E-Content

On

Theory and Practices of Silviculture

(Course Code:SA-1203) Credits: 3(2+1)

[For B. Sc. (Hons.) Forestry IIndSemester Students]

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PREFACE

Theory and Practices of Silviculture(SA-1203) is a compulsory course offered to the students of B.Sc. (Hons.) Forestry,which includes Definitions: Forests and Forestry-Silviculture objectives and scope of silviculture-relation with other branches of Forestry Silvics. Site factors - climatic, edaphic, physiographic, biotic and their interactions. Trees and their distinguishing features, growth and development. Root growthfine root/functional root production- Direct and indirect benefits- biophysical interactions- trees and buffering functions- C sequestration potential of forests. Silvicultural systems-definition, scope and classification. Systems of concentrated regeneration- systems of diffused regenerationaccessory systems- Clear felling systems- Shelterwood system - Selection system and its modifications- Coppice systems- Culm selection system in Bamboo, Canopy lifting system in Andaman. Silvicultural systems followed in other countries Regeneration of forests – objectives - ecology of regeneration- natural, and artificial regeneration. Natural regeneration- seed production, seed dispersal, germination and establishment, requirement for natural regeneration, advance growth, coppice, root sucker, regeneration survey, natural regeneration supplemented by artificial regeneration. Artificial regeneration - object of artificial regeneration - advantages. Factors governing the choice of regeneration techniques. Tree planting- Sowing v/s planting different kinds of pits- tending and cultural operations-weeding- kinds of weeding- release operations- singling, cleaning–liberation cutting. It has been long felt to develop a manual covering all the aspects of the above mentioned course which will be very useful for the UG students to understand the various field activities such as produce quality planting materials and management of natural forest tree as well as plantation forest. In developing the material for this manual, authors have relied upon the literature from several sources which is highly acknowledged.

The author extends her gratitude to our Hon'ble Vice Chancellor Dr. (Prof.) Narendra Pratap Singh, for his valuable guidance, encouragement and inspiration for preparation of this e manual. Dr. A.C. Mishra Director of Research, Dr. A.K. Shrivastva Director PMECfor their encouragement and help to write this manual. I hope, thismanual will meet the requirement of undergraduate students studying Silviculture.

Authors

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DECLARATION

This E-content on course "**Theory and Practices of Silviculture** (SA-1203)" is prepared according to the syllabus recommended by the ICAR 5th Dean Committee Report. The course "Theory and Practices of Silviculture (SA-1203)" is being offered by Department of Silviculture &Agroforestry to the undergraduate students of B.Sc. (Hons) Forestry degree Programme. This study material is prepared by consulting different text and reference books, package of practice manuals, online sources such as University websites, e-documents, e-books, e-data and other available off-line sources. The authors do not claim for originality of work.The purpose of this E-content is just to provide the study material to students of B.Sc. (Hons) Forestry degree Programme as reference material for easy and better understanding of the course. This is not meant for the commercial use. The multiplication of this content for commercial activity is prohibited.

AUTHORS

CONTENTS

Definitions of Forest and Forestry

The word forest is derived from the Latin word “foris” meaning outside the village boundary or away from the human inhabitation area. General definition Forest is referred to an area occupied by different kinds of trees, shrubs, herbs and grasses, or Forest is a large uncultivated tract of land covered with trees and underwood, woody vegetation and pasture; preserve for big game.

Legally, Forest is an area of land proclaimed to be a forest under a forest law

Technically, Forest is an area set aside for the production of timber and other forest produce or maintained under woody vegetation for certain indirect benefits which it provides e.g. climate or protective (Anon, 1966)

Ecologically, A plant community, predominantly of trees and other woody vegetation, usually with closed a canopy.

Classification of Forests

Forests can be classified on the basis of 1. Age 2. method of regeneration 3. Composition 4. Ownership 5. Object of management 6. Growing stock

1. On the basis of age.

On the basis of age forests are classified in to (i) Even aged forest and (ii) Uneven aged forests (i) **Even aged forest**: Those forests which consists even aged wood. Even aged meaning the trees of approximately same age. True even aged forest can be only plantations. A difference up to 25 per cent of rotation is allowed in to the natural forest or in case where forest is not harvested for 100 years or more. Even aged forest also known as regular forests.

(ii) **Uneven aged forest**: Those forest which consists uneven aged wood or vary widely in age. These are also known as irregular forests.

2. On the method of regeneration

(i) **High forests**: Those forests which are regenerated from seed

(ii) **Coppice forests**: Those forests which are regenerated through coppice or some vegetative part of tree. When the forest regenerate naturally are called natural forest and when it is obtained artificially, the forests are called man made forests or plantations.

3. On the basis of composition

(i) **Pure Forest**: A forest that is dominated from almost entirely one single species to the minimum extent of 50 per cent are called pure forest.

(ii) **Mixed forests**: Forest which composed of trees of two or more species intermingled in the same canopy. The tree species in mix forests are known as principal species (first important species either by highest frequency, dominance or volume of silvicultural value), accessory species and auxiliary species.

4. On the basis of ownership

Government forests, Private forests and forests owned by Panchayats, Corporations and societies etc. Government forests are further classified as (i) Reserve forests, (ii) Protected forests and (iii) Village forests.

(i) **Reserve forests**: An area with complete protection, constituted according to chapter II of the Indian Forest Act, 1927.

(ii**) Protected forests**: An area subject to limited degree of protection constituted under the provision of chapter IV of the Indian Forest Act, 1927.

(iii) **Village forests**: It is a state forest assigned to a village community under the provisions of chapter IIIof Indian Forest Act, 1927.

5. On the basis of object of management

(i) **Protection forests**: Forests which are managed for ameliorating climate, conserving soil and water, checking soil erosion, regulating stream flow and increasing water yield.

(ii) **Production forests**: Forests which are manage primarily for various products like wood, leaf, bark, fruit, dye, seed etc.

(iii) **Social forests**: Forests which are manage to full fill local needs of neighbouring society.

6. On the basis of growing stock

(i) **Normal forest**: It is an ideal forest with regard to growing stock, age class distribution and increment. These types of ideal forests are standard for comparison and rarely found in nature. (ii) **Abnormal forest**: A forest which have growing stock, age class distribution of stems, increment either in excess or in deficit than normal forest

Definitions of Silviculture

Silviculture is the art and science of cultivating forest crops (Indian Forest and Forest Products Terminology)

Silviculture refers only to certain aspects of the theory and practice of raising forest crops (Champion and Seth)

Silviculture is that branch of forestry which deals with the establishment, development, care, and reproduction of stands of timber (Toumey and Karsitien)

Silvics is the study of life history and general characteristics of forest trees and crops with particular reference to environmental factors, as the basis for the practice of silviculture.

Objectives of Silviculture

1. Production of species of economic value 2. Production of quality timber 3. Production of larger volume per unit area 4. Reduction in age of rotation 5. Raising forests in blank areas 6. Creation of plantations in place of natural forests 7. Introduction of exotics 8. Control of stand structure 9. Control of composition 10. Control of stand density 11. Conservation of site quality 12. Increase employment opportunities 13. Increase the production of fuel and fodder 14. Development of forest industries

Relation of silviculture with other branches of forestry

Forest Mensuration: Silviculture deals with raising of forest crops, forest mensuration deals with measurement of diameter and heights of crop so produced, calculation of its volume, age, etc., for sale and research to decide the best treatment to be given to the crop while it is being raised. **Forest Management**: It manages forest crops according to the dictates of the policy and prescribes the time and place where the silvicultural techniques and operations are carried out to attain the goal of management. **Forest Utilization**: Silviculture deals with cultivation of forest crops, forest utilization is concerned with the harvesting and disposal of crops so produced. **Forest Ecology**: It is concerned with forest ecosystem. It deals with different species of flora and fauna, whereas silviculture deals with their cultivation and maximization of their production. **Forest Protection**: A knowledge of the injuries caused to forests by the local human and animal population, both domestic and wild, insects, fungi and other adverse climatic factors and preventive and remedial measures to counteract them, whereas silviculture is concerned with raising forest crops. **Forest Economics**: Silviculture deals with cultivation of forest crops, forest economics works out the cost of production including rental of land and compound interest on capital spent in raising the crop. It

compares the cost of production by different methods and then decide the most profitable method of raising that crop.

Site factors

Site factors also known as factors of locality which are the effective climatic, edaphic, topographic and biotic condition of a site, which impact the vegetation of the locality. These are Climatic factors, Topographic factors, Edaphic factors, Biotic factors.

In general speaking climate is the general weather conditionprevalent in an area or locality.

A. CLIMATIC FACTORS

1. Solar radiation 2. Moisture 3. Wind

1. **Solar radiation**: The energy radiated by sun reaches the in the form of electromatic waves of length ranging, ranging nearly from 290 mμ to 5300 mμ. Visible wavelength-39% (400 to 720 mμ), ultraviolet wavelength-1 %(infrared-60% (720 mμ).

(i)Light: Light is part and parcel of solar radiation, the requirement of which varies with species. Various species show varying tolerance to light intensities. But they depend on stages of development, eg. Sal is light demander, but requires partial shade in the beginning or earliest stage. So, to classify the species, detail information on conditions of species are required. On this basis, they are classified as follows:

A.Light demander: A species that requires abundant light for its best development. Like *Shorea robusta*, *Dalbergia sissoo*, *Tectona grandis*, *Bombex ceiba*, *Gmelina arborea*, *Ailanthus excelsa*, *Acacia nilotica* etc.

B.Shade bearer: A species capable of persisting and developing under shade. Like *Artocarpus spp*. *Cedrus deodara*, *Quercus dilatata*, *Cuppressus torulosa*, *Picea smithiana*, *Toona ciliata* etc.

C.Shade demander: A species requiring some degree of shade at least in its early stages, for its normal development. Like*Abies pindrow*, *Mallotus philippensis*, *Syzygium cumini* etc.

(ii)Temperature: The temperature of various place on the earth is different because it is affected by the following factors:

A.Latitude: As the latitude increases, the temperature decreases. Temperature is highest at equator and when we move north or south the temperature falls.

B.Altitude: It has been estimated that there is a fall of 1^0C in average temperature in the Himalaya for every 270m rise in altitude. As the altitude increases, temperature decreases.

C.Distance from the sea: The farther a place from the sea, the greater is the diurnal and seasonal ranges of temperature.

D. Winds: Generally, winds decrease the temperature when they come from sea side.

E. Landforms: The direction of the mountain ranges affects temperature through its effect on winds and rainfall.

F. Cloudiness: As clouds screen off the sun, their presence affects temperature.

G. Forest vegetation: The rays of the sun strike bare sites directly and such places are therefore hotter than the places covered with forest vegetation. Forest vegetation bring about moderating effect on temperature.

Frost: Chilling of air below the freezing point is called frost. It is of three types:

A. Radiation frost: It is produced by loss of heat by radiation during winter nights with clear sky. It occurs in plain and kills back young plants. Whenever ice crystals are formed on the ground and other objects near the surface.

B. Pool Frost: The accumulation to a considerable depth of heavy cold air flowing down into natural valley bottom or depressions from adjoining areas. It occurs in mountainous areas like Dehradun valley.

C. Advective frost: A frost produced by cold air brought from elsewhere.It occurs in open areas like in Indo-Gangetic plains. When an area is affected by frost more than other areas in the locality, it is referred to as frost pocket or frost hole or frost locality. Frost Injuries: a. Killing of young plants or their parts. Khair, Sissoo, Chir pine, Ber, Mahuwa, etc are the examples pf frost hardy species. Banj oak, Kadam, Semal, Rosewood, Gamhar, etc. are moderately frost hardy and Babool, Neem, Teak, Arjun, Asna, etc. frost tender species.

2. Moisture

Moisture is important climatic factor that affect the forest vegetation because it is an important part of cell sap, cell wall and protoplasm. Precipitation happens when water saturates the atmosphere so that the water condenses and ‘precipitates’ or falls. Fog and mist are thus not forms of precipitation. Water is a medium for absorption of essential nutrients

and minerals. Water is also essential for seed germination and soil formation. The water comes in different forms on earth these are:

A. Rain: It is a liquid form of precipitation having drop size >0.5 mm and intensity < 6mm/hour.

B. Drizzle: It is also a liquid form of precipitation with fine size of drops < 0.5 mm and intensity < 1 mm/hour.

C. Snow: It is a frozen form of precipitation in which ice crystals forms resulting from sublimation.

D. Hail: It is also frozen form of precipitation in which small lumps of ice (>5 mm diameter) forms.

E. Sleet: When the transparent ice pallets with a diameter of less the 5 mm get precipitated, then it is known as sleet. It is a form of snow precipitation.

F. Dew: The condensation of moisture in small drops upon cool surface is called dew. Occurrence of dew is a common feature in open winter nights. Its contribution n total precipitation never exceeds more than 1 to 2 per cent.

3. Wind

Wind has a Beneficial as well as Harmful influence on forest vegetation.

