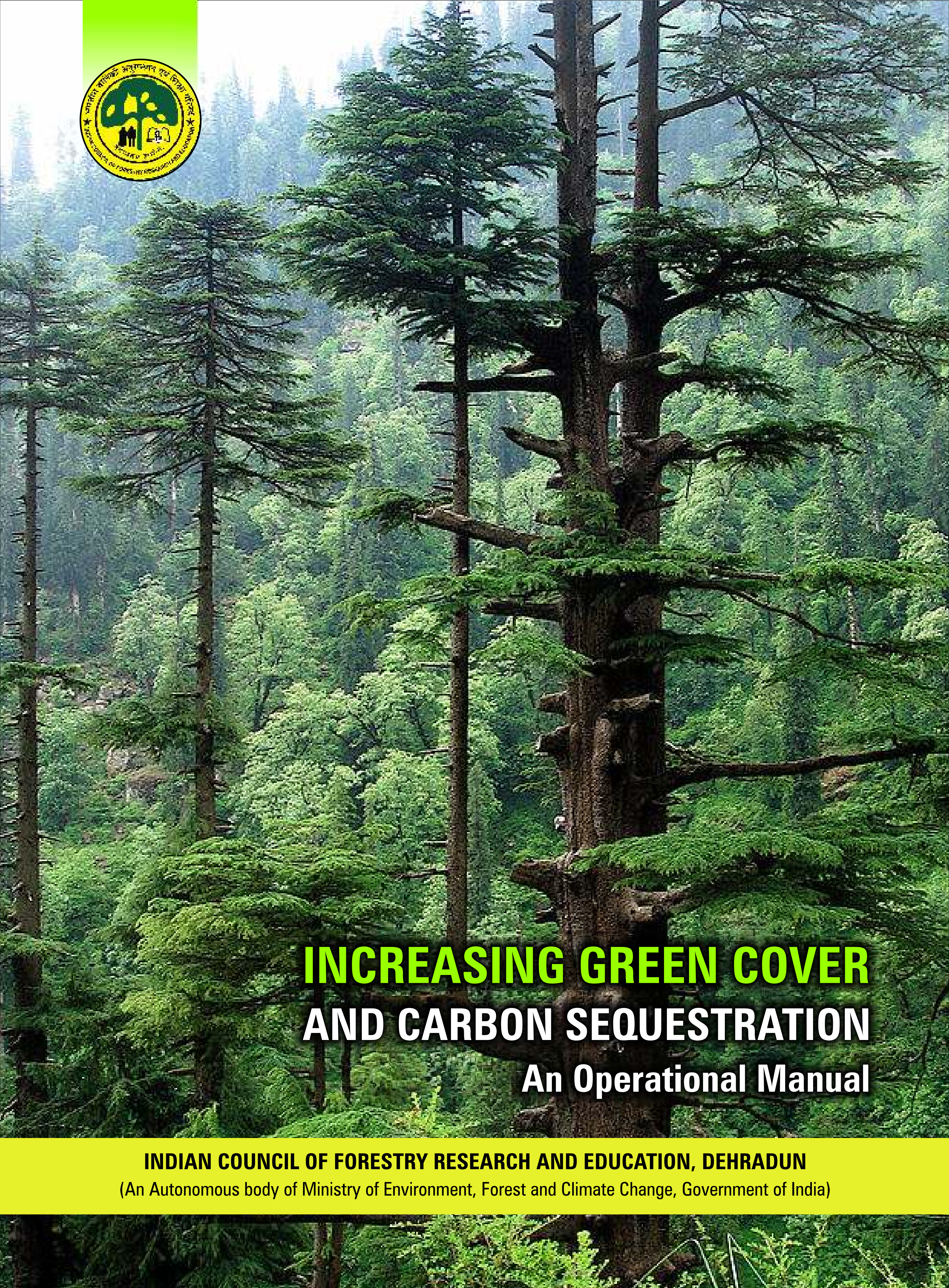

INCREASING GREEN COVER AND CARBON SEQUESTRATION

An Operational Manual

INDIAN COUNCIL OF FORESTRY RESEARCH AND EDUCATION, DEHRADUN

(An Autonomous body of Ministry of Environment, Forest and Climate Change, Government of India)

INCREASING GREEN COVER AND CARBON SEQUESTRATION

AN OPERATIONAL MANUAL

INDIAN COUNCIL OF FORESTRY RESEARCH AND EDUCATION
P.O. New Forest, Dehradun - 248 006

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Foreword

Dr. Suresh Gairola, IFS
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ICFRE with its Headquarters at Dehradun is an apex body in the national forestry research system that promotes and undertakes need based forestry research and extension. The Council that came into being in 1986 has a pan India presence with its 9 Regional Research Institutes and 5 Centers in different bio-geographical regions of the country. Since then research in different fields of forestry has been a major focus of ICFRE.

There is an earnest need to present its research findings to the stakeholders in a simple and lucid manner, to improve the visibility and relevance of ICFRE. Therefore it was decided that the information available on the technologies, processes, protocols and practices developed by ICFRE be published in the form of operational manuals/user manuals. It is also desirable that the manual should be a comprehensive national level document depicting extent of knowledge in applicable form.

Accordingly, 18 scientists of ICFRE were nominated as National Subject Matter Coordinators (NSMCs) to carry out the task on the specified subject. These NSMCs were assigned the task to select and nominate nodal officers from other Institutes of ICFRE as well as other organizations if necessary, collect and collate the information on the subject from various sources in coordination with the nodal officers of ICFRE institutes.

India is not just one of the top 10 countries of the world by forest area, but by virtue of its varied climate and geography, it is one of the 17 mega-biodiversity countries. In today's perspective, when our country is on the path of rapid industrialization and other developmental activities, the pressure on forests is increasing day by day. The gap between deforestation and afforestation can be minimised by increasing green cover either in forests or other land use systems. Reclamation of degraded lands has huge potential for carbon sequestration to counteract the climate change. According to latest ISFR 2019 report, India's green cover is increasing, but this increase is taking place mostly outside the traditional boundaries of the forests.

A huge amount of carbon is naturally stored in the forests by trees, other plants and forest soil. Indian forests stock more than seven thousand million tonnes of carbon with an annual increase of more than 21 million tonnes. Agroforestry also provides a unique opportunity to combine the twin objectives of climate change adaptation and mitigation and has the ability to enhance the resilience of the system for coping with the adverse impacts of climate change.

I am happy to note that detailed methodology has been described in the operation manual to assess carbon in different pools. Different case studies mentioned in the manual will guide calculate carbon stock and annual sequestration in natural forests, plantations and other land use systems.

I congratulate the efforts made by the authors and I am sure that this publication will prove effective to all the people working towards the conservation and sustainable management of native biodiversity in the country.

Dr. Suresh Gairola

Preface

Nearly 25 percent of India's total land area is now under forest and tree cover. However, there is still a long way to go before India reaches its target of having 33 percent of its total area under forest and tree cover. The latest 'India State of Forest Report (ISFR 2019) released by the country's environment minister Shri Prakash Javadekar on December 30, 2019, revealed that the total forest and tree cover of the country is 807,276 sq. km. (which is 24.56 percent of the geographical area of the country) compared to 802,088 sq. km. (24.39 percent) in ISFR 2017. The report marked an increase of 5,188 sq. km. of forest and tree cover combined, at the national level, as compared to the previous assessment. When the last assessment, ISFR 2017, was released, an increase of 8,021 sq. km. was recorded compared to the data in ISFR 2015.

"Forest cover" includes all tree patches which have canopy density more than 10 percent and area of one hectare or more in size, irrespective of their legal status and species composition. The term "Recorded Forest Area" (RFA) is used for lands which have been notified as "forest" under any government Act or rules or recorded as "forest" in the government records. The increasing demand of forests for ecosystem services, carbon sink, fuelwood, fodder, timber and NTPFs is causing stress to increase green cover within and outside forests of the country.

The carbon stock in India's forests for 2019 has been estimated 7,124.6 million tonnes, and there is an increase of 42.6 million tonnes as compared to 2017 assessment, which means the annual carbon sequestration by India's forests is 21.3 million tonnes or 78.1 million tonnes of CO_2 equivalent. Out of five carbon pools, soil organic carbon is the largest pool (56.19 %), followed by AGB (31.67 %), BGB (9.84 %), litter (1.80 %) and dead wood (0.50 %). Moreover, the largest increase has been observed in soil organic carbon, followed by AGB and dead wood.

Indian Council of Forestry Research and Education (ICFRE), Dehradun has taken initiative to publish quality publications to improve the visibility and relevance of the council. This operation manual on "Increasing green cover and carbon sequestration" is one of the manuals in the series, which is a document depicting extent of knowledge in applicable form. This manual has two parts: Increasing green cover and Carbon sequestration. The first part covers methodological approach for seed production areas, plus tree selection, provenance testing, progeny testing, nursery raising of quality planting stock, plantation techniques and maintenance of plantation areas, while the second part of the manual includes terrestrial carbon pools, estimation of forest carbon using volume equations and carbon sequestration in bamboos and agroforestry systems.

I express my gratitude to Dr. S.C. Gairola, Director General, Indian Council of Forestry Research and Education, Dehradun for giving me the opportunity to prepare this manual. I am heartfelt thankful to Dr. G. Rajeshwar Rao, Director, Tropical Forest Research Institute (TFRI), Jabalpur for his valuable guidance and continuous support. Thanks are also due to Dr. Mohit Gera, Dr. A.K. Mandal, Dr. H.S. Ginwal and Dr. Sanjay Singh for their published TFRI bulletins and manuals on various sub-chapters included under Increasing Green Cover section. I have enjoyed the support and guidance from scientists of different institutes of ICFRE and technical staff of Forest Ecology and Climate Change Division, Tropical Forest Research Institute, Jabalpur in preparing this operation manual, for which I am grateful to them.

