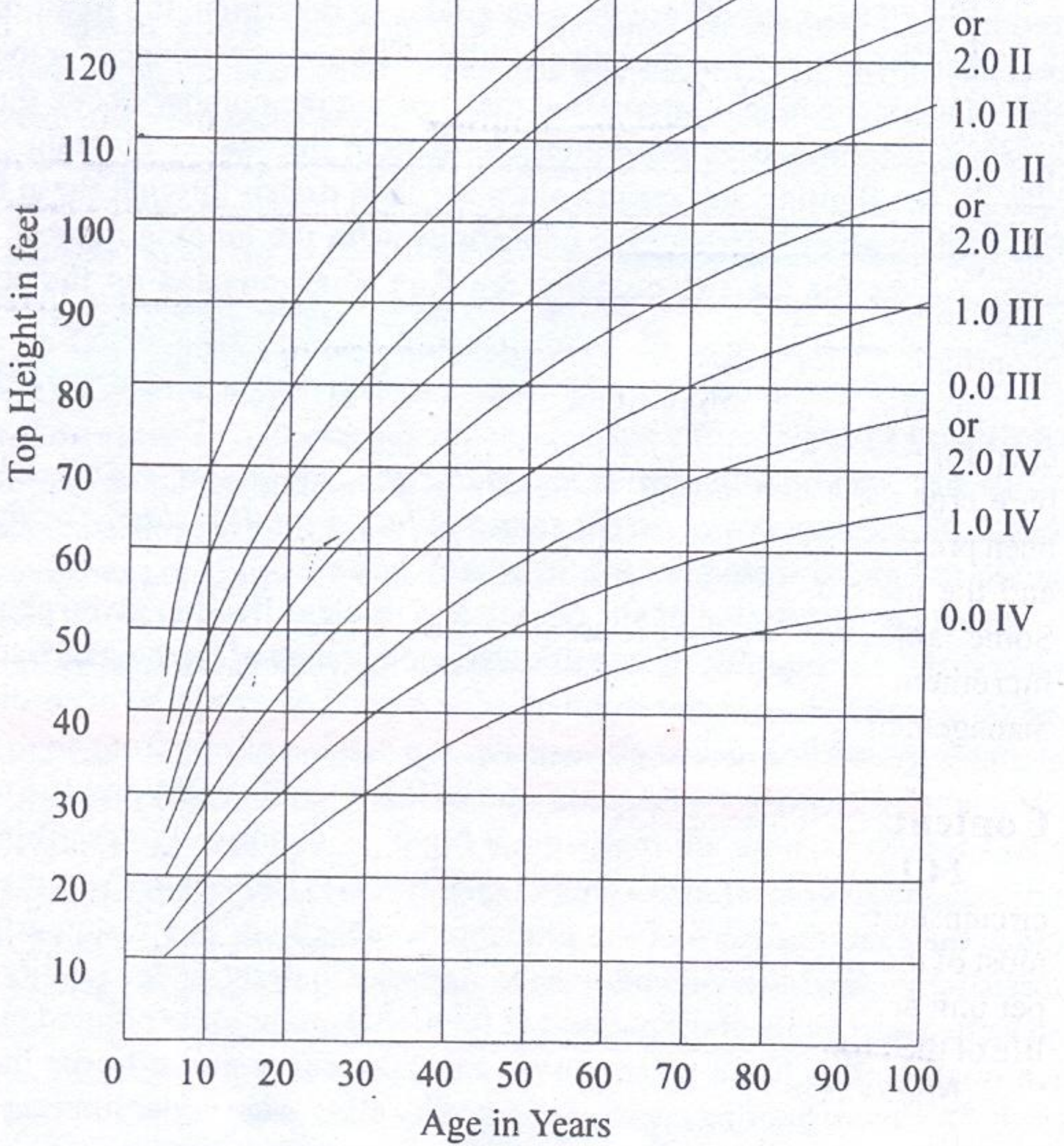


Fig. 117 Age-top height curves for plantation teak

Fractional site qualities

- Top Ht. of a teak plantation of 60 years age is 69 ft. Find it's quality class?

- No curve describing this height
- This is between 0.0 III to 1.0 III and the range is covered by 10 ft.
- 4 ft above 65 ft i.e 4/10 and hence described as 0.4 III



or
2.0 II
1.0 II
0.0 II
or
2.0 III
1.0 III
0.0 III
or
2.0 IV
1.0 IV
0.0 IV
Top Height in feet
120
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
Age in Years