Beneficial effects

1.Wind brings fresh supplies of carbon dioxide to the foliage of trees and helps in photosynthesis.

2. Wind helps in pollination of anemophilous flowers.

3. Wind helps in the dispersal of seed of many forest trees like *Toona ciliata*, *Bombax ceiba*, *Holoptelia integrifolia*, *Ceiba pentandra* etc.

Harmful effects:

1. High speed winds create high tapering in the boles.

2. High speed winds and storms causes uprooting and breakage of branches.

3. High speed winds causes erosion and removes fertile soil depositing sand etc.

B. EDAPHIC FACTORS

Edaphic factors pertain to the properties of soil, type, composition etc all of which have important affect the forest vegetation in various ways.The formation of soil is called soil weathering. Vertical sections with respect to the sequence of layers are called soil profile.

Physical Properties: Supply of moisture, nutrients and airaffect physical properties of soil cause significant influence on tree growth. Such properties of soil relate mainly to its texture, structure and porosity.

A. Soil Texture: The relative proportion of the various size groups of individual soil particles. The individual size groups are referred to as soil separates. Soil groups are recognized as clay (2mm). Coarse textured soil is called light soil and fine textured soil is called heavy soil.

B. **Soil Structure:** The arrangement of individual soil particles into aggregates of definite size and shape. Clod (>25mm), prism, crumb (3mm), granules (upto 6mm), etc are soil aggregates and their sizes differ. Importance (i) It affects soil moisture and soil air relations (ii) It is an indication of nutrient status and activity of microorganisms in the soil (iii) It affects soil erosion. Crumb is least liable to erosion while single-grained structure is most liable to erosion.

C. Soil Porosity: The extent to which gross volume of the soil is unoccupied by solid particles. Pore space is the space unoccupied by soil particles. Clayey soil has very small pore spaces and retains too little air, on the other hand sandy soils are well-aerated. Capillary porosity is the portion of soil not fulfilled by water when the soil is wet, whereas Non-capillary Porosity is the air space in a soil at field moisture capacity.

Chemical Properties: The soil is known to be the chemical laboratory of nature in which various chemical decomposition and reactions taking place in a hidden manner. The major chemical properties which affect plant growth are discussed below in brief;

a. Cation Exchange Capacity (CEC)

The total capacity of soil for holding cations and is usually expressed in terms of milli-equivalents per 100gms of oven dry soil. An equivalent is the quantity chemically equal to one gm (No. of hydrogen atoms=6.02×1023) of hydrogen and so a milliequivalent is equal to 0.001gm of hydrogen. Soil has both positive and negative charge, yet negative charge is of much greater magnitude, which has capacity to absorb positively charged ions from the soil solution. The cations absorbed are Ca, Mg, K, Na and H. The exchangeable cations of Ca, Mg, K, Na are all associated with compounds which are more basic than acid in reaction. So,

these are referred to as exchangeable bases, while H as exchangeable acid. Therefore, cation exchange is the process by which a colloidal nucleus absorbs certain cations from the soil solution and gives up other cations held by it in equivalent quantities.

b. Soil Acidity: Acidity of a soil solution is due to an excess of hydrogen ions over hydroxyl ions. But if hydroxyl ions are in excess over hydrogen ions, the solution becomes alkaline. Pure water contains equal amount of hydrogen and hydroxyl ions and is, therefore, said to neutral. Those concentration of ions are indicated by PH. PH of 7 indicates neutrality; higher values indicate alkalinity and lower values acidity. PH value does not remain constant throughout the soil profile. It usually varies from horizon to horizon.

c. **Silica-sesquioxide ratio**

Due to loss of silica by leaching, sesquioxides get accumulated in the soil profile. The relation between silica and sesquioxides of soil is known as silica-sesquioxide ratio. Increase in sesquioxides results in decrease in cation exchange capacity and moisture retentively of soil.

C. TOPOGRAPHIC FACTORS

The factors pertaining to the physical configuration of the earth are known as topographic or physiographic factors. These factors influence vegetation which causes variation in climate of a geographic region, ultimately give rise to a characteristic microclimate.

a.Altitude: As the altitude above the sea level increases, there happens a decrease of temperature. Besides, the values of pressure, humidity, wind velocity, intensity of solar radiation etc. also changes. All these factors together give a definite pattern of vegetational zone.

b. Aspect and Exposure: The slope of mountain affects the nature of vegetation. In northern hemisphere, south facing slopes receives more solar radiation than the north facing slope. This may be due to the fact that the steep southern slope receives the solar radiation almost at right angles during the mid-day whereas the northern slopes receive only oblique rays during morning and evening hours. This difference in solar radiation brings about a change in vegetation in the two sides of the slope.

3. Direction of mountain chains: The direction of mountain chains considerably influences the rainfall in an area. If the mountain chains lie in the path of wind full of water vapour, then there is heavy rainfall on the wind striking side on the mountain chain.

D. Biotic factors

Biotic factors are defined as 'the influence of living organisms.'

Influence of biotic factors can be described under the following headings.

1. Influence of plants.

2. Influences of insects

3. Influence of wind animals; and

4. Influence of man and his animals

1. Influence of plants

i.) Parasites- Parasite is defined as 'an organism that draws a part or whole its nourishment from another living organisms'. Among the total parasites, *Cuscuta reflexa* and *Cassytha filiformis* are common in forest area. Among the partial parasites *Viscum, Loranthus*, and *Arceuthobium* are partial commonest. *Arceuthobium* is found on kail and juniper while *Viscum* occurs on oaks, chestnuts and walnuts in the western Himalayas. *Loranthus longiflorus* is mostly found in the sub -Himalayan tract of U.P. and H. P.

One useful and valuable parasite tree species, *Santalum album.* Sandal tree is a root parasite as contrasted with the above mentioned stem parasites.

ii.)Epiphytes – Epiphyte is 'a plant growing on, but not nourished by another plant'. Epiphytes commonly found in forests are *Ficusbengalensis*, *F. religiosa*, orchid and *Tinospora.*

iii.)Climber – Climber is 'a herbaceous or woody plant that climbs up trees or other support by twining round them or by holding on to them by tendrils, hook, aerial root or other attachments'. Large woody climbers in tropical areas are also called *liane* or *liana*. Some of the common climber found in forests are *Dioscorea, Mucuna,Ichnocarpus, Ipomaea,Atylosia, Naravelia*, *Combretum decandrum*, Bauhinia *vahlii*, *Milletia auriculata*, *Butea superba*, etc.

iv.)Abnoxious weeds- One of the most important abnoxious weeds is *Lantana camara* which has covered large area of forests of this country.

Another troublesome weed is *Eupatorium odoratum* which is found in the forests of Assam, West Bengal, parts of Bihar, and the Deccan.

2.) Influence of insects- Insects are an integral part of the environment of forests. One of the most important of such harmful insects is *Hoplocerambyx spinicornis,* popularly known as Sal borer. *Hapalia machaeralis* and *Hyblaea puera* are important defoliator and skeletonizer

of teak. Some other harmful insects are *Ips longiflia, hypsipyla robusta, Hylobius angustus, Plecoptera relfexa,*etc.

Characteristic features of tree

It is a woody perennial with a well marked single trunk or bole, more than 6 m height e.g. *Tectona grandis* (Teak), *Azadirachta indica* (Neem), *Cedrus deodara* (Deodar) etc. In forestry there are five stages of growth viz. Recruit, seedling, sapling, pole and tree has been standardized for a tree (Anon, 1966).

Recruit: From germination stage to emergence of 2-3 leaves of the plant.

Seedling: From recruit stage upto height of 1 m of the plant.

Sapling: From seedling stage to the lower branches begin to fall. It is characterized by the dead bark on the stem and its vigorous height growth.

Pole: From the fall of lower branches increase in height starts to fall, crown expansion becomes marked and diameter at breast height is 30 cm.

Tree: After passing the pole stage or more than 30 cm diameter at breast height.

Root growth

The root system is the descending (growing downwards) portion of the plant axis. When a seed germinates, radicle is the first organ to come out of it. It elongates to form primary or the taproot. It gives off lateral branches (secondary and tertiary roots) and thus forms the root system. Its branches penetrate through large and deep areas in the soil and anchor the plant very firmly. It also plays another vital role of absorbing water and mineral salts from the soil and transporting them upwards.

Characteristics of root

- Not divided into nodes and internodes
- Non-green due to absence of chlorophyll
- Absence of leaves and buds
- positively geotropic (grow towards gravity)
- Positively hydrotropic (grow towards water)
- Negatively phototropic (grow away from light)

Types of Roots

Tap root: Tap root – It is the primary and the main root that develops from the radicle, bears numerous branches and remains underground. It is usually found in dicots e.g. Neem, Jamun, Kaith, Madar, mustard, mango etc.

Adventitious root – These are roots that develop from any part of the plant except the radicle. They may be aerial or underground (Fig. 6.1b). They may grow from node (money plant, bamboo), stem cutting (rose), tree branch (banyan) or stem base (fibrous roots in monocots).

Regions of Root

The apical region of roots of any root system shows the same zones or regions. A longitudinal section of root apex shows the following structures which are responsible for growth in root:

Root cap region — It is a thimble-like structure produced by meristematic (rapidly dividing) zone and protects the tender apex (apical meristem) from harsh soil particles. As the root grows further down in soil, root cap wears out but it is constantly renewed . In aquatic plants (Pistia and water hyacinth) root cap is like a loose thimble, called root pocket.

Region of meristematic cells — is a small region of actively dividing cells called the apical meristem. It consists of : (i) Dermatogen (outermost layer whose cells mature into epiblema and root cap); (ii) Periblem (inner to dermatogen whose cells mature into cortex) and (iii) Plerome (central region whose cells mature into stele). In monocots, cap is formed by independent group of cells known as Calyptrogen.

Region of elongation — This is situated next to the meristematic region, wherein, the cells elongate and enlarge to make the root grow in length.

Region of maturation — This is next to the region of elongation, wherein the cells mature and differentiate into various tissues constituting (i) Root hair or piliferous region having unicellular hairs which absorb water and mineral salts from the soil and (ii) Permanent region which lies behind the root hair zone and is without hairs. It produces lateral roots, anchors the plant in soil and conducts water and minerals upwards.

Fine root biomass

Fine roots (i.e. roots ≤2 mm in diameter) are a small but functionally important component of plant biomass, which controls the uptake of water and nutrients and influences biogeochemical cycles through rapid biomass turnover. The lifespan of fine roots, in particular of the smallest 1st and 2nd order rootlets, is short, in woody plants typically not more than a few months. Despite representing only a few percent of plant biomass, fine roots

have been estimated to consume about a third of annual global net primary production, and they represent a major source of soil carbon through root death and rhizodeposition.

Under contrasting environmental conditions, trees adopt different strategies of resource allocation to the fine root system, which all aim at minimizing the resource investment needed to secure nutrient and water uptake. These strategies vary with the species and functional groups, and in dependence on climatic and edaphic factors such as temperature, precipitation, nutrient availability, soil acidity, and soil bulk density. In correspondence, large variation in fine root system size, mean fine root diameter, branching patterns, and fine root turnover has been found in different forest types, even when the general climate is similar. For estimation of fine root a sample is taken from various depths with a soil corer of a define diameter. Samples are washed under running water over a sieve of 200 μm mesh size. All root fragments greater than 1 cm in length and ≤2 mm in diameter are selected and subsequently separated under the stereoscope into biomass (living) and necromass (dead) fractions for estimation of fine root biomass.

Benefits

- Fine roots play an important role in the cycling of water, nutrients, and carbon (C) in terrestrial ecosystems.
- Fine roots control the uptake of water and nutrients and influences biogeochemical cycles through rapid biomass turnover.
- Fine roots minimize the resource investment needed to secure nutrient and water uptake.

Variety of Roots

Roots of various plant species have evolved various specializations.

Food storage roots - used by the plant to store starch for metabolic activities later in the season. Typical examples: carrot, beet, sweet potato.

Water storage roots - found in arid regions, these are roots that collect large amounts of water during rainy season for the plant to use during dry season. These are most often found in xerophytes (sometimes spelled xerophytes). Local examples include the East Indian Rosewood and the *Clerodendron sp.*

Propagative roots - have meristematic regions from where new, genetically identical plantlets can grow. These regions are not the same as nodes: they do not contain a true apical meristem. Local examples include the East Indian Rosewood.

Pneumatophores - gas exchange surfaces on root tips protruding from water-logged soil. Certain species of mangrove have these. But, contrary to popular myth, cypress "knees" apparently have no gas exchange function. (Cypress trees with knees removed do not suffer from any apparent lack of oxygen.

Prop roots - These grow from the lower part of a stem or trunk down to the ground, and providing extra support for the plant. These tend to be more common in plants with a tall, soft stem structure, as well as in plants that live in softer soils. Common examples include corn (*Zea mays*), Screw "Pine" (*Pandanus tectorius*), various species of palms, and mangroves.