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INTRODUCTION

Earth is the only known planet in the universe supporting life mainly because it is neither too hot nor too cold but just right for living beings, including human beings. However, a disturbing phenomenon of steady rise in average temperature, known as global warming, has been observed during last few decades causing worldwide concern, as it has the potential to threaten this delicate balance with adverse consequences. Over the last 1500 years, several warming and cooling periods with fluctuations ranging up to 2°C in the average global temperature have happened greatly affecting the people. However, in spite of the swings, the average temperature had always been below the present level. A distinct warming trend was noticed in 1750s lasting until the 1940s when temperature again began to cool. This cooling continued till about mid 1960s and from then the average global temperature has been constantly rising and during the past 50 years, it has increased by more than 0.5°C.

Among the anthropogenic activities, burning of fossil fuels alone adds about 5.4 billion metric tonnes of carbon each year to the atmosphere. Deforestation adds another 1.6 billion metric tonnes of carbon each year. These two activities are primarily responsible for fast increase in CO_2 emission levels. Till the beginning of the industrial revolution, the atmospheric CO_2 concentration remained almost constant at the level of 280 ppm for previous 7 centuries. Thereafter, it has increased rapidly and has now reached more than 406 ppm.

World's forest cover is estimated to be around 4 billion ha covering 31 % of land area. As per the latest State of Forests Report (2017), India has been able to preserve and expand its forest wealth in spite of tremendous anthropogenic pressure. The biennial report stated that in 2017, India's forest cover increased to 7,08,273 sq. km. or 21.5 % of the country's geographical area, as against 7,01,495 sq. km. two years ago. This was the net gain made over two years, as while forests were cut down in some areas, they emerged in others. The tree cover outside forests also increased from 92,572 sq. km. to 93,815 sq. km. during last two years says the report. According to a report on India's forests and REDD+ released by Ministry of Environment and Forests, Govt. of India, Indian forests neutralize 11 % of country's greenhouse gas emissions through carbon sequestration.

India is not just one of the top 10 countries of the world by forest area, but by virtue of its varied climate and geography, it is also one of the 17 mega-biodiversity countries. It is also the second most populated country, where a large number of people still depend on primary sectoral activities for livelihood. Traditionally forests have been treated as open access resources by the society. However, massive deforestation of natural forests is posing a serious threat towards achieving the target of 33 % forest cover. Between 1999 and 2013 India might have lost close to 10.6 million of forest cover. In such situation, it becomes more important to accelerate the task of increase our national green cover. This will also help achieving our nationally committed target of carbon sequestration through forestry sector.

The gap between deforestation and afforestation can be narrowed down and even exceeded through socio-biological rehabilitation by growing multipurpose trees and by adopting new land use systems. Degraded lands are present in various forms i.e. salt affected lands, waterlogged areas, shifting sand dunes in arid and semi-arid regions, degraded hilly areas etc. There are about 130 million hectares of wasteland in India. These wastelands and other degraded lands provide ample opportunity to develop green cover and plantations as renewable source of fuelwood.

Suitable trees and grasses may be grown at degraded sites using optimum management practices to sequester higher amount of carbon in these degraded soils (Vaidya et al., 2017). Reclamation of degraded lands has huge potential for carbon sequestration to counteract the climate change (Purakayastha et al., 2016).

The operation manual is designed for the use of students, progressive farmers, state forest department officials, horticulturists, researchers and scientists working in the field of tree improvement and climate change. The 'Increasing Green Cover' section of the manual will provide in-depth information and technical know-how for selection and raising of quality planting material, plantation techniques and restoration of degraded lands. The other section of the manual covers 'Carbon Sequestration' in different ecosystems.

INCREASING GREEN COVER

Any plantation programme requires good quality planting material for which seed is the basic necessity. The quality of seed and nursery management determines the quality of planting stock. Therefore, it is mandatory to use quality seed from known sources to realize the gains of productivity. Green cover can be increased through raising plantations of suitable tree species on degraded and open forests, barren lands, salt affected sites, waterlogged areas, mine overburden dumps and other types of problem lands, for which following procedures may help in raising quality plantations and their maintenance.

1 SEED PRODUCTION AREAS

Seed Production Areas (SPAs) are areas where, plants of known seed source are grown to produce seeds. This can be done using a horticultural type method or as part of a mixed biodiversity planting. They are important and immediate source of well-adapted and quality seed, which is produced at a moderate cost. It may be a natural stand (natural forest) or forest plantation composed of phenotypically superior trees.

The purpose is to perpetuate quality tree crops as sources of seed for plantation development. In SPAs, the poor phenotypes are rogued from the stand and the good trees are left to intermate and eventually, seeds are collected from them. Further, it is not always the whole stand that is converted into SPAs but only a part of it for various reasons. Seeds used from SPAs provide early genetic gains in productivity.

THINGS TO CONSIDER WHEN DECIDING TO ESTABLISH SPA

- Land or area.
- Time, machinery and equipment.
- Availability at harvesting time.
- Water availability and quality.
- Seed sourced from healthy populations and plants in known localities.
- Species selection and the needs of each species.
- Market and regional needs of species.
- Plant and seed predation from birds, insects and other animals.

SELECTION OF SPECIES AND PLANTING DESIGN FOR SPAs

Any planting design should allow optimal plant growth, easy seed collection and site management while discourage excessive competition between plants or opportunities for weed dominance.

- To maintain genetic diversity and produce high quality seeds, it is suggested to plant more than 100 seedlings per species with seed sourced from at least 20 different widely spaced parents.
- It is advisable to consider the impacts of shading and wind when designing a SPA. For example, larger plants on the edges of SPAs can act as a windbreak and/or minimize internal shading.
- Species/ genera that can easily hybridize should be physically separated or limited to one species per site.
- Sufficient spacing should be maintained between the planting rows to facilitate the tasks such as watering, mowing, pruning and harvesting.
- Native species should be preferred having edaphic and climatic requirements of the plantation site of SPA.
- Pollination in the plants can be assisted by locating site close to natural bush especially from insects. However, care should be taken to check escape of seeds into the bush and hybridize.

SPA SITE ESTABLISHMENT AND MAINTENANCE

- Prior to planting, soil preparation like soil ripping (up to 6 months in advance) and preferably mounding, particularly in waterlogged sites should be carried out, at the prospected site for SPAs. Soil mounds should rise approximately 30 cm above ground level to create boundary for the areas.
- The site should be well fenced to minimize predation damage by rodents, rabbits, insects, birds etc. using a combination of deterrents such as fences, tree guards and bird netting.
- Each block or row should be labelled with species and provenance code using aluminum tags.
- Sufficient inter row spacing should be maintained, depending on plant height, form and site aspect. Plant density, plant type and size of fully-grown plant should be taken into consideration so as to not encounter crowding of the crown during the growth. Proper planting space will maximize space and consolidate management, infrastructure and harvesting.
- Fire lines/firebreaks should be made and low vegetative growth should be maintained to check instances of fire.
- Irrigation checks for regular watering, replacing mulch or weed mats, inspection of irrigation connections, fittings and drippers should be done. Reliable watering system such as dripper hose or micro-drip design can be used for smaller plants
- Mulch or plastic woven weed mat can be laid for effective weed control.
- The site should be inspected periodically for any disease, pest or insect attack or nutrient deficiency.
- Silvicultural operations such as pruning, lopping etc. should be done to limit plant height and encourage large, open crowns to facilitate fruit and seed production.
- Weed control is critical particularly in seed production areas. Weed competition for light, space, water and nutrients will severely limit growth, plant survival and access.
- Mortality replacement can be done for five years to maintain yields.

HARVESTING AND STORING SEEDS IN SPAs

- Plants hold onto seed for different periods. Some species expel seed rapidly, while others such as Eucalyptus tree can hold seed for a lot longer.
- A lot of harvesting occurs during summer break when weather conditions can rapidly ripen seeds.
- Most understorey species fruits can be removed by hand or cut with secateurs.
- Open weave material such as stockings can be placed over the fruit or sheet can be spread below tree to catch seed.
- Seeds should be temporarily stored in porous materials such as paper bags, hessian or stockings. Sealed plastic bags can be used for long term storage as long as the seed is fully dry.
- It is important to treat the seed to avoid insect attack.
- Some seed can cause irritation during harvesting, drying and processing and should be handled by wearing gloves.
- Fruits should be dried in a well ventilated, dry, shady place away from insects and may need to be shaken to release seed from fruit.
- Clean and dry screens and sieves are should be used for cleaning seeds.

2 PLUS TREE SELECTION

Phenotypic selection of superior individuals within a species forms the basic part of the most tree improvement programmes as it makes use of the tree-to-tree variation within a population. These superior (Plus) trees are outstanding individuals with one or more desirable traits occurring in stands (or in plantations), but usually in low frequency and hence, special efforts are needed to locate them. They form the foundation for tree improvement by selection. Whether these plus trees, selected on the basis of external appearance, also possess the capability of transmitting the good traits to the progeny is determined later by conducting appropriate progeny trials.