... This falls on ... quality and therefore can be said to be 1.0 III. If the

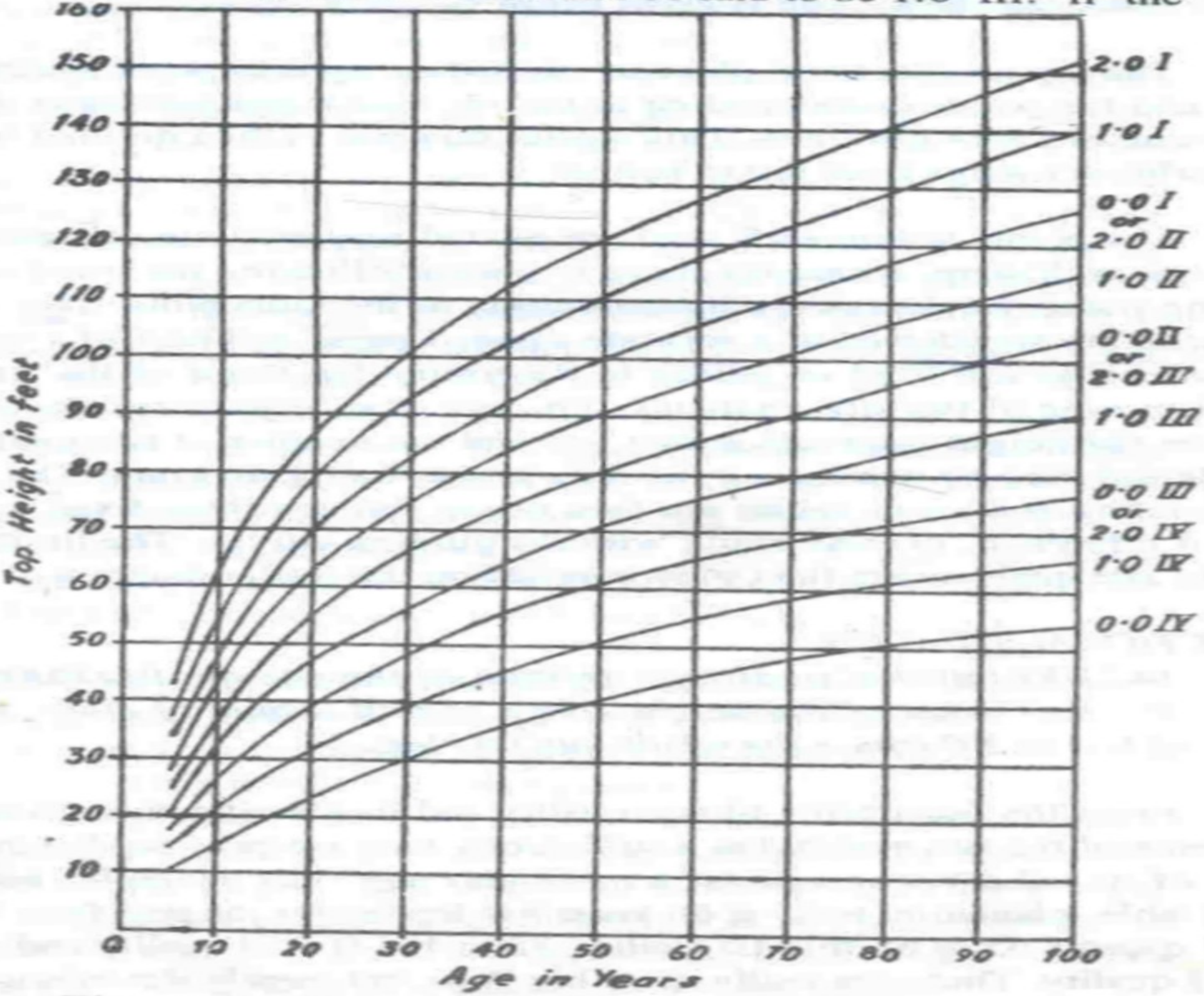
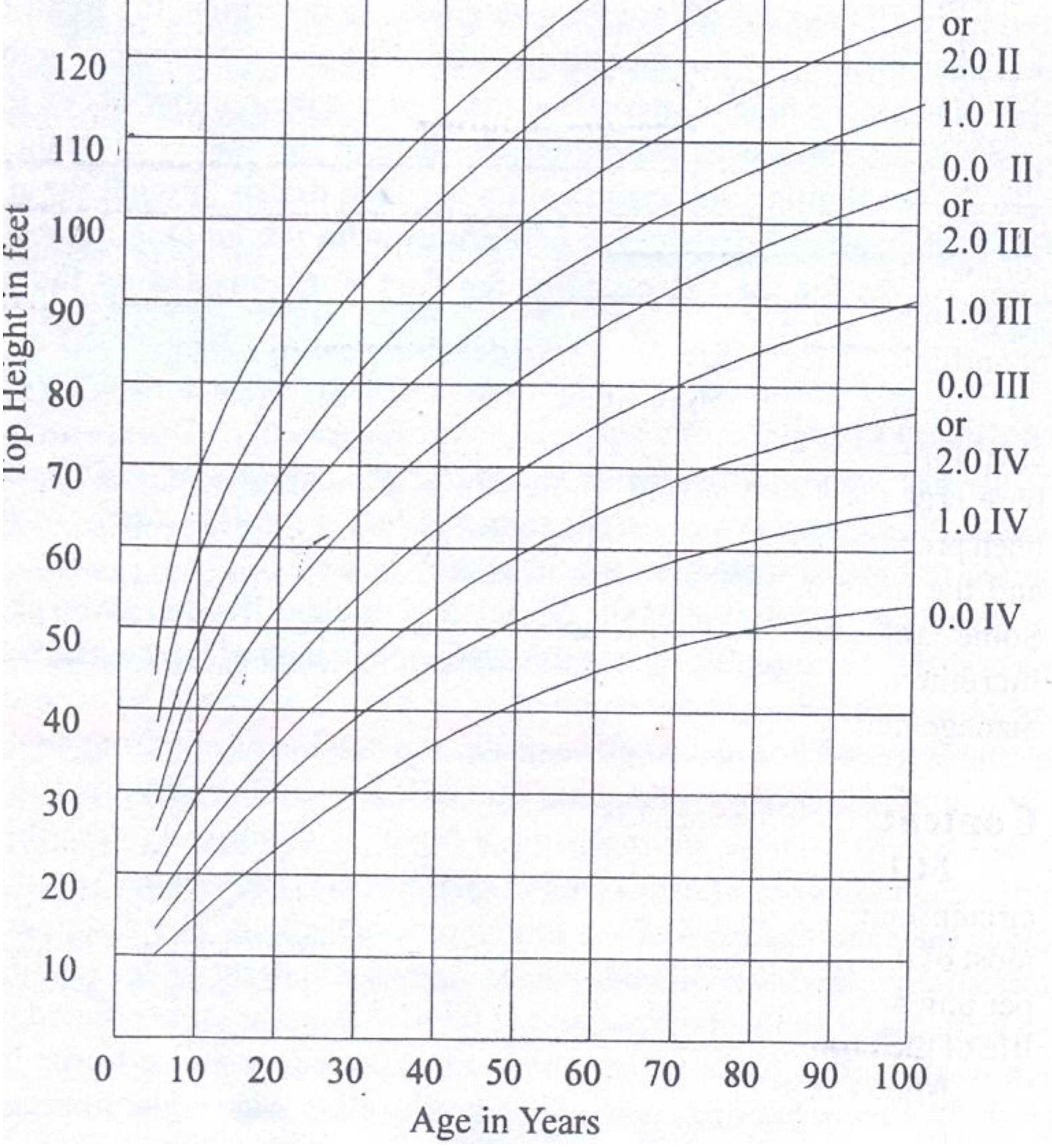