Aerial roots - typical of epiphytes such as orchids (in which these roots are called velamen, with a spongy outer surface very good at absorbing and holding water) and bromeliads.

Buttress roots - wall-like extensions off the base of the trunk which provide support against physical assault from high winds.

Our local *Ficus* spp. and the *Delonix regia* tend to develop these in certain environments.

Contractile roots - these specialized roots, usually found at the base of an underground organ (e.g., a bulb) actually contract to perform such functions as getting a bulb to its proper soil dept for growth

Haustoria - parasitic plant roots that invade the tissues of a host plant and transfer nutrients from host to parasite.

Examples of plants that have haustoria are dodder and mistletoe

Adventitious roots - are roots that grow anywhere they are not "expected." Examples are the adventitious roots that grow so prodigiously from some of our native and introduced species of *Ficus* trees. Several of the root types listed above (e.g., prop roots, aerial roots) can also be considered adventitious.

Regeneration:

Regeneration is a renewal of a forest crop by natural or artificial methods. It is a synonym for reproduction which is brought by naturally or artificially in a forest.

Regeneration in a forest can be achieved by the following methods:

1. Natural regeneration

2. Artificial regeneration

3. Natural regeneration supplemented by artificial regeneration

1. **Natural regeneration**

Natural regeneration is the renewal of a forest crop by two natural process of seed germination and vegetatively like coppice and root suckers.

A. Natural regeneration by seed

This type of regeneration is totally depended on nature which includes process of seed production, dispersal, germination and establishment.

a. Seed production

All tree and shrub species do not produce seeds every year. Some species produce seeds at the interval of 2 or more years. Production of forest seeds depends upon type of forest species, age of tree/shrub, crown area of the tree/shrub and factors of locality of that area. Some species produce seeds every year whereas some species have poor seed year and good seed year. Many tree species like *Acacia catechu*, *Azadirachta indica*, *Albizia lebbeck*, *Madhuca longifolia* produce seeds every year whereas *Shorea robusta*, *Dalbergia latifolia*, *Terminalia tomentosa* etc produce seeds in alternate years and *Abies pindrow* after a long interval of 10 to 11 years. Some species of bamboo like *Bambusa tulda* produce seeds after a long interval of 60 years and die off, where as some species of bamboo flower every year without die like *Arundinaria sp.*

b. Seed dispersal

The seed produced by the trees is dispersed by the agency of wind, water, gravity, birds and animals. Some examples of seed dispersal by various agencies are given as:

Wind: Conifers, Acer, Betula, Populus, Alnus, Salix, Terminalia, Dalbergia, Acacia, Adina , Bombax, etc.

Water: Most mangrove species, *Dalbergia sissoo*, *Tectona grandis*, *Acacia catechu* etc. **Birds**: Prunus, Mulberry, Diospyrus, Trema, Vitex, *Broussonetia* spp. etc.

Animals: *Acaica nilotica*, *Prosopis cinerarea*, *Zizyphus spp*., *Anthocephallus spp*., etc.

Gravity: *Quercus spp.*, *Juglans spp.*, *Asculus spp*., etc.

c. Seed Germination

After dispersal, insects, birds and rodents destroy a lot of seeds. The others germinate provided they are deposited on suitable soil. Germination of seeds depends upon several internal and external factors listed below:

i. Internal Factors: Permeability of seed coat to water, permeability to O_2, development of embryo (i.e., *Frixinus floribunda* takes one year), after ripening (i.e., *Juniperus macropoda*), viability of seeds, size of seeds, germination capacity, germination energy. Some seeds

ii. External factors: Moisture, air, temperature, light (i.e., *Cassia fistula* or *Albizzia procera* requires light), seed Bed.

(d) Seedling establishment: Even if germination is good, it does not mean that natural regeneration would be good because a large number of seedlings die at the end of rains or as a result of frost during winter or drought during summer. Establishment is defined as the development of new crop 'naturally or assisted' to a stage when the young regeneration 'natural or artificial' is considered safe from normal adverse influences and no longer needs special protection or tending operation other than cleaning, thinning and pruning. The following factors affect establishment of seedlings:

1. Development of roots
2. Soil conditions – moisture, aeration, nutrients
3. Light
4. Other Climatic Factors- high or low temperature
5. Rainfall
6. Drip (Slash erosion)
7. Condition of grasses and other competing weeds
8. Grazing, browsing and fire
9. Composition of the crop

Natural Regeneration from vegetative parts:

When regeneration obtained from vegetative part, it is called coppice crop and when it develops into a forest, it is called coppice forest to differentiate it from the high forest. Natural regeneration from various vegetative parts of the tree can be obtained either by:

1. **Coppice:**Vegetative reproduction in which the tree, plants or the seedlings of a species when cut near the ground level produce shoots. It is of two types: seedling coppice and stool coppice. *Albizia spp*. *Eucalyptus spp*. *Hardwickia binata*, *Lagerstroemia parviflora*, *Salix spp*., *Morus alba*, *Shorea robusta*, *Tectona grandis*, *Butea monosperma*, *Acacia catechu* are some examples of good coppice tree species. Whereas, *Terminalia tomentosa*, *Madhuca longifolia*, *Pterocarpus marsupium*, *Adina cordifolia*, *Juglans regia* are the examples of bad coppicing trees and most of the

gymnosperm trees like *Cedrus deodara*, *Pinus roxburghii*, *Abies pindrow* etc. are non coppicers.

2. **Root Sucker:** A shoot rising from the root of a woody plant) Vegetative reproduction in which a root of a plant is partially or wholly cut to produce a shoot called root sucker.

3. **Cutting:** Vegetative propagation in which a portion of the stem, branch or root is placed in the soil or other medium, in order that it may develop into a plant. Depending on the part of the plant used, cuttings may be classified into stem cutting, branch cutting, root cutting and root and shoot cutting. Root and shoot cutting is a young plant with pruned taproot and severed stem used for planting.

4. **Layering:** Inducing development of roots on branches while they are still attached to the trees is called layering. Layering may be done in soil or in air and so layering is of two kinds: Air Layering and Soil Layering.

5. **Grafting**: Vegetative propagation in which a portion called scion (unrooted portion of a plant used for grafting), of one plant is applied to stock (rooted plant on which a scion is grafted), usually rooted, which is another plant, with the object of securing vegetative union between the two, when the scion is detached from the parent plant and the shoot of the other plant is severed, to produce a new plant to be planted out. Attempt is made to transport the scions to the grafting place within 24 hours.

6. **Budding**: A vegetative reproduction in which, a bud with some portion of the bark of a genetically superior plant is grafted on an inferior plant so that it can produce shoot when the old shoot of the stock is cut off. Bud is grafted on the stock in the form of a patch after removing the bark of the stock in that portion or by making an incision in the bark of the stock in the form of T and then fixing the scion inside it.

2. Artificial regeneration

The renewal of a forest crop by sowing, planting or other artificial methods is called artificial regeneration. It is also called plantation in another term. It is the supplement of natural regeneration that restocks forests destroyed by fire and other biotic factors. It helps in changing the composition of the forest crop, mostly valuable species are introduced which are indigenous or exotic. Regeneration is important for lands which are at risk of erosion and landslides.

Seed production: A good seed production is the foundation of successful plantation, which needs good seed year and healthy, genetically improved trees or seed orchard. Tree which we are going to mark for seed collection should be free from hybridization and disease. The seed orchard is restricted to stands planted for seed production and composed of trees to be of desirable genotypes from test of their progeny. Seeds are collected from the seed orchard to produce seedlings. Surplus seed should be collected and store for poor seed years.

Seed Extraction: The seeds have to be separated from the fruit before they are sown or stored. The methods of seed extraction vary with the type of fruit. For example, the seeds of pulpy and fleshy fruitsare sown immediately, as in the case of *Artocarpus sp*., *Michelia sp*., etc, Depulping is adopted for the fleshy fruits with very small seeds e.g. *Morus sp*., *Anthocephalus sp.* etc in water, the water containing the pulp and seeds is put in a fine muslin cloth through which the water and the soft pulp can be squeezed out, leaving the seed behind. The dry fruits in which the entire fruit is sown with seed contained in it, like *Tectona grandis*, *Juglans regia*, *Quercus spp*., etc. These seeds do not require any extraction. The seed of Dalbergia sissoo, *Ailanthus spp.* etc do not require extraction. Such seeds require only beating to break the fruit. The usual method of extraction for conifers consists of spreading the ripe fruit in the sun on clean hard floor or in trays until they open up. They can then be shaken or beaten to separate the seeds.

Seed Storage: It is known that most of the species do not seed every year. So, it becomes necessary to collect and store the seeds in good seed years without impairing their quality for use in the poor seed year. The seeds of most species can be stored at low temperature and low moisture content in sealed containers for 3 -10 years. Species whose seeds ripen in winter or summer and germinate in the following rainy season. Such seeds can be stored in dry conditions either in a room or store house depending on quantities of seeds to be stored. Gunny bags or sealed tins or drums can be used to store the seeds in store house.

Artificial regeneration is carried out to fulfill the two objectives

a. Afforestation

Plantation on an area on which no forest vegetation has existed previously from long time.

b. Reforestation

Plantation on an area by artificial means which have previously vegetation and now felled or cleared.

Process of Artificial regeneration

The process of artificial regeneration involves nursery techniques and methods of planting which includes site selection, choice of species and spacing.

Site selection

Site selection for successful plantation is very important. The different factors like soil type, climate, physiognomy and aspect are the important factors that needs to consideration for successfully raising forest crops.

Methods of planting

Advance earthwork and soil conservation work should be done in well advance before planting season. Planting should be done as early as possible in monsoon season by adopting suitable panting method as given below:

Neked root planting: it is adopted in high humid areas and should be done at the beginning of the monsoon. The pit should be deep enough to accommodate the roots of the plant. In this method the soil should be should be compacted firmly by hands or feet. This method can be uses in temperate region plants are dormant at that time. Some tree species can be planted naked root like *Bauhinia variegata*, *Albizia lebbeck*, *Aesculus indica*, *Juglans regia*, *Robinia pseudo-acacia* etc during favorable conditions mostly in rainy season when atmospheric humidity level is very high.

Planting with ball of earth

Those plant species which are not able to resist the exposure of their roots which results long transpiration are planted with intact soil ball. Tree species like *Swietenia mahagoni*, *Michelia champaca*, *Pinus roxburghi i*etc give good results when planted with soil ball.

Stump planting

Stump planting is carried out by making pits or cow bar holes in moist and tarai areas. It should be avoided to adopt in arid areas.This method is used for *Tectona grandis*, *Dalbergia sissoo*, *Gmelina arborea*, *Terminalia spp.*, *Bombex ceiba*etc extensively raised by

Stem cutting planting

Stem cuttings or branch cuttings can be plant directly in field at appropriate spacing o in a nursery. This method is adopted for planting of *Tamarix aphylla*, *Boswellia serrata*, *Populus deltoids*,*Lagerstroemia parviflora* etc.

Planting with plant containers

The plant species which does not resist the sock of transplanting those should be raise in plant containers like earthen pots, leaf pots (dona),bamboo tubes and polythene bags. Generally, a standard thickness of200–250-gauge polythene bags are used in forest nurseriesof India. This method is suitable for most of the plant species for giving high success rate of plantation.

Objectives of Forest Regeneration:

Two major objectives of forest regeneration are a. Afforestations b. Reforestations

Other objective of the Natural and artificial regenerations

1. To assist or supplement of Natural regenerations

2. To change the composition of existing tree species.

3. To develop plantation for domestic and industrial utility.

4. To rehabilitate the barren and wastelands.

5.To develop the agroforestry and farm forestry plantation.

6.To introduce the desire exotics tree species.

Requirement for natural regeneration: Successful natural regeneration can occurs only if sufficient amount of growing space is available for the establishment and growth of seedlings.Except in certain cases,it is easy to ensure that sufficient vacancies have been created by manipulation of main crop by carrying out regeneration fellings, thinning *etc*. Sufficient growing space both in the air and soil is a pre-requisite for regeneration establishment for most of the species.

Regeneration Survey:

Regeneration in forests occurs in the form of recruits, seedlings, saplings and poles. Sapling and poles can be considered as established regenerations.The natural regeneration obtained in the forest under the various systems is generally hidden under herbs and shrubs therefore,its ocular estimate is generally inaccurate. In the absence of 100 per cent enumeration, reasonably accurate assessment of natural regeneration can be obtained regeneration survey. Regeneration survey defined as a survey for the assessment of established and unestablished regeneration generally by sample enumeration.The main objective of this survey is as follows

1. To compare natural regeneration in any regeneration area.

2. To evaluate the effects of operation carried out during working plan period.

3. To prepare stock map of any area.

3.Natural regeneration supplemented by artificial regeneration:

Natural regeneration and artificial regeneration are both methods of forest regeneration, and artificial regeneration can be used to supplement natural regeneration. The most important decision made in artificial regeneration is the selection of the species used in each new stand. The species chosen should be adapted to the site.