Various related definitions are given below:

- Candidate tree: A tree which has been selected for grading because of its desirable phenotypic attributes such as superior growth, good form, better wood quality, etc. but has not been compared with other superior trees i.e. check trees for final selection.
- Select, superior or plus tree: A tree that has been compared, selected and recommended for development at production and breeding populations, but has not been tested for its genetic merit.
- Comparison or check tree: Trees against which candidate plus tree is compared is called comparison or check tree. Such trees are located on the same stand, are nearly of same age and are growing on the same or better site as the select or plus tree. These are next best trees compared to the candidate tree.
- Elite tree: A tree that has been found to be genetically superior after progeny testing (genetic testing). Such tree is the most desired one for use in mass production of seeds, vegetative propagules and breeding programmes.

SELECTION OF SUPERIOR TREES

Desirable individuals (first generation selection) are selected from wild populations (natural stands) or unimproved plantations. This forms first generation selection of plus trees from base population. While advanced generation selection is made from populations that are raised from genetic tests.

Selection of superior individuals in first generation selection system is done from two main kinds of forest stands:-

- Even-aged natural stands or plantations raised from unimproved sources where parentage of trees is unknown.
- Uneven-aged stands where parentage is not known. Such stands may include sprouting or intermixed species where cheek trees are not available.

Selection of Superior Trees from Even-Aged Stands

- Careful selection of base population would be helpful to account for phenotypic effects caused due to genes of the individual carries. The individuals in the even-aged natural stands composed of single species show their responses mainly to genes. As a result, the relative expression of growth, form, disease resistance, adaptability, etc. is not confounded with age effects. Trees in such stands are found to grow under conditions similar to those that will be faced when improved planting stock that will be planted in commercial plantations.

- The plantations where the age, spacing and cultural practices are same are the most useful base population for selection of individual trees as the relative expression of trait will not be confounded with age and cultural conditions in view of less or uniform competition. The genetic effects (heritabilities) will be more pronounced. Therefore, plantations are preferable to natural stands for selection of plus trees tor first generation improvement provided plantation of known seed sources are available.
- Search to locate superior trees should be concentrated in stands and plantations that are average to better in growth stem form, pruning ability, bole straightness, branch angle, etc. The probability of locating a good tree is always higher in a good stand than a poor stand.
- Prior to selection, information related to adaptability and other quality of the seed source used to raise the plantations should be obtained. Selection should not be made from plantations raised from seed sources known to be of poor adaptability. Also, plantations and stands in which trees are planned to be selected should be located on the similar sites where plantations from improved seed will be raised. In other words, trees selected from fertile site should not be planted on poor site and vice-versa.
- Tree should be selected which are reproductively matured. Generally, trees which have attended half rotation age are considered for selection. However, care should be taken to avoid over matured trees or trees which have crossed the rotation age. In some species with small rotation like eucalypts and casuarinas, selection can also be equally effective at the age of 2-3 years.
- Selection should not be made from the stands, which have been logged for poles or piling or that have been graded or thinned for above purpose. Selection should also be avoided in stands which are not pure in species composition.
- There is no minimum size of a stand or plantation in which a candidate tree is to be located. However, the stand should be large enough to locate minimum required number of comparison trees in addition to candidate tree. To minimize the possibility of selecting candidate trees that are related by descent, only one select tree should be selected from any small natural stand. Such restriction does not apply in case of plantations.
- At the time of selection, the candidate tree should be reproductively matured. In other words, the tree should be in flowering and fruiting stage. However, in dense stands because of insufficient light many trees show no sign of flowering. But such trees are found to flower in seed orchard conditions.
- Once stands with above noted criteria are found, systematic survey should be made to locate candidate tree with desirable character combinations.

Selection of Superior Trees from Uneven-Aged and Mixed Species Stands

Trees in an uneven-aged stand differ in age and there is tendency for storeyed age class and so their characters of interest cannot be compared. Selections are generally avoided in uneven-aged stands. However, such stands are used in the absence of even-aged stands. Mixed stands trees are found scattered in the whole area and grow under different environments. The selection methods such as regression and base value method are found to be suitable in such cases. The following methods are generally used for selection of phenotypically superior trees under different situations. Careful search is made by competent selection team for locating candidate tree.

Comparison tree method

This method is also known as point grading method. In this method, the candidate tree is compared with at least five check trees for different characters considered for selection and accordingly candidate tree is awarded points for each character. Characters like height, clear bole height, and diameter at breast height are actually measured on candidate and comparison trees, whereas some characters like branching habits, apical dominance, crown formation, pruning ability are subjectively scored in relation to check trees by visual observations. Bole straightness and disease and insect incidence are subjectively scored on candidate tree only.

In this method observations on the characteristics of economic importance are recorded on candidate tree and comparison trees in the Candidate Tree Record Proforma (Appendix I). The comparison trees are the next best trees in the vicinity of candidate trees. In other words, like candidate tree comparison trees must have dominant or codominant characters. The method used for selection of comparison trees is the same as used for candidate tree.

Comparison trees may be found at different distances from the candidate tree. The distances reported for comparison trees are 25 to 50 meters, or within one chain or within a radius of two chain. The important point is that comparison trees should be selected on a site and under an environment similar or better to the candidate tree. In case a candidate tree is located on sloppy land, the comparison trees should also be selected on similar contour.

A few characters like total height, clear bole height, and diameter at breast height, volume and wood specific gravity are measured actually for candidate and comparison trees (objective grading). Bole straightness, disease and insect resistance, pruning ability, flowering and fruiting, crown conformation, etc. are subjectively scored. For evaluation and scoring of candidate trees, appropriate grading sheet should be developed. A generalized guideline is given in Appendix II, which can be modified depending upon species and objective 'of the selection. Candidate trees can also be scored for important quantitative characters on the basis of their per cent superiority over average of check trees. All the records and results of evaluation (scoring) should be carefully recorded on plus tree record form (Appendix III).

No tree should be selected, if it is found to be infested by serious diseases or insects.

For analysis of wood characteristics, 2 mm bark-to-bark increment core should be extracted. A large core of about 8 to 10 mm in diameter should be taken for analysis of tracery elements and fiber length, included for selection.

The comparison tree or grading method described above is suitable for selection of plus tree in timber yielding species. However, depending on differing emphasis for different characteristics in different species, different grading sheets with different weightage should be developed.

Regression Method

This method is used for selection of individuals in uneven aged or mixed species stands. The regression line is prepared by plotting the observations recorded on traits of economic interest against age of the tree.

A regression curve for height or volume can be prepared with 50 trees. Sometimes determining age is difficult, as some species do not depict clear-cut growth rings. Regression lines are prepared for each trait, and for each stand and region.

The position of placement of point on the regression line for candidate tree determines its selection or rejection as plus tree. If the candidate tree falls at some defined distance on the regression line, the tree is selected. When the value of the trait falls below the minimum acceptable level, the tree is rejected.

Base Value Method

Base value method is used in uneven-aged stands for these traits, which are not much affected by the environment including age difference among the trees because of strong genetic control of the characters such as stem straightness, branching habit, disease resistance, wood density, etc. a base value (average value) for such traits is prepared for each stand. The values of candidate trees for different traits are compared and a candidate tree is either selected as plus tree or rejected.

Individual tree method

In this method, selection is evaluated and selected without making any condition. This method is not very effective, as the method does not take care of confounding effect of environment and genes in the development of character. There are three variations of this method

- Total score method: The scores assigned to different characters are added and the total score is used as a guide to select or reject a candidate tree. The tree having highest scores is selected as plus tree.
- Independent culling method: A minimum standard is fixed for each character. The candidate tree is selected as plus tree if it meets minimum fixed standards for each trait, otherwise the candidate tree is rejected.
- Selection indices method: Development of selection indices is difficult and requires detailed knowledge of economic value of the characters in addition to knowledge on the genotypic and phenotypic covariances of the characters. If information on these aspects are available, selection indices can be developed for the selection of plus trees. The component characters are combined together into a score or index. Selection is then applied to the index as it the index is a single character. Index is derived by multiple regression equation. For two characters X and Y, the index will look like $I = Px + WPy$. Where, I is the index by means of which individuals are to be chosen, W is a factor by which phenotypic value of character y is to be multiplied and Px and Py are phenotypic values measured as deviations from population mean. For detailed method any standard book on Quantitative Genetics may be consulted. Though a difficult method, selection of plus tree by this method is very effective as it is based on both genetic information and economic value of a trait. However, use of selection index where economic weights are not properly assigned can lead to erroneous selection of individuals.

METHODS OF SELECTION IN NON-TIMBER SPECIES

The methods described above are equally applicable for selection of plus trees in non-timber species. However, the individual tree method is more applicable as population sizes in most cases are small and individual trees are found scattered.

TRAITS FOR SELECTION

Different traits considered for selection of plus trees vary with the species, utility and economic importance of the traits and objective of the tree improvement programme. Any number of characters can be considered. But it is wise to take only limited number of characters which are most important.

For timber yielding species, both primary (teak, sal, shisam, sissoo, gamhar, pinus sp. etc.) and secondary (*Mitragynaparviflora, Hardwikiabinnata*, haldu, etc.), the characters listed in the Candidate Tree Report Proforma may be considered. In general, the trees should possess the following characters which the forester values: good height growth, good diameter growth, good stem form, long clear bole, cylindrical bole with less of taper, narrow crown, self pruning ability, no forking, free from diseases and insects and high wood specific gravity.

- Successful vegetative propagation method should be developed for the species prior to selection of superior individuals. Total genetic variation can be exploited when such methods are available.
- Care must be taken to find out the genetic worth of the selected individuals immediately for taking a final decision on the selection.
- All efforts must be made to select plus trees carefully as these form the base population of all future tree breeding activities.
- A genetic gain of about 5 per cent is achieved simply by selecting phenotypically superior individuals (plus trees).