Fig. 117 Age-top height curves for plantation teak

Fractional site qualities

- A teak plantation of 60 years of age is having top ht. as 80 ft. Find it's site quality??

- No curve describing this height
- This is between 1.0 III to 2.0 III and the range is covered by 10 ft.
- 5 ft above 75 ft i.e 5/10 and hence described as 1.5 III



Top Height in feet
120
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
Age in Years
or
2.0 II
1.0 II
0.0 II
or
2.0 III
1.0 III
0.0 III
or
2.0 IV
1.0 IV
0.0 IV

... This falls on
... quality and therefore can be said to be 1.0 III. If the

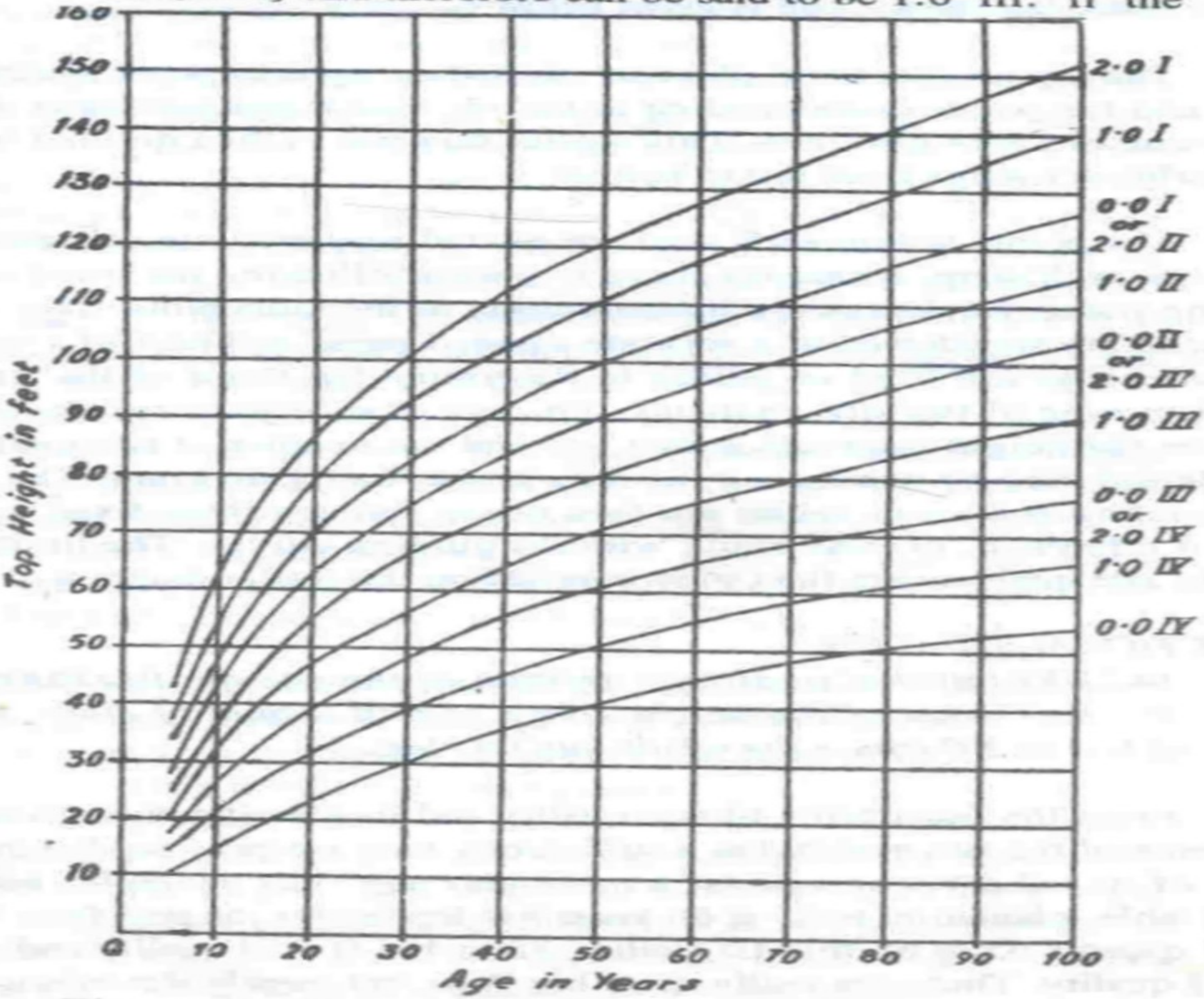


Fig. 117 Age-top height curves for plantation teak

Example of fractional site quality

- At 60 years and top height = 75 ft
  - Site Quality = 1.0 III
- At 60 years and top height = 65 ft
  - Site Quality = 0.0 III
- At 60 years and top height = 69 ft
  - Site Quality = 0.4 III
- At 60 years and top height = 80 ft
  - Site Quality = 1.5 III

Determination of site quality or Fractional site quality

Method 1 (Top height method) :

i. Ht of some dominant trees measured (Top ht)
ii. Age is obtained either from records or from field methods
iii. Table of **top ht by site quality and age** is referred
iv. In the table, different ranges of top height are given for different SQs for a particular age
v. See the age and find out the column in which the calculated top ht of the stand falls