General Rules for Tree Planting:

- Choose a site that is appropriate for the particular species you are planting.

- After you have bought your tree plant it within a day or two.
- Dig the hole before removing the tree from its original store wrappings.
- Dig at least twice the width of the root ball or root mass.
- Put the tree in the hole with the 1st main roots (the uppermost roots) of the tree at grade; thus, the root collar (the junction where the uppermost roots join the main stem) of the tree should be level or just above the final ground level after being planted.
- Make sure the tree is straight and plumb (to your satisfaction).
- Backfill the hole with the existing soil on the site; add water every so often while backfilling.
- Gently compact; water after backfilling is completed.

Kinds/ Methods of tree planting:

The following methods of tree planting are generally adopted in India

1. Planting with naked root plants
2. Planting with ball of Earth
3. Brick planting
4. Stump Planting
5. Planting of Cutting
6. Planting of Container plants
7. Tall Planting

1. Planting with naked root plants: In this type of planting, it is necessary to take out the plants from the nursery properly and protect the plant from sun and wind. It should be ensured that naked root plants are planted as soon as possible. Planting of naked root plants is generally done in temperate areas or where humidity is very high.

2. Planting with ball of Earth:

Naked root planting leads to higher mortality in event of a slight exposure to plants. It is better to take out plants along with soil intact on their roots. The plants along with soil are taken out from the nursery bed by plant extractor. Plant extractor consists of a metal sheet 2cm long, 60cm wide and 26 gauge which is put around the centre of plants. This is then locked and forced into the soil to make a ring around the tap root of the plant which is cut by

a blade and the plant is taken out of the extractor. Special care is necessary while transplanting plants with a ball of earth so that the soil remains undisturbed.

3. Brick planting: Brick planting is generally done in arid areas. A mixture of soil, sand, clay and farmyard manure is used for making bricks. Bricks are made by mixing the above mixture with water and preparing them into a thick paste. The bricks are made with the help of wooden frame. The bricks are generally 30cm high and 15 cm square at the top with a cavity of 2.5 cm diameter and 15 cm deep. Sowing or pricking out is done in the hole of earthen brick. In sandy areas and sand dunes, the earthen bricks along with the plant is planted about 10 cm deep below the soil surface.

4. Stump Planting:

Stumps are planted in pits or bar hole. In case of teak, stumps are planted before the onset of the monsoon which gives a good success and it is the most common practice of planting offers advantage in easy handling and transport of planting stock.

5. Planting of Cutting: Cuttings are generally rooted in nursery and planted out. Brach cuttings can also be planted directly in the field. Normal size of cuttings is 20-25cm long and 1 cm in diameter. In dry areas, long cuttings are planted. In case of Poplar the cutting of the entire plant (2-3 m long)is planted in larger holes at a depth of about 75 cm.

6. Planting of Container plants:

Planting of container plants is the most common practice of planting in a large number of species. The most common containers used are the polythene bag of different sizes. The seedlings are raised in the polythens bags. The seedlings are grown in pot either by directly sowing seeds in the pots or by pricking out seedlings in the pots.

7. Tall Planting: Large plants along with root system are excavated and planted in large pits. This is common practise in road side plantations**.**

Pattern of Planting:

1. Line Planting: In this planting, the plants are planted in lines. There is a specific distance between the lines. Plants are planted within line at some definite spacing. This is the most common method of planting. The number of plants per hectare of planting and spacing of plants is calculated as formulas

$$\text{Number of plants/ha} = \frac{1000}{\text{Distance between lines} \times \text{Distance between plants in lines}}$$

$$\text{Spacing}=\sqrt{\frac{10000}{\text{Number of plants / ha} \times \text{Spacing of plants in lines}}}$$

2.Square Planting: Plants are planted in a square pattern(spacing between the lines and spacing between the plants are same).The number of plants per hectare of planting and spacing of plants is calculated as

$$\text{Number of plants/ha}=\frac{10000}{\text{Square of the planting distance}}$$

$$\text{Spacing}=\sqrt{\frac{10000}{\text{Number of Plants/ha}}}$$

3. Triangular Planting: Plants are planted in an equilateral triangular fashion (plants planted on the corners of the equilateral triangle). This number of plants per hectare of planting and spacing of plant is calculated as

$$\text{Number of plants/ha}=\frac{10000 \times 1.115}{\text{Square of the planting distance}}$$

$$\text{Spacing}=\sqrt{\frac{10000 \times 1.155}{\text{Number of plants per /ha}}}$$

4. Quincunx Planting: Quincunx planting is defined as planting in a group of five points, four of which forms the corners of square with the fifth as corner. The number of plants per hectare of planting and spacing of plants is calculated as

$$\text{Number of plants/ha}=\frac{10000 \times 2}{\text{Square of the planting distance}}$$

$$\text{Spacing}=\sqrt{\frac{10000 \times 2}{\text{Number of plants/ha}}}$$

Different kinds of seed sowing:

1. Broadcasting: In these methods seeds are scattered uniformly all over the area which is suitable for small sized or lighter seeds (*eg*.*Ecalyptus* and C*asuarina*)

2. Line sowing: Line with suitable spacing is drawn first. Then seeds are sown at a defined spacing within the lines.

3. Strip Sowing: The sowing of seeds in narrow strips at definite intervals Strips vary in their width (40-150 cm). In this portion, soil is worked well and exposed to sun for certain time, thereafter sowing is done.

4. Patch sowing: Patch sowing is defined as sowing a number of seeds in specially prepared patches. The shape of patches may be square, triangular or circular. These are spaced at definite intervals.

5. Dibbling: In this method seeds are sown into the containers by making a hole to a depth of one centimetre. This is suitable of bigger size seeds.

Carbon sequestration

Carbon sequestration refers to the natural and deliberate processes through which carbon dioxide (CO2) is either removed from the atmosphere or diverted from emission sources and stored in the ocean, terrestrial environments (Plants)and geologic formations.

Carbon cycle in a forest

The carbon cycle in a forest ecosystem is the flow of carbon between the atmosphere and a series of carbon pools.

The main carbon pools in a forest ecosystem are:

1. Live trees:
2. Standing dead trees
3. Understory vegetation: shrubs, bushes, and saplings
4. Coarse woody debris: dead wood on the ground over 7.5 cm in diameter, includes stumps and coarse roots of stumps.
5. Forest floor: organic material on the ground, includes fine woody debris, fallen leaves and twigs, humus, and fine roots.
6. Soil organic carbon: below the forest floor layer, includes fine roots and all organic carbon mixed in with the soil.

Carbon neutrality

Carbon neutrality refers to achieving net zero carbon emissions by balancing a measured amount of carbon released with an equivalent amount sequestered.

Carbon sinks

Carbon sinks are natural or artificial reservoirs that absorb and store carbon through the process of carbon sequestration. Examples of carbon sinks include photosynthesizing plants and plankton, and the ocean.

Carbon sources

Carbon sources are any natural or artificial production site of carbon and/or any chemical compounds composed of carbon, such as carbon dioxide and methane. For example, the

burning of fossil fuels, forest fires, animal respiration, and plant degradation are all sources of carbon.

Tending Operations in Forest Crops:

For establishment of the regeneration and subsequent development of the forest crop up to harvesting, several operations are carried out. These operations are carried out in the forest crop at different stages of growth in order to provide a healthy environment for their development.

These operations are called tending operations includes:

i) Weeding

ii) Cleaning

iii) Thinning

iv) Improvement Felling,

v) Pruning

vi) Climber Cutting

i) Weeding: Weed is an unwanted plant at a particular site. Weeding is therefore, defined as removal of all unwanted plants particularly in seedling stages in the forest**.**

Objective: Toreduce the completion for moisture, nutrients and to provide sufficient growing space for the desired species**.**

Control: Weeds may be controlled by following methods:

a) Mechanical Methods

b) Biological Methods

c) Chemical Methods

ii) Cleaning: Cleaning is carried out in a crop which has not crossed the sapling stage and is defined as the cutting made in order to face the best individuals from undesirable one of the same age which interfere or are likely to interfere with the growth of the desired individuals.

•Methods of cleaning may be mechanical, biological and chemical as described under weeding.

iii) Thinning:

Thinning is defined as a felling made in an immature stand for the purpose of improving the growth and form of the trees that remain, without permanently breaking the canopy. Thinning principles are so formulated that these are applicable only to pure even aged or relatively even, aged crop or even aged groups of the trees in a crop. Thinning principles have been developed on the basis of natural development of the stand. Thus, thinning, takes place naturally in a density stocked forest under the law of Survival of the fittest.

Objectives of Tending Operation

1) To Improve the Hygiene of the Crop: By removing dead, dying and diseased trees, hygiene or health of tree can be maintained well.

2) Salvage of Anticipated Losses of the Merchantable Volume: A large number of trees die of suppression. This amount contributes of about 20 per cent of the merchantable volume. Reduction in number of trees in thinning increases the diameter of the remaining trees.

3) To assure the Best Physical Conditions of Growth: The objective of the thinning is to keep growing stock somewhere within the range. The effect of extreme competition is reflecting by decline in the rate of growth with increasing density in crops which are very dense.

4) To Obtain Desired Crop: Thinning helps to improve the stand structure. It ensures a uniform and proper distribution of trees all over the area. The composition of the crop can also be improved. The less valuable species may be removed in thinning and the important and valuable species may be retained for future.

5) Improvement of Stand Composition, Regeneration and Protection: If an undesirable species is not eliminated during regeneration stage it can be done during thinning to a certain extent. Thinning helps in obtaining suitable seed bearers for obtaining successful regeneration. The dead, drying and diseased trees are removed to afford protection from insect pest, disease and fire because these trees may serve as a source of infection.

6) Improvement in Wood Quality: Thinning may also improve the quality of wood because trees with higher diameter are likely to be of better quality than smaller ones.

7) To Increase Net Yield and Financial out turn from a Stand: Thinning help to obtain returns early. The sale of thinning material helps to reduce investment burden because of early returns from thinning and shortening of rotation.

8) To Help Decomposition of Raw Humus: In temperate forests, thinning increases light and temperature on the forest floor and causes mechanical disturbance which help the decomposition of raw humus and release of nutrients, etc.

iv) Improvements in Felling: Improvement felling has been defined as per removal of less valuable trees in a crop with the interest of better growth of the more valuable individuals, usually applied to a mixed, uneven aged forest. It may include thinning of closely stoked groups along with clearing and general assistance to young growth of valuable individuals.

v) Pruning: Pruning is defined as the elimination of branches in order to obtain trees with clean bole. The elimination of branches by physical and biotic agencies of the environment is called Natural pruning. Removal of branches from the selected portions of the tree by mechanical means is referred as artificial pruning. The process of natural pruning:

i) Killing of branches,

ii) Shedding of dead branches

•The lower branches of trees usually die when crows of the adjacent trees are close to each other. Death in such cases occurs below the point of closer. The shading of branches occurs after the dead branches are attacked by saprophytic fungi, insects, etc. are broken away by winds etc. Natural pruning can be accelerated by manipulation of the density and composition of the crop. The rate of killing of lower branches, their shedding and healing of the branch stub depends on species and their habitat factors..

Artificial pruning results in production of clear boledtrees on shorter rotation than would be required in natural pruning.

•Plantation cannot be raised in closer spacing because it leads to higher investment and therefore artificial pruning, sometimes may be necessary.

vi) Climber Cutting: Climber cutting should be done along with the tending operations as well as while carrying out markings for felling in the forest. Climbers are particularly harmful when the trees are young. In older trees, they constrict the stem and deteriorate the value of wood.

•The climber cutting should be done at the base and one meter above and the piece should be removed in order to ensure that climber has been cut. A more effective method for the control of climber is to dig up tubers during the rains. The climbers should be cut preferably during monsoon.

Silvicultural System

Silvicultural System: Silvicultural System may be defined as a method of silvicultural procedure worked out in accordance with accepted sets of silvicultural principles, by which crops constituting forests are tended, harvested and replaced by new crops of distinctive forms.

As a silvicultural system deals with the removal of a forest crop, its replacement by a new crop of distinctive from and it's tending, it has the following important characteristics:

Characteristics of Silvicultural System:

(i) The pattern of felling to be adopted in harvesting a mature crop to be regenerated.

(ii) The method of regeneration to be adopted

(iii)The tending of the new crop

(iv)The form or character of the crop produced

Thus, a silvicultural system is a specialized tool or technique for achieving the objects of forest management.

Classification:

Silvicultural Systems have been classified in a variety of ways but, in India, the most commonly used classification is based primarily on the mode of regeneration, and this is further classified according to the pattern of felling carried out in the crop. According to mode of regeneration, Silvicultural Systems are classified into following two main categories or groups:-

(I) High Forest Systems

(II) Coppice Systems

I) High forest systems :-

High Forest Systems are those silvicultural systems in which the regeneration is normally of seedling origin, either natural or artificial and where the rotation is generally long.