APPENDIX- I CANDIDATE TREE RECORD FORM

Organization: ……………………
Species ……………………
Age: ……………………
State: ……………………
Division: ……………………
Range: ……………………

Compartment no.: ....
Location: ....
Plantation/Naturalstand: ....
No. of trees/ha ....
Site quality: ....
Candidate tree no.: ....

S. No.	Particular	Candidate Trees	Comparison (check) Tree					Check Tree Average
			1	2	3	4	5	
1	Total height(m)							
2	Clear bole height (m)							
	(1st live branch or point of cut)							
3	Height at 3rd live branch (m)							
4	Crown diameter (m)							
5	diameter/girth at breast height (cm)							
6	Bole volume (m^3)							
7	Straightness of bole							
	i) Bole (straight/spiral)							
	ii) Bends							
	(iii) Taper (normal/moderate)							
	iv) Flutting/buttress							
	(absent/present)							
8	Crown (narrow/compact)							
9	Branching habits							
	i) Branch angle							
	ii) Branch thickness							
	iii) No. of epicormic branches							
	iv) Remicorn							
	v) Self pruning ability							
10	Forking							
11	Disease/pest (absent/present)							
12	Flowering/Fruiting							

Any special Remarks

Date: Signature

APPENDIX- II

GENERALIZED GUIDELINES FOR EVALUATION OF CANDIDATE PLUS TREE

Candidate trees should be preferably good at all characteristics and possibly at least in two or three important traits. Trees inferior in an important character should not be considered at all. Following traits may be contoured for evaluating candidate plus trees and results of evaluation should be recorded in plus tree recording form.

VIGOUR (25 points possible)

Height and diameter are considered under vigour. Measurement on these characters are actually taken both on candidate and comparison trees. Comparison tree average are hence used to measure the candidate tree.

i) Height (15 points)

Take measurement of candidate tree. Take measurement of check trees, calculate mean or average. Score candidate trees on the basis of this average in the way:

0-4 points for less than average

5-10 points for more than average

11-12 points for more than average but shorter than tallest check tree

13-15 points for taller than tallest check tree

ii) Diameter (10 points)

Diameter or girth at breast height be measured and score can be awarded as follows:

0-2 points for smaller than average

3-5 points for equal to average

6-8 points for between average and largest check tree

9-10 points for more than the largest check tree

BOLE FORMS (20 point possible)

Candidate tree is scored subjectively on the basis of ocular observation with reference to check trees. Maximum pants are given if a tree is perfectly straight and less taper. Appropriate point should be deducted for abnormality main stem form as follows:

Deduct 1- 3 for basal sweep

Deduct 1- 5 for trunk bends, spiral bole

Deduct 1- 5 for trunk curves

Deduct 1- 3 for cross section not circular

Deduct 1- 3 for detectable bole swelling

BRANCHING HABITS (25 point. possible)

i) Branch angle (15 point)

Trees with flat angle are preferred. Angle between the main stem and third branch is measured and points are given:

15 points for branch angle of 80°- 90°

13 points for branch angle of 70°- 80°

10 paints for branch angle of 60°- 70°

06 paints for branch angle of 50°- 60°

02 points for branch angle of 40°- 50°

00 points for branch angle of < 40

ii) Branch thickness (10 points)

Trees with thinner branches are preferred. Trees are visually observed for average branch thickness and subjectively scored as under:

10 points for less than 1/4 of main stem

7-9 points for 1/4 to 1/3 of main stem

4-6 points for 1/3 to 1/2 of main stem

0-3 points for more than 1/2 01 main stem

CROWN (5 points possible)

Trees with well-formed and balanced crown should be selected. Generally, trees with narrow crown are preferred: however, in certain species, wide crown is preferred. Maximum points may be awarded if crown is balanced. 1 to 2 points may be deducted if crown is not balanced due to excessive branch length.

APICAL DOMINANCE (10 points possible)

Measure stem length to the first live branch i.e. clear bore length, recorded as percentage of total height.

10 points for over 70 %

7-9 points for 55 65 %

4-6 points for 40 64 %

1-3 points for 25 39 %

0 points for below 25 %

FORKING (5 points possible)

5 points	for forking above 10 meters from the ground
3-4 points	for forking from 5 ~ 10 meters from the ground
1-2 points	for forking below 5 meters from the ground

HEALTH (10 points possible)

Candidate trees are expected to be healthy and free from disease or insect attack. Points should be deducted for evidence of pest, dead-top, insect boring, rotten knots, etc.

WOOD PROPERTIES (30 points possible)

Candidate trees are expected to have higher specific gravity and longer fiber length than the average for a certain geographic location. Core wood property analysis may be done as described in the main text. Candidate trees are scored as given below.

(The assessment of wood properties is optional as it relates to the end-use objectives of the organization. However, these are important traits for pulpwood and timber production).

i) Specific gravity (20 points)

15-20	points for above average
10-14	points for average
5-9	points for light
0-4	points for very light

ii) Fiber length (10 points)

5-10	points for above average
3-4	points for above
0-2	points for short

APPENDIX- III PLUS TREE RECORD FORM

Species: ………………………………

Candidate tree reference: ………………………………

Plus tree No. ………………………………

Location: ………………………………

Origin of stand: ………………………………

No. of flowering trees contributing pollen within a radius of 20 m.: ………………………………

Distance from nearest selected tree in stand ………………………………

Height: …………… DBH: …………… Age:…………

Crown diameter: ………… Clear bole height:……………

Basis for Selection

S. No.	Characteristic	Point scored
1.	VIGOUR	
i)	Height:	…………………
ii)	Diameter:	…………………
2.	BOLE FORM:	…………………
3.	BRANCHING HABIT	
i)	Branch length:	…………………
ii)	Diameter:	…………………
4.	CROWN:	…………………
5.	APICAL DOMINANCE:	…………………
6.	FORKING:	…………………
7.	HEALTH:	…………………
Sub Total	…………………	
8.	WOOD PROPERTIES	
i)	Specific gravity:	…………………
ii)	Fiber length:	…………………
Grand Total	…………………	

Date:

Evaluated by …………

CATEGORIES OF SELECTED TREES

In adopting this method, selected trees should be categorized as:

(I) Acceptable Seed Tree: A tree which receives 80 – 90 points (before wood property evaluation) or 110 -120 points (after wood property evaluation). This tree is marked (painted with one band). Assign a code number to this tree.

(II) Plus Tree: A tree that receives greater than 90 points (baton wood property evaluation) or 120 (after wood property evaluation). This tree is marked with two bands. Assign a code number to this tree.

(III) Elite Tree: A selected tree that has been progeny tested and proven to have high general combining ability. This tree is marked with three bands.

3 PROVENANCE TESTING

Increasing demand of human population and livestock on dwindling forest resources has jeopardized forest productivity. The Continuous destruction of forest on one hand and increase of human population and industrial development on the other have resulted in widening the gap between demand and supply and consequent Increase in pressure on forests. It has also resulted in serious ecological imbalance and increased environmental pollution. The threat of firewood famine and fast deteriorating environment can only be met by increasing land under forest and that too with improved planting material.

In the face of high rate of deterioration, coupled with increasing forest degradation, the country has embarked on large scale afforestation/reforestation programmes in the past few decades. However, the results have shown that they have been less than optimal due to site conditions, vagaries of weather, lack of after-care and inadequate management. Apart from these reasons, poor seed source/provenance selection and inappropriate choice of species seem to contribute a major part. Tree species generally have wide range of geographical distribution and it has been well recognized that seed from different geographical origins can result in substantial differences in growth, form and health of resulting plantation.

Provenance trials are conducted to use naturally and artificially available variations at different population and genetic levels to select individuals having combinations of genes that express in the phenotype, the qualities most desired (Subramanian, 1994). In general, these trials are established to determine the best populations for commercial planting by examining the extent and pattern of variation between and within species in survival, productivity or the trait of interest.

WHAT IS A PROVENANCE?

It is the geographical area and environment in which parent trees grow and within which their genetic constitution has been developed through artificial and or natural selection: in simple words it is the original geographical area from which seed or other propagules were obtained (Burley, 1973).

Example: If the seeds of *Dalbergia sissoo* were obtained from its natural zone, says Haldwani (U.K.) and grown in Jabalpur (M.P.), they would be classified as the Haldwani provenance or geographical source. If seed from the same trees grown in Jabalpur were harvested and planted in Coimbatore (T.N), they would be referred as the Jabalpur seed source and Haldwani provenance.

It is important to note that a provenance which was the original source of seed for an artificial stand is important in determining performance and genetic characteristics of the seed it produces. Two neighboring artificial stands will produce quite different seeds if they are derived from two widely differing natural provenances. Therefore, it would be misleading to describe them as the same artificial provenance.

WHAT IS PROVENANCE TEST?

A provenance test is an experiment in which seeds are collected from a number of widely scattered stands from their natural range of distribution and the seedlings are grown at test sites under similar conditions. It is conducted to screen the naturally available genetic variation and to choose best performing provenances for the desired traits for afforestation programmes or further breeding work. It is assumed that natural provenances have each been subject to selection from their particular set of local environmental conditions and so will often differ in performance when grown at a test site.