If table is not given then:-

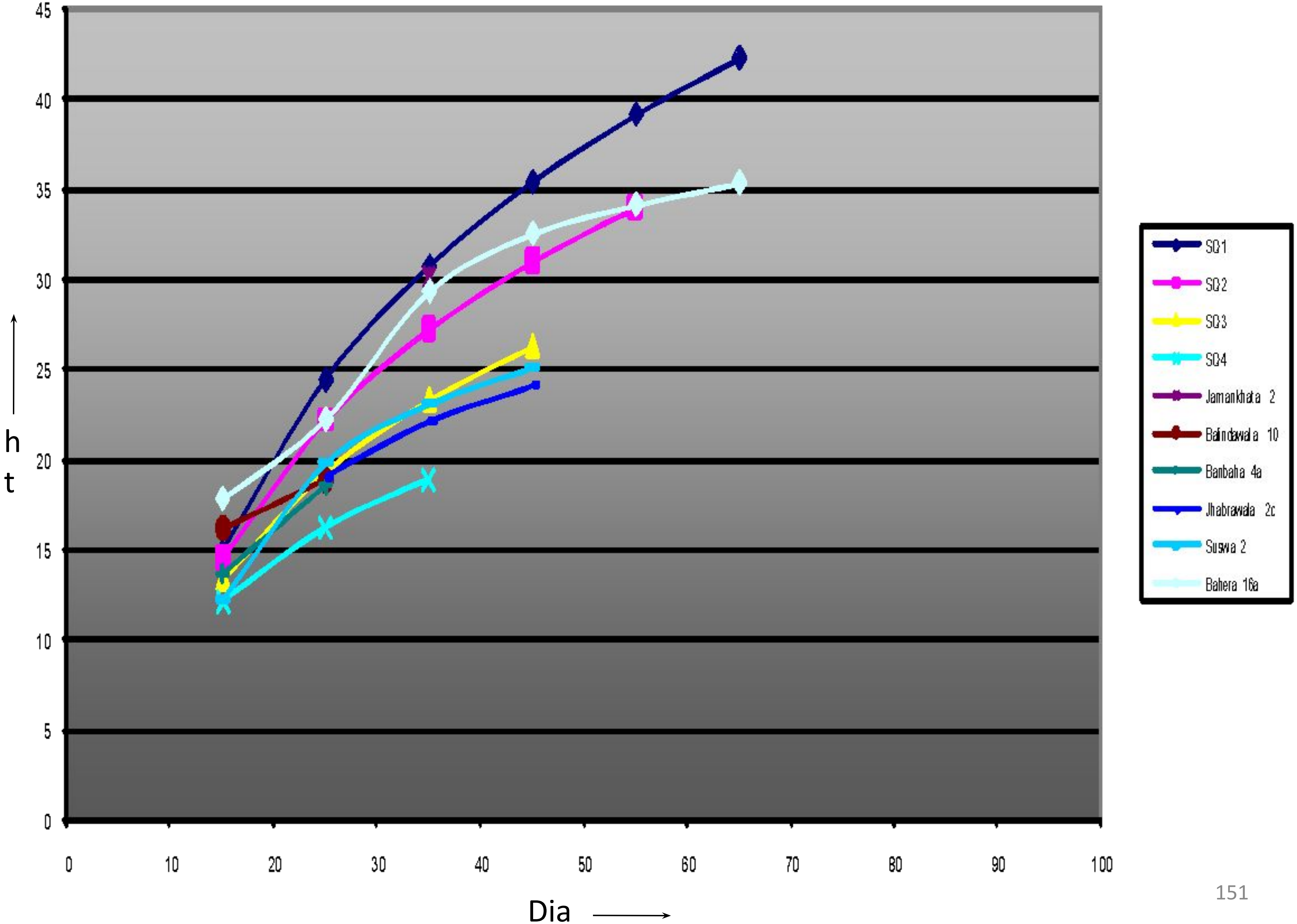
i. Site quality curves (Age ~ Top ht) available for different site quality classes
ii. The point corresponding to the top ht and age as measured is located and quality class within which it falls is determined.
iii. Site quality or fractional site quality can also be determined from the table directly instead of plotting site quality curves

Estimating the site quality of a Compartment

Method 2 - (By Plotting Dia vs Height Curve) :

- Steps
  - Lay a Representative Sample plot
  - Get data for plotting **ht vs dia** curve
  - If data for all dia class is not available go out side the sample plot to get the data
  - Plot **ht vs dia** curves for various site qualities
  - Overlay the field data curve with the site quality curves (yield table) to see the site quality

For standard Site Quality curves crop dia (cm) has been taken on X axis rather than age as it is difficult to determine the age of a *Shoera robusta* stand in the field.


45
40
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
SQ1
SQ2
SQ3
SQ4
Jamankhata 2
Balindawala 10
Banbaha 4a
Jhabrawala 2c
Suswa 2
Bahera 16a
ht
Dia

2. <u>Forecast of future yields…</u>

1. Stand structure

↓

2. ***<u>Stand growth</u>***
3. Stand density
4. Productive capacity of site, “site quality”