1. **Systems of concentrated regeneration:**

(a) Clear felling systems

(i) The clear felling systems

(ii)The clear strips systems

(iii)The alternate strip systems

(b) Shelter wood systems

(i)The uniform system

(ii)The Group System

(iii)The Shelter wood strip system

(iv) Wagners blender saumschlag

(v) Eberhards Wedge System

(vi) The strip and Group System

(vii) The Irregular Shelture wood System

2. **Systems of diffused regeneration:** Are those systems in which regeneration fellings are distributed over the whole felling series and the crop is always irregular**.**

(a) The selection system

(b) The group selection system

3. Accessory Systems

(a) Two –storeyed high forest system

(b)High Forest with reserved system

(c) Improvement felling

II) Coppice systems

Coppice Systems are those silvicultural systems in which the crop originates mainly from coppice and where the rotation of the coppice is short. This main group is further differentiated into the following silvicultural systems on the basis of pattem of felling:

1. The Simple Coppice System
2. The Coppice of the Two-rotation System
3. The Shelter wood Coppice System
4. The Coppiced with Standards System
5. The Coppice with Reserves System
6. The Coppice Selection System
7. The Pollard System

1. Systems of concentrated regeneration

(i). The Clear-Felling System

The Clear-felling system is defined as a silvicultural system in which equal or equi-productive areas of mature crop are successively clear-felled in one operation to be regenerated, most frequently, artificially but sometimes naturally also. The area to be clear-felled each year in uniformly productive sites is 1/n of the total area allotted to this system, where n is the number of years in the rotation, and is usually referred to as the annual coupe.

Removal or felling of mature crop:

According to definition, the crop of the coupe should be felled and removed in one operation, but in practice following variations are observed:

(i) Retention of some mature trees as a frost protection measure or as an insurance against failure, though from the point of view of both these objects, their number is very small, Such trees are sometimes also retained to serve as a nurse crop to facilitate establishment of frost tender species.

(ii) Retention of promising groups of saplings and poles to prevent unnecessary sacrifice of immature crop of the desired species.

Crop: Even-aged

Method of regeneration:

1. **Artificial Regeneration:** The artificial regeneration is preferable and widely used in clear felling system over the natural regeneration because of the following reasons:

a) It is the surest and quickest method of improving crop composition which remains under strict control.

b) It facilitates to introduction of fast-growing and high yielding exotics.

c) It completes regeneration operations quick, and therefore results in considerable economy in cost of formation and in better financial return.

d) As seedlings established quicker, the area is to be opened for grazing sooner.

Method of artificial regeneration:

(a)Departmental plantations: In this demarcation, marking, felling, planting, Inspection and care are carried out by the forest departmental personals.

(b) Taungya: Taungya refers to the method of raising forest plantations in combination with field crops. This may be different kinds as listed below:

1. Departmental Taungya 2. Leased 3.Village

2. Natural Regeneration: NR is obtained by the following ways

(a) NR from the seeds stored: In this seed stored in the area give profuse seedlings. Here felling should be done after seed ripening so that regeneration is possible.eg. *Acacia mearnsii*, *Pinus pinater.*

(b) Seed received from outside the forest: In this regeneration is obtained from the seeds which are received from outside the felling area. This is through seed dispersal mechanism by flood water, irrigation water, birds etc. E.g., *Avicenia, Morus indica* , *Acacia nilotica*

(c)N.R. from advanced growth: In case of felling area having many advance growth of the desired species, it may be retained for the next generation. This avoids sacrifice of immature growth. e.g., *Shorea robusta* and *Tectona grandis*.

Advantages:

1. It is the simplest of all high forest systems as.
2. The yield per unit area is more and consequently the cost of felling and extraction is less.
3. Increasing the proportion of more valuable species and introducing fast-growing exotics, timber, of specific quality and processing characteristics, in sufficient quantities in perpetuity.
4. It makes the supervision of all operations, viz., felling, conversion, extraction and regeneration of area, easy.
5. This system does not involve any damage to new crop

6. If properly tended, the even-aged crop produced by this system.
7. The distribution of age classes is very regular, approaching the normal more closely than under any other system.
8. The success or failure of regeneration work is absolutely clear by the end of the second year.

Disadvantages:

1. It is the most artificial of all silvicultural systems
2. As the soil remains exposed till the canopy closes.
3. When first applied, it sacrifices all the immature trees that may still be putting on valuable increment.
4. The devastated appearance of large clear-felled areas, particularly in the hills, makes the system undesirable from the aesthetic point of view also.

(ii) the clear strip system:

The Clear-strip System may be defined as a silvicultural system in which clear-felling is done in the form of strips which progress successively in one direction (usually against the prevailing direction of the wind) across the regeneration area. As the strip felling are made progressively in one direction, it is also known as progressive Clear felling Strip System or, briefly, just as progressive Strip System.

The regeneration area will have to be divided into four cutting sections marked I to IV, and successive strips arranged as shown in the **figure** below:

Wind Direction ⟶

(IV) Cutting Sections				(III)Cutting sections				(II) Cutting sections				(I)Cutting sections			
	10						9	8	7	6	5	4	3	2	1

⟵ Strip progress

Objective:

1. To regenerate the area naturally by seed from the adjoining area.

2. To protect young crop against wind, snow, insect, fungal attack.

Application:*Pinus keysia*—In Assam

Felling Pattern: In this felling strips are separated from un-felled strips of sufficient width. The width may be equal or multiple of the width of the felled strip. If the number years after which felling in successive adjacent area is 3 years, then the felling area is divided in to three cutting section viz., I,II,III.

Strip arrangement: 1. The strip are arranged in such way that successive felling strips fall sequentially.

2. Strips arranged against the direction of wind.

3.Width of the strip is depends upon the dissemination of seed.

Method of regeneration: Regeneration is obtained mostly by natural regeneration is done whenever need arises.

Advantages:

1. There is possibility of natural regeneration through seeds received from adjacent strips.

2. Young regeneration get protection from the matured stems retained from adjacent strips.

3. Weed problem is lesser.

4. Soil is getting protected from the adverse agents.

5.It does not deteriorate the site and maintains the aesthetic beauty of the area.

Disadvantages:

(1) Protection of regeneration is strips are not only difficult but also costly.

(2) For protecting these strips against grazing, much more fencing material will be required.

(iii) The alternate-strip system

The Alternate-strip System may be defined as a silvicultural system in which clear-felling is done in the form of strips, and the clear felled strips.

Pattern of felling: - The width of the felled and un-felled strips varies from place. In India in the clear-felled strip was 12m and 20m while the width of the un-felled strip was 36 m and 80 m, respectively. The alternate un-felled strips not only supply seed for the felled strips but also exercise protective influence on the regeneration of the latter.

Wind Direction ⟶

Clear felled strip	Un felled strips	Clear felled strip	Un felled strips	Clear felled strip	Un felled strips	Clear felled strip	Un felled strips

Strip progress ⟵

Crop obtained: Even aged
Application site:
1.*Shorea robusta* in Dehradun
2.*Abies pindrow*-Kullu
3. *Acacia mollissima*-Tamil Nadu

Advantages:

(i) It supplies seed to the felled strips from two sides.
(ii) Lesser damage to seed bearers form wind.
(iii) It protects the seedlings from frost, cold winds and other adverse factors.

Disadvantages:

(i) It creates a serious problem for the extraction of timber,
(ii) Fire protection is very difficult.
(iii) No protection is difficult one.

(a) Shelter wood systems

As the regeneration is obtained under shelter of the over wood, such systems are called Shelter wood Systems, Shelter wood Systems involve gradual removal of the entire stand in two or more successive felling which extend over a part of the rotation. With the opening up of canopy in the first regeneration felling, natural regeneration starts coming in under the shelter of the remaining over wood. It the regeneration felling is carried out Group System.

(i) The Uniform System

The Uniform System is an abbreviation of the Shelter wood Uniform System, which is defined as a kind of Shelter wood System aiming at concentrated regeneration, in which the canopy is uniformly opened up over the whole area of a compartment to obtain uniform regeneration. It is also called the Shelter wood Compartment System.

Kinds and pattern of fellings:

(I) **Seeding Felling:** - Seeding felling is defined as opening the canopy of a mature stand to provide conditions for securing regeneration from the seed of trees retained for the purpose. This is the first stage of regeneration felling under a Shelter wood System.

Seeding felling keeps two considerations in view,

(i) Selection of trees to be retained, and

(ii) The distance between the trees retained and their position.

(II) Secondary felling:-Carried out between the seeding felling and the final felling under a shelter wood system remove the shelter and admit increasing light to the regenerated crop.

Secondary felling also helps in the manipulation of mixture of species in a young mixed crop.

(III) **Final felling:-**The removal of the last seed or shelter tree after regeneration has been effected under a shelterwood System.

The regeneration interval, which is defined as the interval between the seeding felling and final felling on a particular areaunder one of the shelter wood system.

Methods of Regeneration: Mostly natural or sometimes artificial regeneration.

Tending:

1. Burning of materials obtained from seeding felling.
2. After seedling establishment, weeding and cleaning is done whenever essential.

Crop obtained: Even-aged

Example: 1. Uniform system is chirpine in Kangra, HP.

2. Uniform system for Deodar and kail:It is done in Uttrakhand and its successful.

3. For Sal in Saranda, Bihar and South Raipur, Chattisgrah.

Regeneration period and periodic blocks:

Uniform System, this is not possible as it requires several years to regenerate an area naturally. If the rotation is 120 years and it takes 30 years to regenerate the rotation will be divided into 4 periods.

Allotment of areas to Periodic Blocks:-

(i) Fixed or Permanent

(ii) Floating

$$\text{Area of the F.S.} \times \frac{\text{Rotation period}}{\text{Estimated regeneration period}}$$

Factors affecting length of regeneration period:

(i) Frequency of seed years

(ii) Light requirement

(iii) Other climatic factors

(iv) Soil conditions

(v) Fire

Advantages of the uniform system:

1. The soil is not completely exposed
2. The marking and felling of trees of the over wood are simple in execution.

3. The young crop is protected against adverse climatic factors such as frost, cold winds and insulation *etc.*
4. The system is fairly flexible with the result that is used for regeneration of both light demanders as well as shade bearers.

Disadvantages:

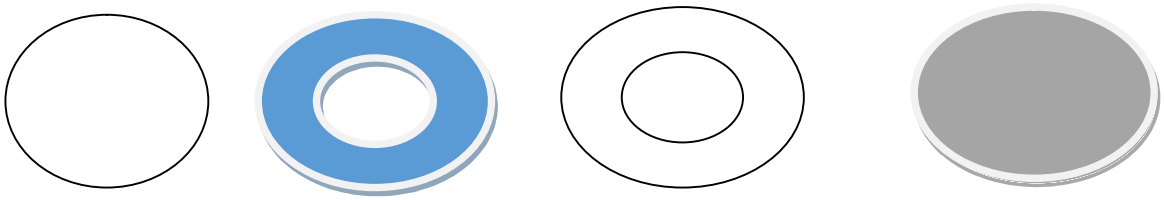
1. Damage is caused to regeneration while carrying out felling.
2. Manipulation of canopy requires more skill.
3. Not applicable where regeneration requires protection against climate.
4. This is not suitable for areas such as frequent windstorm and very steep slopes.

(ii)The group System: It is a silvicultural system in which regeneration felling are carried out in a scattered groups due to the presence of advance growth which induces regeneration de novo. This is also known as **Bavarian femelschlag.**

Application: 1.It was first tried in Chamba (H.P.) for deodar and Pabar (H.P.) for kail but it was not successful.

2. It was again tried in Chakrata (UK) for deodar during 1953 to 1967.

Felling pattern:



Group-I **Group-II** **Group-III** **Group-IV**

1. Group of promising advance growth is identified and located in the compartment.
2. Seeding felling is done all around the periphery. (group-I)
3. If advance growth is inadequate, gaps and created by felling.
4. Gap created will be more for light demanding species and vice-versa.
5. Secondary felling is done when regeneration appears in gaps in the first group.
6. Now seeding felling is done around this (group-II).
7. When regeneration comes up well in this, secondary felling is done in group II.
8. Now final felling is done in the group-I and seeding felling is done in the successive areas (group-III).
9. In this way, the felling proceeded so as to complete the whole forest.(Group-IV)

Tending: Tending operations includes slash disposal, weeding, cleaning and shrub cutting.

Crop obtained: Younger crop is un-even aged, but it become even-aged at the end rotation.

Advantages:

1. Young crop develops in a more natural way.
2. Little danger to seed bearers is being uprooted.
3. Damage from logging and conversion can be decreased.

Disadvantages:

1. Locating groups having advance growth is difficult one.
2. Marking of tree for felling is difficult.
3. Isolated seed bearer a are liable to wind throw.
4. Weeding and cleaning is difficult.

5. Supervision and control is difficult.
6.This system is not applicable to extensive areas.

(iii) The shelter wood strip System: The shelter wood strip system is silvicultural system in which regeneration felling are done in the form of strips arranged successively from one side of the compartment to other usually against the direction of wind. The main objective is to get the protection against the wind.