NEED FOR PROVENANCE TESTING

The role of production forestry is becoming increasingly important in meeting the ever-increasing demand for forest products. Establishment and maintenance of plantations requires huge investment. It costs as much to establish a plantation with genetically poor seed as with a more suitable provenance. The essentiality of provenance test can be summarized in following points:

- A 25 % improvement in yield per hectare by using more suitable genetic material identified through trials can be easily obtained. Such an improvement is equivalent to establishing 25 % more plantation area at no additional cost (Carter, 1987).
- Going for large scale afforestation projects without assessing the suitability of a species or a provenance within the species has often resulted into costly failures.
- Provenance trials also provide some of the basic information on which policies concerning afforestation are made and there are obvious advantages if such trials are initiated well in advance when large investment decisions have to be taken.
- The most successful tree improvement programmes are those in which the suitable seed sources and provenances are used.
- Use of suitable provenance is the key to having successful plantation programmes with exotics. Provenance differences that exist within the natural range of a species often become more evident when it is grown as an exotic. This facilitates the selection and introduction of exotic to a new environment for enhanced productivity.

Identification of the best suited provenance is therefore an effective way of improving the economic viability of forest plantations and future tree improvement strategy. However, it is often neglected.

PRINCIPLE OF PROVENANCE TESTING

When a species or provenance is planted in an exotic environment, it rarely adapts fully to the new environment. As individuals of the exotic grow in the new environment, the best adapted will survive and perform the best. When the best trees are selected from the best selected population for use as source of propagules for planting or the next generation, either through seed or vegetative propagation, the performance of the new crop will be moderately to greatly better than local land race or population/ seed source and the original stand from which the trees chosen. The basic principle is that the genetically improved population/ material which is initially available in small quantities in localized area is identified after evaluation and testing in a particular environment and mass produced for further planting to benefit from the genetic gain achieved through selection.

PROVENANCE RESEARCH IN TREE IMPROVEMENT

Tree species like other biological organisms exhibit wide degree of phenotypic variation which results from their genetic constitution, the environment in which they grow as well as the interaction between these two factors. Most widespread species therefore appear to be composed of geographical clines or moderately distinct ecotypes. In order to develop an effective tree improvement strategy, it is essential to recognize this variability, isolate it, package it in a desired tree and multiply it. Variability may be among the species or among the population of a species and among the individuals of a population. Therefore, initiation of all tree improvement programmes relies on:

- Determination of the species or geographical source within a species.
- Amount and cause of variability within the species.

The provenance tests are conducted to reveal such intraspecific variation in plant species in relation to environment and are fundamental components of tree breeding programmes which aim to mass produce genetically improved planting material. Selection of the provenances after proper testing offers large, rapid and easily available genetic gains. It is a waste of time and resources to use advanced breeding methods on breeding populations of inferior provenances.

OBJECTIVES

Provenance trials should be conducted according to written plans based on the priorities and objectives of the long-term tree improvement strategies. The plan should clearly state the precise objectives of the particular provenance test. A lot of information can be generated from the provenance trials; however, priority should be fixed for few traits which are more important.

For example, in case of provenance trial of *Dalbergia sissoo*, a timber species, the main consideration will be for stem straightness, clear bole length, wood quality, adaptability and growth. Similarly, in case of *Acacia nilotica*, the objectives should be maximum productivity, fodder value, calorific value and drought resistance. The scope of genetic improvement on the basis of desired traits should be kept in mind while fixing the objectives.

PHASES IN PROVENANCE TRIAL

Range wide Provenance phase

The main objective of this phase is to determine the extent and pattern of variation among the provenances with wide natural distribution. Ten to thirty provenances are suggested at this stage. It indicates groups of promising provenances and also areas from which large-scale seed import should be avoided. Trials are adequate for duration of 0.25 to 0.5 rotation age.

Restricted Provenance phase

The main objective of this phase is to find sub-regions and ultimately provenances most suited to the sites under test. The differences detected between provenances may be relatively small and experimental design must take this into account. Generally, 3-5 provenances may be expected with duration in excess of 0.5 rotations.

Provenance proving phase

At this stage one or two provenance are selected for each species.

PROVENANCE SELECTION FOR COLLECTION AND TESTING

When detailed provenance tests are planned for intensive evaluation of a species, always one local land race or seed source (or other seed source currently used in) is included. Without such standards for comparison, it is difficult to relate trial results to those obtained from current practice.

Beware of simply collecting / accepting all provenances, collectable in the field or available from an agency. It is desirable that geographical locations of available provenances are plotted on a large-scale map, and provenances are selected on some rational basis. This should take into account the number that can be easily handled in the testing programme and commonsense predictions about the performance of provenances.

For a wide range species, it is not necessary to test all provenances from across the entire range in a particular target environment. Climatic data and computer based climatic matching programmes (Booth and Pryor. 1991) can assist in selection of species and provenances most likely to succeed in the target environment.

SEED PROCUREMENT

For all stages of provenance trials, seed is a critical factor and should be of authenticated origin.

Planning Seed Procurement

Planning of seed collection for provenance research should start several years in advance, owing to possible occurrence of poor seed year and need to collect for one or two years in order to cover the entire range. Even when seed is obtained through organizations like FAO, DANIDA, CSIRO it is essential to make the request at least a year and preferably two years before the seed is to be sown.

Survey of Information and Area for Collection

Before undertaking survey, literature should be scanned to get the information on the natural range of the species and pattern of its distribution. Time of flowering and fruiting in different parts of the range should be recorded. Much of the necessary detailed information may only be available through personal contact with local officials.

Time of Seed Collection

It is preferable to collect seeds in a single year from all possible sources. Fruit maturity assessment should be made a few months before harvest by reliable and experienced observers. Seeds should only be collected from the ripened fruits. Since fruit maturity time is very narrow for a species, it may not be possible for one team to collect the seeds from all selected zones of its distribution. In order to facilitate seed collection several teams may have to be formed in advance so that two-three sources can be collected by each team. Teams should have clear picture of location and time of fruit ripening. It is desirable that the teams visit their areas well in advance and select the points from where collection is to be made. The essential labor force in each team is normally two to three climbers and sufficient labors to clear vegetation, collect the fruits, carry the collection material and equipments.

Selection of Stands and Trees

Stand : For a first range wide provenance test, at least five or six collection sites will be needed to sample the limits as well as the center of geographical range. Having decided the approximate location of the collection sites, the actual stands must be determined. The stand selected should be representative of that part of the species and range, and should be sufficiently large and well stocked.

Trees : For seed source trials and even more for gene conservation, it is desirable to capture all possible genetic variation within the population. It is best to collect from relatively large number of trees of each site, avoiding immediate neighbors. Callaham (1964) has suggested 5-10 individuals in homogenous populations and 25-30 trees in heterogeneous populations. It is preferable to collect from not less than 25-30 trees. Selection of seed trees should be done randomly ensuring equal representation of all classes of trees in the sample. It is desirable to collect from dominant and co-dominant. Exceptionally straight and well-formed trees separated by at least 100 meters. The following points should to be taken into consideration while collection.

- Do not collect seed from isolated trees.
- Collect seed from well-spaced trees.
- Do not collect from plantations
- In order to establish a provenance / progeny trial, seed collection should be retained as separate individual tree-seedlots.
- Collect equal quantity of good seeds from each selected tree for making a composite sample of one population.

Technique of Collection

Seed is collected from standing trees, usually with the help of a long bamboo stick with sickle attached to it. However, seed of some species can be safely collected after it falls to the ground without serious risk of damage.

Field Records

In order to ensure that site can be located exactly in later years for interpretation of results, the important information required to be collected along with seed collection is, name of territorial division (country, department, district. division, range. forest stand etc.), name of natural geographical features (mountain, rivers), name of town and village, latitude, longitude, mean annual rainfall, vegetation characteristics of the site, number of trees included in the collection, characteristics of the trees (branching, straightness, crown characteristics etc.), soil characteristics of the site and state of maturity of the fruits.

NURSERY STAGE IN TRIAL

The nursery stage of provenance testing should fulfill three main functions:

- Raising seedlings for field.
- Evaluation of juvenile genetic differences.
- Evaluation of juvenile/mature correlations.

Location of Nursery

Nursery conditions and treatments should be uniform as far as possible. Nursery site should not vary much in light, drainage and aspect.

Experimental Design in Nurseries

It is desirable to use replicated, randomized design to assess the amount of differences which arise from nursery practice. It is further desirable that similar experimental designs are used in the field. In order to avoid the edge effect in nursery beds, the edge plants should be ignored or used as surround of blocks.

Nursery Practice

- Seedlots should be divided into replications and sown one replication at a time.
- Provenances must be separated by bricks or separator board if sowing is done in a bed.
- Pregermination, i.e. in moist sand, vermiculite of blotting paper may be useful for ensuring rapid and uniform germination.
- Germinated plants should be pricked out, in polythene bags arranged in appropriate design.
- Very poor or deformed plants should be discarded.
- Introduction of mycorrhizae should preferably be done uniformly in all the plants.
- Penetration of roots from polythene bags should be checked by spreading polythene sheet below them and their frequent shifting.
- Nursery inputs like, irrigation, fertilization shade etc., should be uniformly provided to all the plants.
- Insect/disease attack should be checked by periodic spray of insecticides and fungicides.

EXPERIMENTAL DESIGNS

The primary objective of an experimental design for provenance trial is to ensure precise and accurate estimates of differences between populations, between distinct environments and, where appropriate, between silvicultural or other superimposed treatments. Experimental design should be simple in execution and analysis. One among the simple and efficient design is randomized complete block (RCB) which provides high degree of information. Some of the designs used in provenance research are being discussed.