2. Stand Growth

- *Development of tree crops as they increase in age*

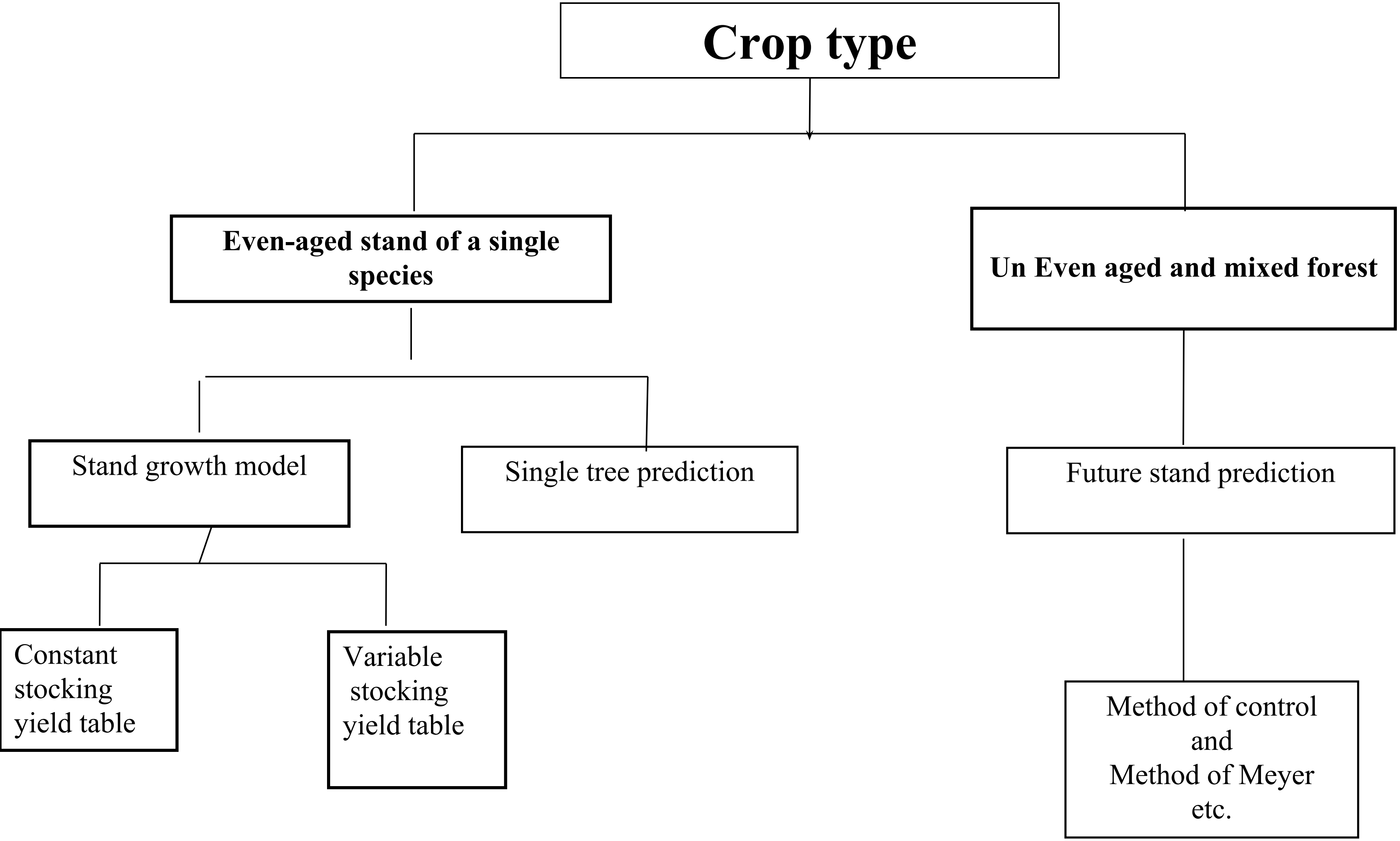
- 'Design of growth model' depends on :
  - Resource available
  - Uses to which it will be put
  - Structure of tree crops

Even or Uneven aged

  - Changes from year to year

- **Even aged stand**
  - **Simplest models**
- **Un Even aged or mixed species stand**
  - **Very complex**

A classification of growth models



Stand prediction
in
Un-Even aged or mixed species stand

- *Factors affecting stand structure*

  - Growth
  - Death
  - Cutting of trees

- **Definitions:**

  - **Ingrowth:**

    - ❑ volume of new trees growing into the minimum measurable size class during the measurement period.

- **Mortality:**
  - the **#** or **vol.** of trees periodically dying from natural causes as:
    - Old age, Disease, Insects etc.
- **Cut:**
  - the # or vol. of trees periodically felled or salvaged

Cont..

- **Types of Stand Growth (in terms of vol.)**

$$Gg = V_2 + M + C - I - V_1$$

Gg= Gross growth of initial vol.

V_2= Stand Vol. at end of growth period

V_1= Stand Vol. at beginning of growth period

M = Mortality Volume

C = Cut volume

I = Ingrowth Vol.

Gn = Net growth of initial volume

→ $Gn = (Gg - M) = V_2 + C - I - V_1$

G_d = Net increase in standing vol.

→ $G_d = V_2 - V_1$

Stand prediction in Un-Even aged crops

- Method of measuring growth of un-even aged crops
  - evolved from those developed in France & Switzerland in last century
  - Swiss forester , M Henri Biolley introduced **“ Methode du Controle”**
    - Established the increment of forest over successive 100 % inventories by 3 categories
      - Large , Medium & small sized trees
    - This data then used to predict or plan future felling

Method of Control ...

- Depends on the following factors:

1. 100% inventories
2. Well defined procedure of measuring and re-measuring the diameter of standing trees
3. Measuring and determining the volume of felled trees and mortality trees
4. A simple method of determining ingrowth
5. Use of permanent local volume tables

- Initial inventory
  - Entire area is enumerated
  - Trees are classified by Dia- class
  - Record all trees removed till the next inventory (dia class as well as volume)
- Next Inventory
  - Entire area is again enumerated