Wind direction →

			1.Final Felling
		2.Secondary felling	
	3.seeding felling		

← **Strip progress**

Felling pattern:

1. Seeding felling is carried out in narrow strip in one side of the compartment.
2. After regeneration is established in the felled strips, secondary felling is done.
3. Now successive strip is selected where seeding is carried out.
4. When second strip needs more light, secondary felling is carried out in this strip.
5. Now final felling will be carried out in strip I and seeding felling was done in strip III.
6. Width of strip may vary from 20-30 m or more.

Advantages: No any advantages

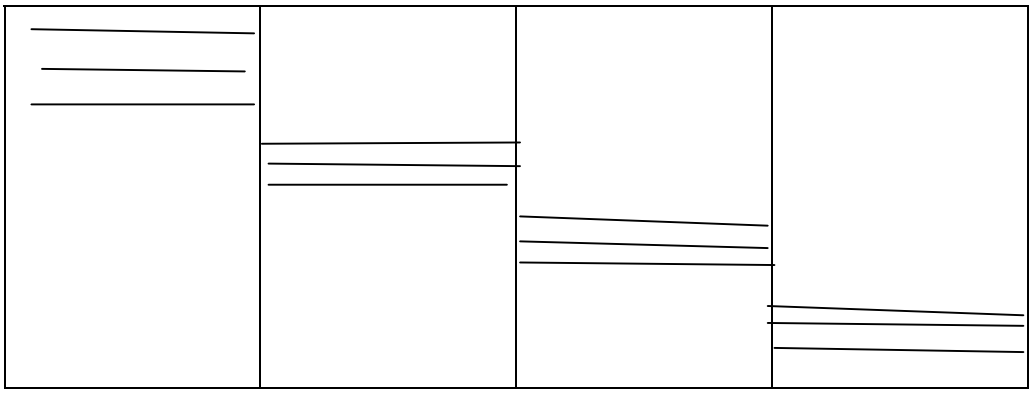
Disadvantages:

1. Laying out of strips is difficult.
2. Execution of felling is cumbersome.
3. Logging and transportation is difficult.
4. Protection against grazing and fire is difficult.

(iv) **Wagners blender saumschlag:** It is a modification ofthe shelter wood strip system and may be defined as a silvicultural system in which regeneration fellings are carried out in narrow strips extending in east –west direction and advanced from of north to south direction. This system was evolved by **Dr. Wagner** Gaildforf, Germany.

Objective: Aligning the strips in this way is to afford side protection to the regeneration from the sun.

Wind direction →



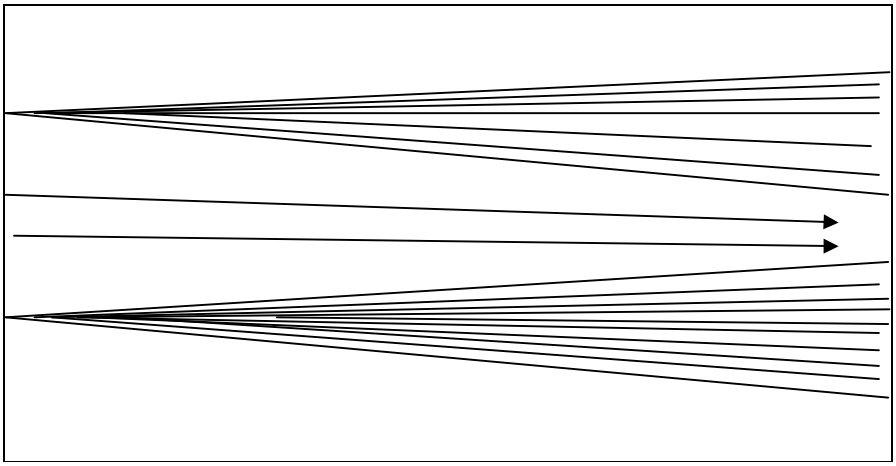
Cutting sections-I, II, III and IV

Pattern of felling: The pattern of felling is not prescribed and it may vary according to the local conditions. First clear felling is done in the northern side. Usually felling carried out from east to west direction. The strip width should be half the height of standing trees. The secondary and final felling is similar to the shelter wood strip systems.

Crop obtained: is even-aged along the east west direction whereas uneven aged crop in the north to south direction. It gives sloping profile to the canopy. As sun lie directly overhead, this system is not applicable under tropical conditions.

(v) **Eberhards Wedge System:** It is a silvicultural system in which the felling strip is located in the middle of the cutting section. The length of cutting section should be along the direction of wind. The strips are 2-5 m wide at a interval of 80 m. First initial seeding felling is made in this strip.

Wind Direction →

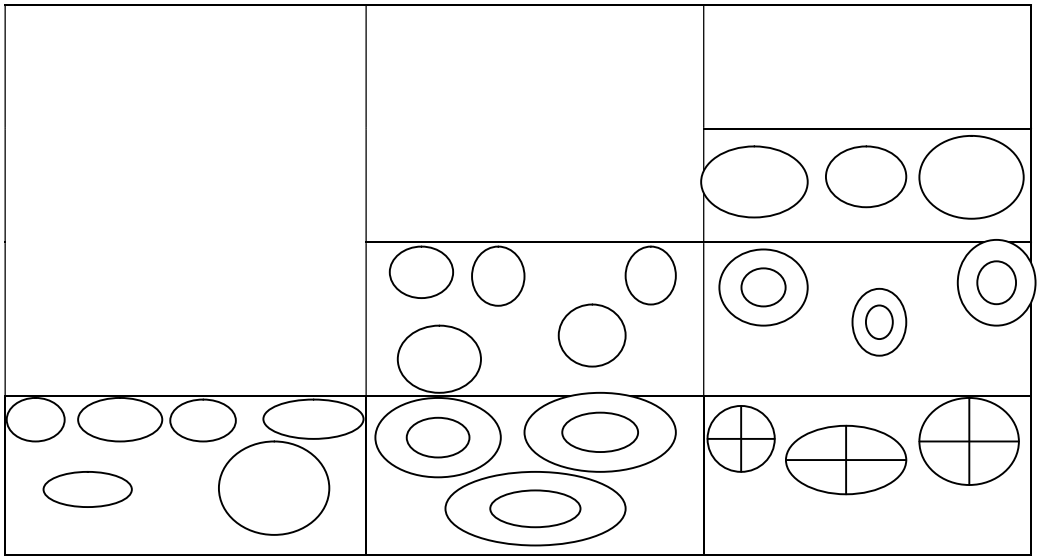


The Wedge Systems

When initial regeneration comes up, it is widened more towards the leeward side and less towards the windward side. This gives a wedge shape to strips. With time progress, base of the strip touches each other as well as one end reaches the top end of the cutting section. Thereafter remaining areas in the strips are felled and regenerated. This system is suitable for wind prone area but the executing of works is more complicated one.

(**vi)The strip and Group System:** It is a silvicultural system in which felling is done in strips conform to the group system. Here first seeding felling is done in an area where growth is presence. When regeneration comes up well, secondary felling carried out in the groups. The direction of progress of strips should be against the direction of wind.

Wind Direction →



(vii) The Irregular Shelter wood System: It is a silvicultural system in which regeneration felling are done in the pattern of group system but the regeneration period is long which resulting in regular crop. This system is applicable to tropical rain forests.

(**viii) Indian Irregular Shelter wood System:** It is in which the crop to be regenerated is opened up irregularly and the resultant crop is uneven-aged.

Crop obtained: Irregular crop.

Application:1. Deodar forest of UK and HP

2.Sal forest of UK and UP.

2. Systems of diffused regeneration:

(a) The selection system

Selection System is defined as a silvicultural system in which fellings and regeneration are distributed over the whole of the area (except in so far as felling cycle introduces a modification) and the resultant crop is so uneven-aged that trees of all ages are found mixed together over every part of the area. The Selection System differs from the systems described so far, mainly in the following respects:

(i) The felling and regeneration in the systems so far described are concentrated, *i.e.,* these are confined to a certain part of the whole area, whereas in Selection System, these are distributed over the whole area.

(ii) The resultant crop in all the systems so far described, except the Irregular Shelter wood System and its Indian counterpart, is even-aged and the constituent age-classes are found in different areas, whereas, in the Selection System it is completely uneven-aged so much so that ail age-classes are mixed together on every unit of area.

(iii) In the systems so far described, the regeneration operations are carried out only during a part of the life of the crop, after which only thinnings are done to improve the growth and form of the remaining trees, whereas in Selection System, regeneration operations are carried out throughout the life of the crop and thinnings are done simultaneously for improving the growth and form of trees.

Pattern of felling:

The Selection System follows nature in respect of its pattern of felling. Thus, scattered single mature trees are selected all over the area and felled to enable regeneration to replace them. As the process is repeated year after year, uneven-aged character of the crop, in which trees of all ages are mixed together in every unit of area, is maintained. This is an ideal

condition but even in nature it is seldom found, it is difficult to find trees of all ages mixed together in every unit of area. The regeneration generally appears in small groups because of periodicity in seed years and these age-classes are found in small groups.

In India, where the areas to be worked under the Selection System are usually very large, it is not possible to go over the entire area annually. Therefore, the area to be worked under Selection System is divided into coupes and fellings confined to one coupe every year. In this arrangement, fellings are done coupe by coupe in a sequence each year and, when fellings are over in all the coupes, these are resumed in the first coupe in the second cycle. Thus, felling is done in a coupe after a certain number of years, which, is equal to the number of coupes. This interval is known as felling cycle, which is defined as the time that elapses between successive main fellings on the same area. The length of the felling cycle affects the silviculture of species, exploitation of forests and the nature of crop produced. The longer the cycle, the smaller will be the area to be worked m a year. This would result in heavier fellings per unit area. If the forest is composed of a mixture of light demander and shade bearing species, heavier fellings would create conditions favorable for the regeneration of light demanders. With heavier fellings, the volume of timber removed per unit area would be more cost of logging and extraction would be less. This would also adversely affect the uneven-aged and stratified structure of the forest. **Simmons** has shown that with a yield assessed at 2 % of the growing stock, a felling cycle of 10 years would result in the removal of approximately 20% of the growing stock in the coupe. This may maintain the selection nature of the forest. But when felling cycle h increased to 30 years, the removal may be approximately 60% of the growing stock and this would be similar to seeding felling and consequently the resultant crop would be even-aged. Thus, with the same intensity of felling, increase in felling cycle creates conditions more and more in to Uniform System and, theoretically, if the felling cycle were equal to rotation.

Conduct of felling - In the Selection System, following categories of trees are usually removed:

(i) Dead,dying, diseased, mis shapen or defective trees interfering with the growth of better trees.

(ii) Trees of undesirable species.

(iii) Immature trees which can be removed in judicious thinning carried out in different age classes so as to maintain or attain, in due course, correct balanced proportion of different age (or size) classes on each unit of area; and

(iv) Mature trees (above the exploitation diameter), which will leave gaps for regeneration to come in.

The above classes of trees are to be removed in such a way that the remaining crop has all age-classes in balanced proportion on every unit of area.

Mode of regeneration

In the Ideal or Periodic Selection System, it is expected that natural regeneration will come up in the gaps created by felling of trees. In case, "however, natural regeneration does not follow, artificial regeneration has to be attempted artificial regeneration under a shelter wood is possible only in case of shade bearing species.

Tending

Weedings and cleanings should be carried out for two or three years to enable the young regeneration to grow up, in addition to the usual cultural operations carried out after a felling.

Character of the crop produced

In the typical selection system, the crop is absolutely un-even aged with all age-classes mixed together on each unit of area.

Advantages of selection system:

(i) The system maintains not only a continuous canopy at the top but also some layers of canopy below it, making full use of the site factors. While the crowns of trees make full use of the environment above the ground,their roots draw sustenance from different layers of soil.

(ii) By maintaining a continuous leaf cover, both horizontally and vertically, the Selection System conserves soil and moisture to the fullest extent possible.

(iii) The selection forest produced by this system is most resistant to injuries by insect pests and adverse climatic factors. It prevents invasion of grass and weeds also.

(iv) Natural regeneration comes up without difficulty due to abundance of seed bearers.

(v) As the lower age-class trees grow below the older trees, the selection System results in producing more growing stock in large-sized trees per unit area than the Uniform System.

(vi) This is the best system for producing large-sized trees. Isolated trees with well-developed crowns and long clean boles, as a result of side shade of the lower trees, maintain high growth percent up to greater age.

(vii)It produces a forest which is superior biologically, as well as in its aesthetic and scenic values, to the forests of Uniform System.

Disadvantages of selection system

The following are the main disadvantages of Selection System:

(i) Considerable skill is required in carrying out marking and felling to ensure regeneration to come up in the gaps.

(ii) As the mature trees to be removed are scattered, cost of logging and extraction is higher.

(iii) As the mature trees stand over the young crop, felling, logging and extraction, howsoever carefully done, results in damage to the young crop.