Randomized Complete Block Design (RCBD)

This is a commonly used design in forestry experimentation. The experimental site is divided into a number of blocks of equal area and each population is represented once in each block. Thus, each block, which should be uniform as far as possible, contains a complete replication of the populations to be compared. The provenances are allotted at random td the plots within each block.

Sequence

- Determine number of provenances (say 4).
- Determine number of replications/block (say 4).
- Determine total number of plots to be laid (replication x provenances i.e. 4 x 4 = 16)
- Allocate the provenances at random to plots within each block.
- Separate randomization should be made for each block.
- Demarcate the plots in field or nursery.

A possible design for 4 provenances and 4 replications is given in Fig. 3.1.

Advantages of RCBD

- It is suitable for a very wide variety of experimental situations.
- Analysis is simple
- It is statistically robust

The RCB design is less suitable where there is large number of provenances to be compared.

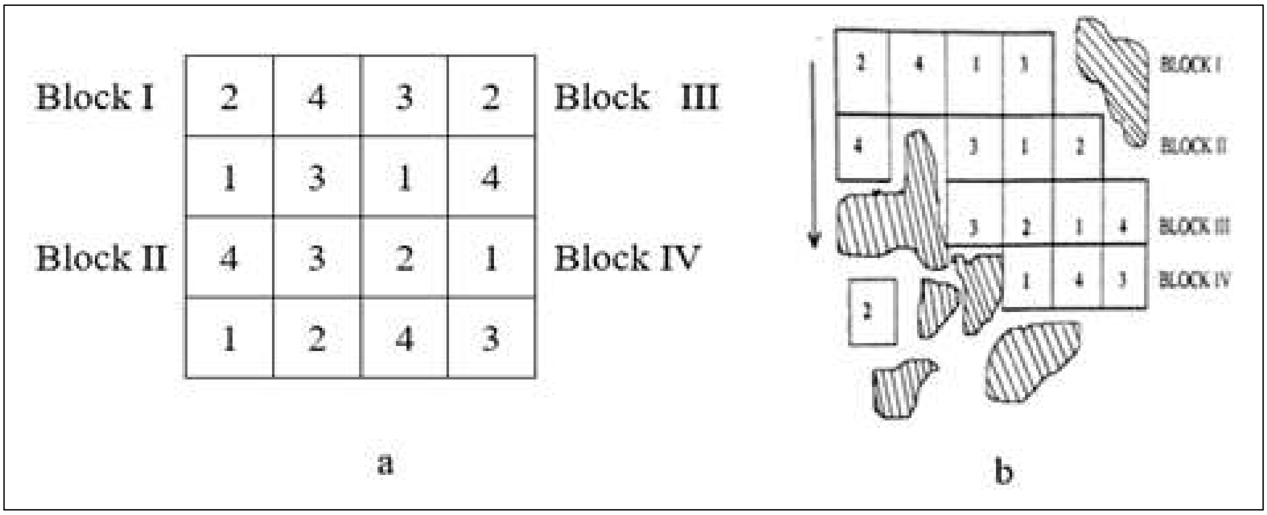


Fig 3.1. Possible RCB designs (a and b) or 4 provenances with 4 replications (Shaded area is unsuitable).

Incomplete Block Design

If the number of provenances to be compared exceeds 15 or 20 and if there are 25-36 or more trees per plot, it is difficult to find a site with sufficient uniformity to accommodate all replications. Incomplete block design has the general feature that the experimental plots are grouped into blocks of less than the total number of populations. In addition, each block has same number of plots and each provenance should occur same number of times in all. An example of incomplete block design is lattice design.

Lattice Design

The number of treatments in a lattice design should be same as the square (4 x 4 = 16, 5 x 5 = 25 etc.) or the product, according to the formula: K (K+1) (3 x 4 = 12, 4 x 5 = 20 etc.). These two types are called square lattice design and rectangular lattice design respectively. In each case K plots (3.4.5 etc.) are arranged within each block and K square or (K +1) (rectangular) blocks within each replication. A complete balanced square design will require K+1 repetition

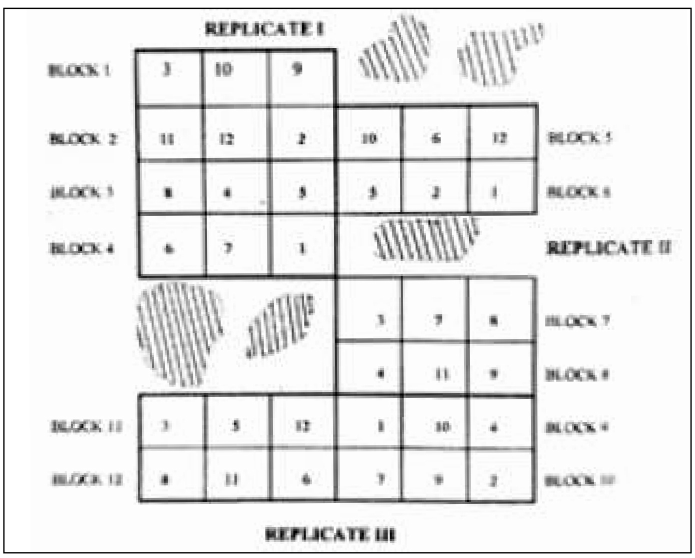


Fig 3.2. Possible layout of three replicates of a 3x4 rectangular lattice design

Sequence

- Unrandomized plans for all the important lattices are given in Cochran and Cox

(1957) and Fisher and Yates (1963). Use a formal design and choose at random the number of replicates desired in the trial.

- Randomize the order (sequence) of the replicates.
- Randomize the order of incomplete blocks within the replicates.
- Randomize the plots within each block.
- Assign the populations at random to the treatment numbers in plan.

The series of randomization described above should be carried out using a table of random numbers and permutations. A possible field layout of three replicates of 3 x 4 rectangular latticesis illustrated in Fig. 3.2. Some ready to use lattice designs suitable for 12, l6, 20 and 25 provenances have been given in Appendix IV.

Fully Randomized Design

This is the simplest type of experimental design. Individual plots of each provenance are arranged completely at random without making blocks. The provenances need not be equally replicated i.e. there could be five plots of one provenance, three of another, four of a third and so on.

Latin Square Design

Latin square design enables estimation of systematic environmental variation in two directions. The plots are arranged in rows and columns. Each population occurs once in each row and once in each column and the number of replicates of each provenance is equal to the number of rows or columns. This design is useful for moderate number of provenances in green house experiments. A Latin square design for 5 populations is given in Fig.3.3.

		COLUMN				
		1	2	3	4	5
	1	A	C	B	E	D
	2	B	D	A	C	E
ROW	3	C	A	E	D	B
	4	D	E	C	B	A
	5	E	B	D	A	C

Fig 3.3. Alatin square design for five populations

Sequence

- One of the formal designs by Fisher and Yates (1963) is chosen at random.
- The column is arranged at random.
- The treatments are designated at random by letters, A, B, C, etc. in the formal plan.

Family Block Design

If the populations divide naturally into number of groups, it may be useful to keep the groups together in blocks within each replication. The group may be separate species or distinct varieties with several provenances of each. The number of provenances needs not to be constant.

Replicate I

B1	A2	C2
B3	A4	C1
B4	A3	C4
B2	A1	C3

Replicate II

C3	B4	A3
C1	B2	A2
C4	B3	A1
C2	B1	A4

Fig 3.4. A family block design for four provenances (1 to 4) of each of three species (A to C). For illustration only two replicates are shown

The resulting design is analogous to a split plot layout with groups corresponding to main plots and provenances to sub plots.

In designing, the groups are assigned at random within each replication and then the individual populations are assigned randomly within each group. A possible layout for four provenances of each of three species is shown in Fig. 3.4.

LOCATION OF THE TRIAL

Provenance trials are planted on several sites. The range of experimental sites may include very widely different environmental conditions and it is likely that the relative performance of the populations tested will vary from site to site. Environmental effects are measured by the average response of all populations at each site or by a control population or they may be expressed as functions of site conditions such as rainfall, temperature, and soil quality.

In order to see the genotype environment interaction, it is always desirable to establish the trials at more than one location. While selecting the location, care should be taken that all the climatic zones are represented for which the results will be applicable. In general, the locations should not be less than three.

SELECTION OF SITE AND DEMARCATION

The sites chosen for trial should cover the extremes likely to be encountered in the future i.e. they should include differences in exposure, frost hollows, aspects, soil moisture etc. The following site data should be collected on priority.

- Rainfall
- Daily maximum and minimum temperature
- Relative humidity
- Evaporation
- Wind speed
- Rainfall reliability
- Soil characteristics after digging a soil profile

- Topography and location
- Biotic factors

Demarcation and in particular internal demarcation is important. Plots and blocks should be marked permanently. The experiment should be mapped in detail, with all the replications and plots marked and copies of this map should be kept in all related files.

PLOT SIZE AND SHAPE

The size of plot depends on the duration of the trial and the expected growth rate of the trees. Plots are usually square or rectangular, but may be elongate to fit certain site configuration.