- Volume calculation
  - Using LVT
  - For each dia –class
  - Add volume of each dia class to obtain volume of each inventory
- Cut and mortality together constitute trees removed

a) Vol at time t = V_1

b) Vol at time (t + 5) yrs = V_2

c) Account total vol. removed during the period = C

Then, net growth, including ingrowth, of initial volume

$$\mathbf{Gn+i = V_2 + C - V_1}$$

The Calculation of increment in the Methode du Controle

		2001		2006		Felled		Recruits		Revised 2006 total		Volume inc./ha in 5 yr	Annual volume increment per ha	
Dbh	Vol./tree	No./ha	Vol./ha	No./ha	Vol./ha	No./ha	Vol./ha	No./ha	Vol./ha	No./ha	Vol./ha			%
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
75	5.56	–	–	1	5.56	–	–			1	5.56		*Large trees*	
70	4.93	1	4.93	–	–	–	–			–				
65	4.32	–	–	–	–	–	–			–				
60	3.72	2	7.44	5	18.60	–	–			5	18.60			
55	3.20	5	16.00	6	19.20	2	6.40			2	6.40			
Total large trees		8	28.37	12	43.36	2	6.40	6	19.20	8*	30.56	2.19	0.44	1.6
									Recruits	6	19.20		*Medium trees*	
50	2.70	11	29.70	7	18.90	1	2.70			8	21.60			
45	2.22	13	28.86	17	37.74	5	11.10			22	48.84			
40	1.66	27	44.82	27	44.82	1	1.66			28	46.48			
35	1.14	32	36.48	41	46.74	4	4.56			19	21.66			
Total medium trees		83	139.86	92	148.20	11	20.02	26	29.64	83*	157.78	17.92	3.58	2.6
									Recruits	26	29.64		*Small trees*	
30	0.12	66	47.52	52	37.44	5	3.60			57	41.04			
25	0.37	69	25.53	83	30.71	13	4.81			96	35.52			
20	0.16	117	18.72	94	15.04	19	3.04			73	11.68			
Total small trees		252	91.77	229	83.19	37	11.45	40	6.4	252	117.88	26.11	5.22	5.7
Total		343	260.00	333	273.75	50	37.87			343	306.22	46.22	9.24	3.6

Methode du Controle

(volume increment by dia class)

1. the classes of diameter at breast height were grouped into three major categories of large, medium and small trees. A separate increment % was calculated for each.
2. data derived from a one parameter volume table.
3. from an inventory of the compartment made in 2001
4. col. 2 X col. 3
5. From an inventory of the compartment made in 2006

6. col. 2 X col. 5
7. From the compartment records of outturn for the period 2001-2006
8. col. 2 X col. 7
9. only to be completed in the line of the totals for the large and medium trees = total of col. 5 + total of col. 7 – total of col. 3, i.e. $V_2 + F - V_1$ or the number of trees of medium size in 2001 recruited to the large tree category, etc.
10. col. 2 X col. 9 for totals only.

11. has to be completed for the total line of the large trees first and must equal the corresponding total in col. 3.

- Then starting with the largest diameter class of the large trees, col. 11 = col. 5 + col. 7 until the sum of these totals equals the figure previously entered in the total line. The balance of trees in the large tree diameter classes has been recruited from the medium category and this balance is entered in the blank line at the head of the medium tree category in col. 11 and labelled ‘recruits’ in the adjoining space in col. 10

12. col. 2 X col. 11

13. completed for the total line of the large, medium and small tree category only = col. 12 – col. 4

14. col. 13 divided by the period of years between the inventories

15. column 14 expressed as a % of col. 4

- **Meyer (1953)** reviewed the Stand Prediction Method
  - Developed new system was similar to Methode du Controle but
    - Predicted the future structure of a stand either from increment measured from successive inventories or in sample plots

Methodology

1. Current diameter increment by diameter classes
   – Use of data collected
2. Predict future structure of stand and growth in volume

1. <u>Diameter increment by diameter classes</u>

- Takes in to account
  - no. of trees rising into a diameter class,
  - Trees remiaining stationery in the class
  - Trees going out of the class

in successive inventories

- Increment in each dia class,

$$I = (DR/DE) * C$$

where,

DR = double rising (sum of trees rising out and rising into a class)

DE = double effective (sum of trees in the first and second inventories after correction for trees removed)

C = width of dia class

Table
Calculation of Periodic Annual Diameter Increment by Diameter Classes by the Method of Control

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
dbh Class (inches)	Inventory Spring 1999 (number)	Trees Removed (number)	Inventory Spring 1999 Minus Trees Removed (number)	Inventory Spring 2009 (number)	Trees Rising (number)	Double Rising (number)	Double Effective (number)	DR/DE	Periodic Diameter Increment (inches)	Periodic Annual Diameter Increment (inches)
					0					
32	0		0	1	1	1	1	1.000	2.00	0.200
30	2		2	4	3	4	6	0.667	1.33	0.133
28	3		3	0	0	3	3	1.000	2.00	0.200
26	3	2	1	9	8	8	10	0.800	1.60	0.160
24	10	1	9	7	6	14	16	0.875	1.75	0.175
22	10	4	6	21	21	27	27	1.000	2.00	0.200
20	23	4	19	39	41	62	58	1.069	2.14	0.214
18	37	7	30	72	83	124	102	1.216	2.43	0.243
16	73	5	68	169	184	267	237	1.127	2.25	0.225
14	194	17	177	234	241	425	411	1.034	2.07	0.207
12	249	9	240	379	380	621	619	1.003	2.01	0.201
10	418	15	403	507	484	864	910	0.949	1.90	0.190
Total	1022	64	958	1442		2420	2400			

$$\frac{\Sigma DR}{\Sigma DE} = 1.008$$

Average = 2.02   0.202

Number of trees ingrowth = 1442 − 958 = 484 (checks with last figure in Column 6). Trees were removed (Column 3) immediately following t 1999 inventory. Data from 143 permanent sample plots of $\frac{1}{5}$ acre located on Morgan-Monroe State Forest, Indiana. Sample area: 28.6 acres. Growth period: 10 years.