(iv) This system cannot take advantage of the genetically superior trees alone, as inferior trees also disperse their seed in the same area.

(v) As regeneration is a continuing process all over the area, protection against grazing can be achieved only when the entire area is closed. But as this is not feasible, the area remains open to grazing with consequent damage to regeneration.

(vi) As the area is extensive, strict fire protection is difficult to achieve.

(vii) Success or failure of regeneration is difficult is assess. his often results in wrong judgment about the success of regeneration and consequently, continuance of felling, even when regeneration is not coming up, depletes the stock.

(viii) In a mixed crop with lower percentage of valuable species, when valuable trees are removed, their vacancies are often filled up by regeneration of less valuable species. Thus, the growing stock progressively degenerates with every felling.

Application of the system:

On account of unregulated fellings of the past, extensiveness of area, poor and undeveloped communications, low market demand, poor financial returns, ideal or typical selection system has not been adopted in this country.

The application of this system to some of the important forests is described below:

1. Sal forests

The hill sal and the western light alluvium plains sal forests, e.g. of Kheri division of U.P. and some sal forests of Bastar, Chhatisgrahare worked under a system of selection felling. The chief aim is to obtain maximum sustained yield of timber from trees of exploitable diameter as far as silvicultural conditions permit.

2. Teak forests

Some areas (e.g., parts of Hoshangabad division of M.P. included in Bori Special Teak Working Circle) are still being worked under selection-cum-improvement fellings with girth limit for teak fixed at 1.5m (5 feet). Even where Conversion to Uniform System is being applied, the unallotted periodic blocks are worked under Selection System.

3. Fir and spruce forests

In areas where the topography is rugged and hill slopes very steep to precipitous, selection fellings and thinnings are carried out in fir and spruce forests of the western

Himalayas, e.g. Kulu (H.P.), Chakrata (U.K.), Kamraj, Kashmir and Pir Panjal divisions in Kashmir.

4. Tropical evergreen and semi-evergreen forests

The **All-India Tropical Moist Evergreen Forest Symposium (1960)** recommended that evergreen forests which are located in the catchment of important rivers, where their function is primarily protective, should be worked under Selection System and that the exploitable diameter limit and the yield should be so fixed that no permanent gaps are caused in the upper canopy. **The X Silvicultural Conference, 1961,** endorsed the recommendations of the Symposium for adoption by the states. In addition, it stipulated that 'unless for unavoidable reasons, nothing should be done in evergreen forests that would cause a set back to its ecological status and floristic composition.

Against the back ground of these recommendations, recent trends of work in some of the important states are summarized below:

Assam - The procedure commonly adopted is selection fellingsand tending of natural regeneration,

Kerala. - Evergreen forests in Kerala are managed on the basis of selection fellings of trees of and over the prescribed girth limit (1.8m to 2.4m, varying with species) on a felling cycle of 30 years. Natural regeneration is supplemented by artificial regeneration in strips 3.3m wide spaced 20m apart.

Karnataka. - Silvicultural system adopted is generally the Selection System. in the final removal of the overwood after 60 years.

Maharashtra. – The evergreen and semi-evergreen forests of this state are worked under selection-cum-improvement fellings.Natural regeneration is generally poor or deficient, resulting in a change from evergreen to semi-evergreen.

Tamil Nadu - regeneration have been mainly based on regenerating the gaps created by these fellings by artificial means.

5. Sandalwood forests

Before the spike disease started taking a heavy tall of trees, these forests were worked under Selection System and natural regeneration was abundant. But since the spike disease started causing extensive mortality in Sandal trees, the working of these forests turned to, what is sometimes called, Natural Selection System, in which only trees killed by disease or other natural causes are removed.

(b) The Group Selection System:

It is defined as a Selection System in which trees are felled in small groups and not as scattered single trees of the typical Selection System.

This system is suitable for light demander trees, as their seedlings can come up and establish satisfactorily in comparatively larger gaps created in this system than in the typical Selection System.

Controversy with relevant to group selection system:

1. The quality of timber produced is more knotty and tapering. This reduces the timber quality but expected is good quality timber from the superior trees.
2. Supervision is very difficult.
3. Young crop is damaged during the felling.
4. There is insufficient data to prove the higher growing stock and increment per unit area from the selection system.

3. Accessory systems

The Accessory Systems refers to those high forest systems which originate from other even-aged systems by modification of technique, resulting in an irregular or two-storeyed high forest.

(1) Two-storeyed high forest system

Two-storeyed High Forest System is an accessory silvicultural system which results in the formation of a two-storeyed forest; *i.e.* a crop of trees in which the canopy can be differentiated into two strata in each of which the dominant species is usually different. The crop in each storey is approximately even-aged and is of seedling origin.

(i) **For protection of soil** -When the upper storey is of a strong light demanding species like teak some evergreen species is planted under it to cover the soil. Planting of Evodia, Mesua, Swietenia and bamboo under teak are examples of this object.

(ii) **For increasing the proportion of valuable species in the moist deciduous and semi-evergreen forests -**When the proportion of valuable species in the upper canopy is low, or when the natural regeneration of the valuable species in the upper canopy cannot be assured, some other valuable species is planted under the main crop. This is also called enrichment planting. Planting of teak in the moist Sal forests of .U.P., Hopea in the mixed deciduous forests in Tamil Nadu and Kerala and gurjanin the Gmelina forests of South Bengal are examples of this object.

(iii) **For propagation of species which cannot he raised in the open -** When a valuable species cannot be raised in the open it is planted under the canopy of some other species e.g. planting of mulberry under Shisham.

Advantages:

The Two-storeyed High Forest System may be adopted for any of the following reasons:

(i) To protect soil with the lower storey crop when the upper storey crop is incapable of doing so;

(ii) To increase production by growing two crops on the same area.

(iii)To propagate shade-bearing or frost-tender species this cannot be grown without protection;

(iv) To change the species gradually.

(v) To provide for a vertical mixture in species composition; and

(vi)To obtain early returns.

Disadvantages of the system

(i) Under-planting is a difficult operation and unless done carefully.

(ii) The under-storey is likely to be damaged during thinning or felling in the upper-storey.

(iii) The under-storey crop may affect the growth of the upper storey crop.

Application

1. The working of Oaks found naturally in the mixed coniferous forests in Chakrata (U.K.), and
2. The working of bamboo found in the dry deciduous forests of outer hills in U.K.
3. In Haldwani, Ramnagar and some other divisions of U.K., teak is being introduced in those sal areas where all attempts to obtain natural regeneration of Sal have failed so far.

(2) HIGH FOREST-WITH-RESERVES SYSTEM

High Forest-with-Reserves System is an accessory silvicultural system in which selected trees of the crop being regenerated are retained for part or whole of the second rotation in order to produce large-sized timber. The recent trend of reserving some trees of the old crop in the Clear-felling System described earlier is an example of this system. In the Uniform System some trees are retained at the time of final felling for light increment.

(3) Improvement Felling

Improvement felling is a method of treatment involving the removal of inferior growing stock or trees with the interest of better growth of more valuable species. It is not considered as a silvicultural system because it is not aimed at regeneration of crop. But this aims at bringing a forest in to normal state. Improvement felling carried out in the following ways.

1. Felling of dead, drying and diseased tree.
2. Felling of unsound and over mature tree.
3. Felling of badly shaped mature or immature tree.
4. Thinning of congested groups of poles and trees.
5. Thinning of badly shaped and damaged saplings.
6. Removal of undesirable undergrowth or tree of inferior species.
7. Cutting of climbers.

III) Coppice systems

Coppice Systems are those silvicultural systems in which the crop originates mainly from coppice and where the rotation of the coppice is short. This main group is further differentiated into the following silvicultural systems on the basis of pattern of felling:

1. The Simple Coppice System
2. The Coppice of the Two-rotation System
3. The Shelter wood Coppice System
4. The Coppiced with Standards System
5. The Coppice with Reserves System
6. The Coppice Selection System
7. The Pollard System

1. Simple Coppice System: It is a silvicultural system where regeneration is based on stool coppice and the old crop is clear felled completely without regeneration.

Pattern of felling: Pattern of felling in simple coppice system consists in clear felling of a fixed area annually.

Season for coppicing: The best season for coppicing is spring because during the period huge quantity of available reserve food material will be utilized for the coppice production *i.e.,* from Nov. to March.

Methods of felling:

1. The stump should neither be too low nor too high.

2. Lower the stump better will be the coppicing ability. Lowest stump leads to splitting and drying.

3. Higher the stumps greater will be the possibility of shoots being damaged by wind or animals.

4. Stumps are usually kept at 15-25 cm high above the ground level.

Mode of regeneration: The regeneration is from stool coppice but trees cannot keep on coppicing indefinitely and they progressively lose their coppice vigour at every felling and are filled up by planting container plants.

Tending operation: After main felling cleaning in done to remove the climbers and inferior species interfering with the growth of coppice, and to reduce the number of shoots to two or three. The first thinning is usually carried out in the fifth year and in this the number of shoots is reduced only to one per stool; the operation being known as the singling out operation.

Nature of crop: even-aged crop.

Merit:

1. The system is very simple and does not require any skill.

2. The regeneration is more certain than regeneration from seed.

3. As coppice shoots grow faster, the cost of weeding, cleaning and protection is less.

4. Reduce rotation period as growth is very fast.

5. Net return is more even small sized wood produced.

Demerits:

1. The simple coppice system produces small sized and low price timber.

2. The system tends to exhaust mineral substances rapidly from the soil.

3. Proper supplemented planting is necessary to have full stock.

4. The coppice crop is liable to get damaged by frost and wind.

5. Not a desirable system from aesthetic point of view.

Conditions for applicability of the system:

1. It is suitable for areas where the factors of locality are low and incapable of producing larger-sized timber.

2. It is applicable to areas where demand for fuel, poles and small sized timber is high.

3. It is highly suitable for private lands due to its low investment and quick return.

Application:

1. ***Eucalyptus globules*** inNilgiris of Tamil Nadu are worked under this system on a rotation of 8-12 years.
2. ***Eucalyptus hybrid*** raised in UP**,** Haryana and Punjab for meeting the demand of pulpwood, fuel and poles etc, is worked on a rotation of 5 to 8 years.

2. The coppice of two rotations system

The Coppice of Two Rotations System is a modification of the Simple Coppice System in which at the end of the first rotation of coppice, a few selected poles are left scattered singly over the coupe in the second rotation to attain bigger size. In the second rotation felling, these poles are felled with the coppice but new poles are selected from among the coppice shoots of one rotation age and left for the second rotation.

Objective: The system is to produce large sized timber in addition to the poles of ordinary size.

3. The shelter wood coppice system

The Shelter wood Coppice System is another modification of the Simple Coppice System, **developed by Trevor** for frosty localities. In this system, even in the first clear-felling, some shelter wood (125 to 150 per hectare) is retained for frost protection. The trees selected as frost protection shelter wood are the most promising ones and are retained till the coppice shoots are fully established. The shelter-wood is then removed gradually. For instance, in the case for which **Trevor developed this system**, he prescribed that the standards be reduced from 125 to 150 per hectare to 67 to 75 per hectare when the coppice is 5 years old and completely removed (except where coppice has failed) when the coppice is 10 years old.

This system is applicable in following special circumstances:

(i) where frost is of common occurrence;

(ii) where the locality is good;

(iii) where the species to be worked can coppice upto a longer age;

(iv) where in addition to small-sized timber, there is demand for some large-sized timber also; and

(v) where a rotation longer than ordinary coppice rotation can be adopted

4. The coppice-with-standards system

Is defined as a silvicultural system based on coppice in which an overwood of standards, usually of seedling origin and composed of trees of various ages, is kept over coppice for

periods which may be multiples of coppice rotation and as a permanent feature of the crop throughout its life, Coppice-with-Standards has following two peculiarities which differentiate it from the Simple Coppice.

(i) Constitution of crop.-The crop worked under Coppice-with-Standards System is composed of two distinct parts:

(a) A lower storey consisting of even-aged coppice crop, treated on "principles of simple coppice and usually grown for firewood or poles;

(b) An over-wood consist of scattered trees, preferably of seedling origin and of different age-classes, treated as a high forest on principles of Selection System, usually grown for larger-sized timber.

(ii) Rotation. - Unlike the Simple Coppice System, the C.W.S. has two rotations, one for the coppice and the other for the standards,. The rotation for the standards is a multiple of coppice rotation. The standards are kept in this system with the following objects:

(i) Supply of large-sized timber

(ii) Protection against frost;

(iii) Enrichment of coppice;

(iv) To provide seedling regeneration to maintain vigour of the coppice; and

(v) Increase in revenue.

Pattern of felling:

Under this system, all trees, except the standards are clear-felled. This requires selection of standards before felling. The following considerations govern the selection of standards:

(i) Species. -The standards need not be of the same species as the coppice. In case of mixed forest, these may be of one or more species of the forest. For instance, in sal forests they may be of sal and *Terminalia tomentosa*, and sometimes also of *Albizzia ,Anogeissus latifolia*or any other light-crowned useful species, in mixed deciduous forests, shisham and teak are also good standards.