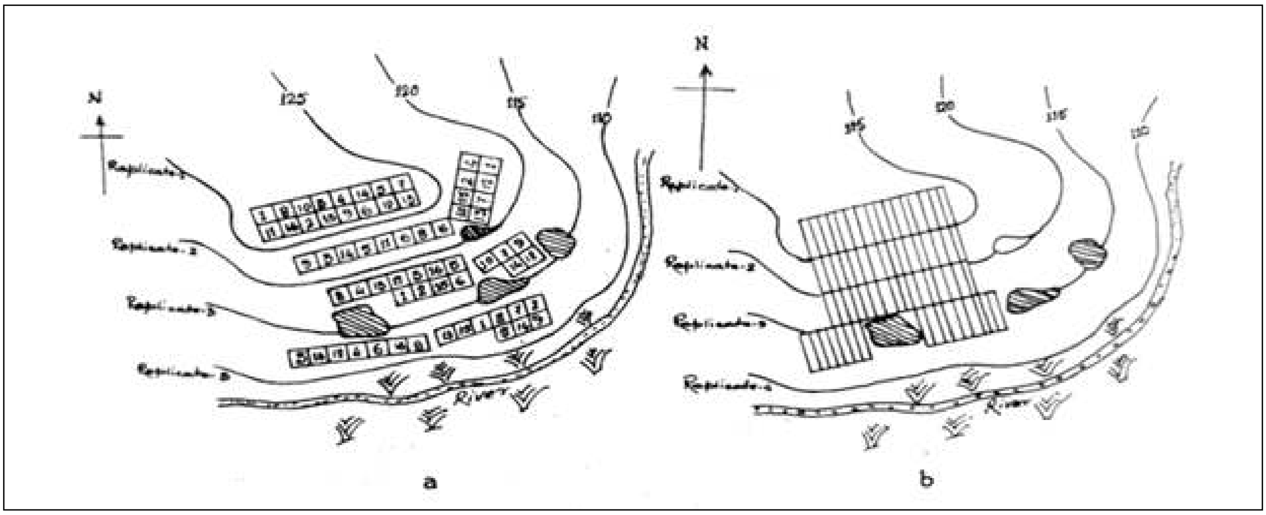


Fig 3.5. PLayout of a field trial (a) with square plot (b) with row plot. The contour lines have heights in meters, the shaded area is out crops of rock, and there is a river running through a swamp.

Layout of plots in a field trial must take into account gradients of the environment, for example slope, fertility and soil moisture. The plots within replicates are arranged across the slope and the row plots are oriented down the slope (Fig. 3.5). Following number of trees per plot are recommended.

- Range wide provenance phase : 25 tree plots, no surround
- Restricted provenance phase : 25-49 tree plots,1 or 2 row surround
- Provenance proving phase : 100 tree plots,1 or 2 row surround

Spacing

Spacing in provenance trials should not exceed 3m x 3m to accommodate more number of provenances in a unit area of land. A suggestion of spacing is mentioned below:

a) 2m x 2m : Range wide provenance phase

b) 2.5m x 2.5m : Restricted and provenance proving phase

c) 2m x 3m : Where access for mechanical cultivation is required

d) 3m x 3m and above : Trials on species with a high crown/bole diameter ratio especially fortropical hardwoods

GROUND AND SITE PREPARATION

The area should be clear felled and competing vegetation should be removed. The debris should be disposed off or burnt in heaps. The whole area is fenced with barbed wire or chain link depending upon the risk of damage from cattle and wild animals. Stacking is carried out in the whole area using rope, chain, compass and wooden pegs according to a pre-decided experimental design. Pits of the standard size are prepared. All this exercise should be completed at least two months before planting so that there is sufficient time for soil weathering to reduce the risk of insect and diseases. If the soil of the site is not good, it is desirable to fill the pits with imported soil mixture of sand soil and farm yard manure in the ratio of 1:1:1 or 1:2:1. This will ensure the initial survival and early establishment of the plants. Later on, the plants have to face the existing soil conditions of the site.

PLANTING AND PLACEMENT

Great care is necessary to avoid mixing of' nursery stock. Seedlings should not be removed from the nursery without clear labels. Before planting, seedlings need to be placed at their respective planting hole / pit as per the experimental design under great precaution and supervision. Planting should be completed in minimum possible time to minimize the effect of day to day variations. As far as possible the same team of workers should plant a complete block at a time.

REPLACEMENT

Beating up of causalities is an essential part of plantation practice. The date and number of replacements should be carefully recorded so that survival assessed can be used with greater confidence.

MAINTENANCE AND PROTECTION

- Timely weeding should be carried out.
- No pruning and thinning in the experiment should be carried out.
- Fire protection measures (fire lines) to be taken up. Hoeing should be carried out two to three times a year during establishment stage.

TRIAL ASSESSMENT

Assessment of trials is often lengthy and expensive. Only characters of practical importance with substantial experimental variation should be assessed. Quantitative traits are generally better than qualitative ones for subsequent analysis and interpretation. Some of the traits which should be assessed at various stages during provenance trial are discussed.

Seed and Nursery Stage

Plant characteristics in the nursery should be assessed as they help to explain variation at a much later stage. Thus, early vigor may be correlated with survival or with ultimate growth in the field. The following traits should be assessed.

- Average seed weight and size
- Median (or arithmetic mean) germination time, assessed as number of seeds germinating daily
- Percentage germination
- Seedling height, hypocotyl and average cotyledon length
- Seedling diameter
- Nursery survival

Field Stage

Assessment in the field is generally made on all the trees or at least those in the inner assessment area of each plot. The initial calibrators of the field stage are assessment of height and survival percent a few months after planting. The characters assessed are:

Growth	:	Height, diameter, dry matter production/stem volume
Seedling	:	Shoot root ratio
Stem	:	Lean, bow, crookedness, persistence, forking, taper, circularity, buttressing, fluting etc.
Crown	:	Length, diameter, shape
Bark	:	Thickness, texture, color
Branch	:	Number, diameter, length, angle, type, self-pruning
Shoot	:	Color, texture, indumentums
Leaf	:	Length, width, color, form
Fruit	:	Dimension, form
Physiology	:	Photoperiodism, phenology, photosynthetic rate, respiration rate, transpiration rate, stomatal conductance, flowering
Health	:	Resistance to pests and diseases, fire, drought, frost etc
Technological	:	Wood properties, wood anatomy, cellulose production and pulping properties
Chemical	:	Nutrient uptake, foliar analysis, formation of chemical compounds

Growth and morphological data can be taken after the end of the growing season and the physiological health data can be recorded seasonally depending upon the time and availability of resources. The technological and chemical data can be recorded after a substantial growth of plants in the field say after formation of wood.

STATISTICAL ANALYSIS

Data from a trial should be analyzed as soon as possible. Many different types and stages of analysis are possible, but the methods of analysis used should be appropriate to the objectives of the experiment, to its design and to the traits being analyzed. Some of the common analyses are discussed here. For detailed description about the analyses, the book "Statistical Procedures for Agricultural Research" by Gomez and Gomez (1984) and "A manual on species and provenance research with particular reference to the tropics" by Burley and Wood (1976) can be consulted.

Preliminary Analysis

Mean

It is the calculation of plot mean values. A plot mean is simply the arithmetic average, the sum of a "measurements of a trait such as tree height divided by number of measurements.

Transformation

The measurements such as survival percent, germination percent and flowering are generally needed to be transformed before analysis. The most frequently used transformations are angular, square root and logarithmic.

- Angular transformation: It is applied to percentage values lying between 0 and 100 which have a binomial distribution. This includes percentage of trees in a given class (e. g. diseased, forked, severely sinuous etc.). Instead of the observed percentage P, the angle sin-1 (√ P/ 100) is analyzed as it has the effect of "stretching" the scale of ' measurement at the extreme (i.e. near 0 % and 100 %) so as to equalize the variance over the whole range. Tables of the angular transformation are provided in Fisher and Yates (1963) and other statistical books.
- Square root transformation :This is used to equalize variance where it is proportional to the mean .This is a feature of counts with a poison like distribution such as number of branches per node .
- Logarithmic transformation :The transformation of data to their logarithms is used where the variance is proportional to the square of the mean .This is often the case with assessment of flowering ,or of infestation or certain type of damages .

Apart from the angular transformation there is generally no need to transform data in provenance testing because of non normality of variation .

Analysis of Variance (ANOVA)

In provenance trials ,the analysis of variance is used to measure the relative importance of variation between populations ,environmental variations and residual variations .It is the most widely used method for interpreting the results of experiments .The analysis provides the following information .

- Estimates of relative magnitude of each identifiable source of variation.
- Estimated difference between populations and between environments.
- Indications of accuracy of estimated differences by means of their standard errors and confidence limits.
- Test of significance of variances and differences:

Although the precise form of analysis of variance varies according to the experimental design and underlying mathematical model, the essential principle is to estimate variance attributable to each source (blocks, populations. residual etc.) of variation. Statistically significant variances are identified by means of the variance ratio test ('F' test). The analysis of variance for the design most frequently used in provenance research are discussed by Burley (1973) and a number of other books on statistics.

Comparison of Means,Test of Differences

If an F-test (through ANOVA) reveals statistically significant variation among the populations, it is necessary to test the differences between individual populations or group of populations. The differences between two populations may be inferred statistically significant if it exceeds the least significant difference LSD = t x s (difference).

Where, t = Value of student 't' for the appropriate residual degree of freedom (generally P = 5 % or 1 %).

s = Standard error of the population differences. Where,

$$s(\text{diff.}) = \frac{\text{MS (Error)}}{\text{n (Error)}}$$

Where, MS = Mean square due to error

n = Degree of freedom (residual)

Analysis of co-variance

In co-variance analysis, an adjustment is made of the values of plots through a co-variable. Computation for the analysis of covariance for simple designs is described by Snedecor and Cochran (1980) and by Cochran and Cox (1957).

Correlation Analysis

The simple correlation coefficient (r) is a measure of the degree of linear association between two variables. It is important in provenance analysis for correlation among the traits and with the geographical locations i.e. latitude, longitude, rainfall and altitude.