- No. of trees rising in to class =

  (# of trees in 2nd Inv)

  - (# of trees in 1st Inv)

  + (# of trees rising out of the class)

→ $C6_{i+1} = C5i - C4i + C6_{i-1}$

→ $C7i = C6_{i+1} + C6_{i-1}$

→ $C8i = C4i + C5i$

2. Predict future structure of stand and growth in volume

- **STAND PREDICTION METHOD**

Dbh Cm	Vol. per tree (Cum)	Inventory - No. of Stems Per Ha	Diameter increment in 5 years Cm (i)	Ratio i/c*	Station ary	1dia. Class	2 dia. Class	Future stand No. of stems per Ha	Present Volume (Cum per ha)	Volume prediction (Cum per ha)
1	2	3	4	5	6	7	8	9	10	11
42	1.80	-	-					1.10	-	1.98
40	1.58	2	1.1	0.55	0.90	1.10	-	2.70	3.16	4.27
38	1.38	3	1.2	0.60	1.20	1.80	-	5.45	4.14	7.52
36	1.19	5	1.7	0.85	0.75	4.25	-	10.55	5.95	12.55
34	1.02	8	2.0	1.00	-	8.00		8.50	8.16	8.67
32	0.88	9	2.4	1.20	-	7.20	1.80	11.70	7.92	10.30
30	0.76	13	2.2	1.10	-	11.70	1.30	17.10	9.88	13.00
28	0.65	18	1.9	0.95	0.90	17.10	-	13.70	11.70	8.90

Dbh Cm	Vol. per tree (Cum)	Inventory - No. of Stems Per Ha	Diameter increment in 5 years Cm (i)	Ratio i/c*	Statio nary	1dia. Class	2 dia. Class	Future stand No. of stems per Ha	Present Volume (Cum per ha)	Volume prediction (Cum per ha)
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
26	0.55	16	1.6	0.80	3.20	12.80	-	22.80	8.80	12.54
24	0.46	28	1.4	0.70	8.40	19.60	-	28.90	12.88	13.29
22	0.38	41	1.0	0.50	20.50	20.50		58.20	15.58	22.12
20	0.31	58	1.3	0.65	20.30	37.70		70.90	17.98	21.98
18	0.25	92	1.1	0.55	41.40	50.60		99.45	23.00	24.86
16	0.18	129	0.9	0.45	70.95	58.05		70.95	23.22	12.77
	Total	**422**						**422.00**	**152.37**	**174.75**

c = class interval = 2 cm

5 years' total increment = (174.75 – 152.37) = 22.38 ;

current annual increment 4.48 per year or 2.9%

Notes on calculation in Example of the

STAND PREDICTION METHOD

COLUMN

1 Classes of diameter at breast height

2 From a one parameter volume table

3 From an inventory

4 From repeated measurements on sample trees

5 Col.4 divided by the diameter class interval

COLUMN

6,7,8 If the increment is 1/n of the class interval, then on average 1/n of the trees will move out of the class in to the next larger dia class;

However, if the increment is more than the class interval, then all the trees will move up

If the increment is 1 ¼ times the class interval, all the trees will move up and ¼ will move beyond into the next but one diameter class

Contd…..

Co.6= 0, if Col.5 is greater than 1, or else = (1- col.5) (Col.3)

Col.7 = Col.3 - (col.6+ col.8)

Col.8 = 0, if col.5 is less than 1, or else = (col.5 - 1) (col.3)

Column 9 Col6 + (the entry in Col.8 of 2 diameter classes lower) + (the entry in col.7of 1 diameter class lower), e.g.

Dbh 42 col.9 = 0+1.10 =1.10

Dbh 40 col.9 = 0.90+1.80 = 2.70

10 col.2 X col.3

11 col.2 X col.9

- The total of column 3 must equal that of column 8 .

Q: Following inventory data has been collected in two different years in the same forest area:

Dia class (in cm)	Volume per tree	Initial inventory in 2001 (number)	Second inventory in 2011 (number)
1	**2**	**3**	**4**
42	1.8	0	1
40	1.58	2	3
38	1.38	4	5
36	1.19	6	11
34	1.02	12	20
32	0.88	18	26
30	0.76	22	30
28	0.65	26	33
Total		**90**	**129**

Calculate annual diameter increment in each dia class, overall annual diameter increment and also future volume in year 2016 using Method of Control.