(ii) Characteristics and quality of standards.-The standards should be of the most valuable species of the crop and should have a long clean bole and attenuated light foliage.

(iii) Number of standards.-The number of standards varies with the object of management, climatic factors and siivicultural characters of the species.

For Indian conditions, **Trevor** has recommended that standards should not occupy more than one third of the canopy. When the rotation of standards exceeds two rotations of coppice, the standards consist of several age-classes. In such a case, the space allotted to the standards is to be properly distributed amongst the various age-classes. For instance, if the space allotted

to standards is 0.3 of the entire canopy and there are three age-classes, each should get 0.1 of the canopy space. This means that the number of standards of lower age-classes will be more than the standards of the older classes.

(iv)Distribution of standards.-The standards should be so selected that they are uniformly distributed over the whole area. The easiest way to do it is to select prescribed number of standards in every 10 m or 20 m squares.

Mode of regeneration-

As in the Simple Coppice System, mode of regeneration is mainly stool coppice but gaps are filled in by artificial regeneration and by allowing the natural seedlings to grow.

Tending

After felling the coupe is cleaned by slash burning.

This provides ideal seed bed for natural regeneration from seed from standards without affecting the coppice.

In the year following the main felling, or the subsequent year, a cleaning is done to cut climbers and useless species. Thinnings in over-wood are often necessary. The first thinning is usually carried out in the 5^{th} year and the second in the 10^{th} year. If necessary, pruning of the stems is also carried out with the first thinning.

Character of crop produced

The crop produced in this system consists of two storeys, viz., (i) under wood, and (ii) over wood. The under wood is even-aged while the over wood is uneven-aged.

Advantages

i. This system affords greater protection to the soil than the Simple Coppice System,
ii. This system allows the standards to grow in isolation and get the benefit of light increment without exposing. The soil which is protected by the coppice.
iii. The standards serve the purpose of seed bearers and provide seedling regeneration. This not only helps the rejuvenation of coppice but also reduces its supplementation by artificial regeneration.
iv. The investment is small as compared with that in most of the high forest systems and the coppice gives early return on the capital. Because of production of large-sized timber along with coppice, the net return is higher than in the Simple Coppice System,
v. This system is aesthetically superior to Simple Coppice System as it does not involve clear-felling.

Disadvantages

The Coppice-with-Standards System has following disadvantages:

(i) The system is difficult to apply in practice. It requires great skill in maintaining correct balance between standards and coppice,

(ii) The Coppice-with-Standards System is a compromise between the Simple Coppice System and the high forest systems with the advantages of none. While the coppice in this system is generally less vigorous than it is in the Simple Coppice System, the standards yield lesser timber per tree, being more branchy and shorter-boled than in the high forest systems.

(iii) This system makes relatively higher demands on fertility of the soil.

(iv) Felling, conversion and extraction costs are higher in this system than in the high forest systems.

Conditions of applicability:

Is applicable under following conditions:

(i) where there is demand for both firewood, poles and large-sized timber; and

(ii) Where climatic factors inhibit the use of Simple Coppice System.

This system is not applicable to irregular dry deciduous mixed forests of this country, which vary considerably in site quality, composition and density because:

(a) the requisite number of uniformly distributed standards of desirable species are not available for retention;

Examples of application

(i) Sal forests- In Pilibhit(U.P.) are worked under C.W.S. on rotations of 30 years for coppice and 60 years for standards. The dry peninsular Sal in Bihar and Orissa are also worked under this system but the recent trend is to replace it by Coppice-with-Reserves system.

(ii) Jamun(*Syzygium cumini*) belts: The jamun belts along streams in Gorakhpur and Gonda divisions in U.P. are worked under this system on rotations of 20 and 30 years for coppice and 40 and 60 years for standards.

(iii) Dry deciduous forests (Type 5B/C_a): This system is applied to dry deciduous forests of Kangra and Una (Himachal Pradesh) on rotations of 30 years for coppice and 90 years for standards.

(iii) ***Anogeissus pendula*** **forests:**The forests of this species in Rajasthan are worked under C.W.S. on rotations of 40 years for coppice and 80 years for standards. But in M. P. such forests are now worked under Coppice-with-Reserves System.

5. The coppice-with-reserves system

The dry deciduous forests with low proportion of teak and Sal which varied greatly in site quality, composition and density from place to place even in the same compartment. Before 1927, these forests were worked under Improvement Felling, As such, these forests were considered suitable for coppice system but the risk was that in poorer sites.

To guard against this danger, from 1927 onwards, a system known as 'Modified Simple Coppice' was applied to these forests, in which clear-felling was to be done only in those parts of the coupe which were expected to restock themselves completely by coppice, supplemented by natural seedlings present in the area, and the rest of the area was to be left untouched or given only light selection and/or improvement felling.

After some time, it was realized that even these modifications did not suit the poor quality teak forests because after clear-felling, teak tended to become pure by suppressing coppice of other species due to its fast growth and eventually deteriorated the soil.

To overcome these difficulties a more elastic system, called 'Coppice-with-Reserves' (C.W.R.) system was evolved and first introduced in 1934-35 in. the working plans of Sagar division (M.P.) by R.N. Datta and Nagpur-Wardha division (Maharashtra) by K.P. Sagreiya. Because it introduced the following new elements to the modified Simple Coppice System of 1927 and its later modifications:

(i) Retention of advance growth and poles of miscellaneous species in areas of poor mixed teak crop to prevent teak from becoming pure,

(ii) Retention of groups of pure teak poles in good sites to avoid unnecessary sacrifice of Immature crop;

(iii) Retention of all crop along nalas and in areas liable to erosion for soil conservation; and

(iv) Retention of trees of local economic importance or those required by industries.

Definition

As a silvicultural system in which felling is done only in suitable areas likely to benefit, after reserving all financially immature growth of principal as well as other valuable miscellaneous species, either singly or in optimally spaced groups, trees yielding products of economic importance and entire crop for protective reasons.

Pattern of felling:

In this system, the emphasis is not on felling but on conservation. Therefore, the first thing to be done is to distinguish areas which require protection or, at the most, some improvement felling, and areas in which felling can be done. Even in areas in which felling can be done, felling does not conform to any predetermined pattern but is carried out according to the

requirements of the crop, local people and the site. Thus felling may vary from clear-felling to practically no felling by reserving all trees. In actual practice, reservation of old crop to form part of the new crop is done in the following ways:

(i) **Reservation by area:**This means that the entire crop of the area is reserved under following conditions:

(a) Under-stocked areas with a density of 0.4 or below where felling is likely to retard the process of rehabilitation by nature.

(b) Eroded areas or areas liable to erosion and strips of land along streams where maintenance of vegetal cover is very essential for soil conservation.

(c) Areas around springs, wells, camping sites and places of worship.

(d) Areas having dense pole crop of teak, sal, *Terminalia tomentosa*, etc.

(e) High quality areas in which the crop is in its optimum condition. In such areas only light improvement felling may be done, if necessary.

(ii) Reservation by species: This refers to reservation of trees of species yielding edible or commercial fruits, important minor forest produce and industrial timber examples of which are given below:

a) Species which yield edible fruits required by local people such as *Madhuca latifolia*, *Buchanania lanzan*, *Diospyros melanoxylon*, *Syzygium cumini*. etc;

b) Species which yield commercial fruit and other important economic minor forest produce such as *Terminalia belerica*, *Terminalia chebula*, *Emblica officinalis,*etc.;

c) Species which yield industrial timbers and are worked under overlapping working circles such as Acacia catechu, *Boswellia serrata*, *Bombax ceiba*, *Sterculia urens*, etc.;

d) Species which are the hosts of lac insects such as *Butea monosperma*, *Ziziphus xylopyra*, *Schleichera oleosaetc.;* and

e) Rare species preservation of which is necessary.

(iii) Reservation by trees: This refers to reservation of individual trees upto a fixed girth class, which is generally between 60 to 75 cm, with the following objects

(a) **Reservation of miscellaneous species for maintaining healthy mixture of species-** In poor mixed teak areas, coppicing results in pure teak crop, partly because the slow growing coppice of miscellaneous species is suppressed and ultimately killed by teak coppice and partly because some of the miscellaneous species do not coppice or coppice indifferently. As soil under pure teak deteriorates, admixture with other species is necessary for maintaining a healthy floristic composition.

(b) All advance growth of valuable species, but not of *Cleistanthus collinus*, up to 24 cm (9 inches) g.b.h. is reserved.

(c) Reservation for completing the stocking and supply of seed: In areas where coppice shoots and advance growth are not likely to be adequate, sound, well-grown poles and trees of teak, *Terminalia tomentosa,Dalbergia latifolia*, *Gmelina arborea*, *Chloroxylon swietenia* and *Ougeinia oojeinensis* are reserved without any limit to the number of trees per hectare.

The rest of the crop is felled. The basic principle which governs marking and felling under this system is the removal of all growth that has become financially mature unless its retention, either individually or in groups or even in large stretches, is required for protection of soil, maintenance of its fertility, for supply of seed, fruit or any other economic forest produce required by the local population, for supply of industrial timber and for meeting the requirements of lac industry.

Mode of regeneration

As the name indicates, regeneration in this system is generally obtained by coppice but advance growth and regeneration from seed, either stored in the area or dispersed by retained trees, also make substantial contribution to it.

Tending

In the year following the main felling, usual subsidiary silvicultural operations, including climber cutting, are carried out. After this a cleaning is carried out when the regeneration is between 5 to 8 years. This includes reduction of coppice shoots to 2 or 3 per stool. When crops are worked on long rotations of 30 or 40 years, thinnings are carried out at mid-rotation ages.

Character of the crop produced

The resultant crop under this system comprises of irregular groups of even-aged coppice with uneven-aged reserved crop scattered irregularly. Thus, taking the crop as a whole, it is uneven-aged.

Advantages:

It helps in improving the quality of locality as a result of soil and moisture conservation, maintenance of crop.

(i) It helps in improving the condition and composition of the crop.

(ii) It fulfills the needs of local population, as well as the requirements of industries.

(iii) If creates suitable conditions for inducement of seedling regeneration of valuable species.

(iv) It avoids the sacrifice of financially immature crop whose value increases steeply with size. Thus it offers best financial returns per unit area.

Disadvantages

(i) Its execution requires a high degree of skill.

(ii) Reservation of a large number of trees affects coppice growth adversely.

Conditions of applicability

i. When the crop varies greatly in density, composition and quality and proportion of the Valuable species is low;

ii. When most, of the species are good coppicers and the coppicing power of the most valuable species is vigorous; and

iii. When valuable species in the crop are light demanders, because otherwise heavier openings may be detrimental to their regeneration.

C.W.R. System is not applicable under the following conditions:

i. When the valuable species are shade bearers and frost tender;

ii. Where there is likelihood of invasion of fast-growing obnoxious weeds, shrubs and grasses, such as Lantana, *Carissa spinarum*, *Petalidium*, *Imperata etc*.

iii. When the crop does not contain valuable species and there is no hope of improving it by coppicing; and

iv. When it is not possible to protect the area against fire and grazing at least for 5 years after main felling.

Examples of application

The system is being used extensively in dry deciduous forests of Madhya Pradesh, and certain forests of Rajasthan, Bihar, U.P. and Maharashtra.

6. Coppice selection system

The Coppice Selection System is defined as a silvicultural system in which fellings are carried out on the principles of Selection System but regeneration is obtained by coppice.

Description

In order to carry out fellings on principles of selection, an exploitable girth or diameter is fixed according to the size of material required and a felling cycle is decided. When the coupe is due for felling under the felling cycle, only stems of and over the exploitable size are removed.

Method of regeneration

The regeneration is obtained by coppice.

Character of the crop produced

The character of the crop produced under this system is uneven-aged.

Application: This system has been applied in the past to Khair (*Acacia catechu*) and *Acacia modesta* in Himachal Pradesh. All trees above a fixed girth limit were felled and regeneration was obtained by coppice.

(7) The pollard system

Pollard is defined as a tree whose stem has been cut off in order to obtain a flush of shoots, usually above the height to which the browsing animals can reach. Thus, the Pollard System consists in pollarding trees periodically to obtain exploitable material.

Application

i. Salix is pollarded in Kashmir valley to produce shoots for wicker work.
ii. *Hardwickia binata*is pollarded in Andhra Pradesh to produce shoots suitable for fibre extraction.
iii. Some species of mixed dry deciduous forests in North Coimbatore (Tamil Nadu) are pollarded to provide fuel of preferred dimensions for boiling jiggery.

Conversion of Silvicultural Systems:

Sometimes, a change from one silvicultural system to another is necessitated and this is usually referred to as conversion. The change may be for any of the following objects:

(i) Change in the mode of regeneration.
(ii) Change in the character of crop without change in mode of regeneration.

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