The simple correlation coefficient (r) is estimated as:

$$r = SP_{xy} / (\sqrt{SC_x} \sqrt{SC_y})$$

Where, SP indicates the sum of the product of the corresponding values of x and y and SC_x and SC_y indicate the sum of square of the deviation for the values of x and y respectively.

The values of r can vary between -1 and +1, indicating negative or positive correlation respectively.

Regression analysis

The form of a relationship between two traits may be further investigated by means of simple regression analysis. The straight line regression line Y = a + bX can be estimated and used to predict and explain variation in Y according to variation in X. Estimates of the regression coefficient are:

$$b = (SP_{xy} / SC_x) \quad ; \quad a = Y - bX$$

SP_{xy} - The sum of the products of the corresponding values of x and y

Y - Dependent variable

X - Independent variable

a - Coefficient

b - Slope

Genotype - Environment Interactions

Provenance trials are often conducted on several sites. Within a single country the range of experimental sites may include very widely different environmental conditions and it is likely that the relative performance of the populations tested will vary from site to site. For example, one provenance may grow well on a wet site and poorly on a dry site, compared to other provenances. Another provenance may adapt well to the dry sites while a third may grow relatively well on both the sites. Genotype- environmental interaction is the extent to which a genotypic effect is measured by average response over all the sites of a population and environmental effect is not additive.

The magnitude of a genotype environment interaction may be estimated by means of an analysis of variance. If P populations are represented at 5 sites in RCBD, the source of variation will be between sites, block in sites, between populations and site its population interactions.

COMPUTER & SOFTWARE PROGRAMMES FOR EXPERIMENTAL DESIGN AND ANALYSIS

The method of most of the statistical analysis and experimental designing particularly in case of incomplete block designs are complex and laborious, if done manually. It is preferable to do this job with the help of a computer which will save time and provide more accuracy. Moreover, data can easily be upgraded by storing them in proper data management files of the computer.

The following computer softwares are commonly used for experimental design and analysis.

- GENSTAT release No. 5.32, product no. T5 WND32NAD, available from Numerical Algorithm Group, Wikinson house, Jordan Hill Road, Oxford OX2 8DR, U.K., used for various types of statistical analysis of experimental data.
- SPAR-I, available from Indian Agricultural Statistical Research Institute, New Delhi, India, used for statistical analysis of experimental data.
- SX computer programme, used for statistical analysis of limited number of data.
- SPSS (Statistical Package for Social Sciences) version 6.2 or 6.0, used for statistical analysis of experimental data.
- MICROSOFT OFFICE, which incorporates the spreadsheet package Microsoft Excel 5.0, used for data storage and retrieval for analysis.
- ALPHA +, version 2.3 available from Dr. E.R. William. CSIRO Division of Forestry. PO Box 4008, Q.V.T. Canberra 2600, Australia, used for the generation of experimental designs particularly incomplete block designs.

AFTER COMPLETION OF PROVENANCE TRIAL

After achieving the results from a provenance trial, the experimental area can be converted into seed production area by removing all but the best provenances, so that pollen from genotypes of the poorest provenances do not degrade the quality of seed collection from the best. Also, there must be sufficient isolation from other possible sources at hybridization with the species in the provenance trial. Even then, the genetic base may be quite narrow since each provenance is usually represented by not more than 10 open pollinated families. A better option after selection of best provenances is to return to the original seed source areas and collect seed from 50-100 or more parents from each provenance region to establish seed production areas.

APPENDIX- IV SOME LATTICE DESIGNS SUITABLE FOR PROVENANCE TRAILS (Carter, 1987)

1. Number of provenances 12
Replication 4
Block

Replicate 1

A	B	C	D
11	3	5	2
8	9	4	12
1	6	10	4

Replicate 2

A	B	C	D
12	4	8	10
3	6	9	1
5	11	2	7

Replicate 3

A	B	C	D
1	7	11	10
6	9	5	3
12	4	2	8

Replicate 4

A	B	C	D
7	8	5	6
3	4	1	2
11	12	9	10

1. Number of provenances 16
Replication 4
Block

A	B	C	D
13	9	1	5
15	11	3	7
16	12	4	8
14	10	2	6

A	B	C	D
3	8	14	9
16	11	1	6
10	13	7	4
5	2	12	15

A	B	C	D
12	13	6	3
8	1	10	15
10	13	7	4
4	5	14	11

A	B	C	D
16	14	15	13
1	3	2	4
11	9	12	10
6	8	5	7

1. Number of provenances 20
Replication 4
Block

Replicate 1

A	B	C	D	E
2	6	16	11	1
14	18	9	4	13
20	5	15	10	19
8	12	3	17	7

Replicate 2

A	B	C	D	E
19	3	12	4	10
8	14	1	15	16
5	6	20	7	13
11	17	9	18	2

Replicate 3

A	B	C	D	E
5	11	17	6	12
16	9	15	4	10
14	2	8	20	3
7	18	1	13	19

Replicate 4

A	B	C	D	E
9	7	10	6	8
19	17	20	16	18
4	2	5	1	3
14	12	15	11	13

1. Number of provenances 25
Replication 4
Block

A	B	C	D	E
17	5	13	9	21
14	22	10	1	18
6	19	2	23	15
25	8	16	12	4
3	11	24	20	7

A	B	C	D	E
12	13	11	15	14
17	18	16	20	19
2	3	1	5	4
22	23	21	25	24
7	8	6	10	9

A	B	C	D	E
15	17	8	1	24
22	4	20	13	6
3	10	21	19	12
6	23	14	7	5
9	11	2	25	18

A	B	C	D	E
24	14	9	19	4
25	15	10	20	5
22	12	7	17	2
21	11	6	16	1
23	13	8	18	3

4 PROGENY TESTING

Progeny test is a method to ascertain the genetic worth of selected parents by measuring the performance of their progenies. This enables separation of parents whose phenotypic superiority is due to their growing in a good environment from those that are superior genotypically.

Once plus trees are selected on the basis of their physical appearance and planted in a seed orchard, their genetic worth can be known only on the basis of performance of their progeny. The relative contribution of genotype and environment towards phenotype of the selected tree can be determined through progeny test.

The objectives of progeny testing are:

- To evaluate family lines for the purpose of rouging out seed orchards.
- To establish plantings from which to make second generation selections.

Progeny testing is advantageous in case where most of the variation is environmental. One can make substantial gains by separating the total variation in environmental and genetic components through progeny testing. Progeny trials are either half sibs or full sibs.

In half sib progeny trials, open pollinated seeds are collected from selected parents to lay out trials for assessment of General Combining Ability (GCA).

In full sib progeny trials, controlled cross pollinated seeds are collected to lay out trials for the assessment of Specific Combining Ability (SCA). A summary of advantages and disadvantages of different progeny testing method is given in Table 4.1.

Location, Establishment and Management of Progeny Test.

LOCATION

The location where progeny test is to be carried out should be chosen carefully. It should represent the area where commercial planting is to be carried out in future. It is important to consider both climatic and soil characteristics when selecting the site. Uniformity of site is very important. Even in the most uniform site, there are difference in soil composition, drainage and fertility which makes it necessary to repeat the planting several times. The progenies may be tested on more than one site.

Table 4.1. Comparisons of advantages and disadvantages of different methods of progeny

Type of Progeny Test	Advantages	Disadvantages
Open pollinated (Half sibs)	1. Can be established easily 2. Cheap	1. Lack of precision 2. Limited usefulness as a source of second-generation selection.
Controlled crossed using pollen mixture	1. Slightly cheaper than individual crosses.	1. No information on SCA 2. Inbreeding will result if used for second generation selections
Controlled crosses using male parents (testers)	1. High precision 2. Gives information on SCA	1. Costly 2. Gives narrow genetic base for second generation selections dur to common parents.
Controlled crosses, using small dialleles	1. High precision 2. Excellent for second generation selection 3. Gives maximum information	1. Costly

ESTABLISHMENT

Site preparation activities must be more intensive than done for commercial plantings. The objective is to create as uniform as an environment as possible so that genetic differences can be detected at an early age. Land should be cleared from other vegetation. Spacing should be wide enough to allow for maintenance during initial years.

The seedlings in the nursery should be raised under uniform conditions so as to provide equal advantage to all the entries. Similarly, utmost care needs to be taken while transporting the planting material from nursery to planting site so that the seedlings are not put under any kind of stress.

EXPERIMENTAL DESIGNS

As indicated above, the site conditions are not always uniform and the progenies have to be properly evaluated. It is necessary to minimize the environmental factors operating on the progenies. Many experimental designs have been developed to control the environmental effects in the experiments.

However, the most commonly used design is the randomized complete block design or incomplete block designs. Replication should be done in both space and time. A poorly replicated plot on a highly variable site will yield little reliable information. Progenies within a replication should be properly randomized. Border rows should be planted to remove the edge effects.

PLOT SIZE

In the past, progeny tests were conducted using the plot size as in the provenance trials that are square plots containing 25-100 trees. This will often result in the large size of the plots thereby increasing variation among the plots. To overcome this problem, in many programmes, progeny tests are conducted using row plots.

Use of small plots ensures that the genetic differences among the progenies are accurately evaluated. Row plots are easier to plant and measure than traditional square or rectangular plots. It is often desirable to use 10 tree row plots and six replications at the beginning of the testing programme.

MANAGEMENT

Usually progeny trials run for half or full rotation age. Therefore, it is imperative that proper labeling and documentation of the trials in the field as well as in the office is done. The maps of the site, layout of the trial should be properly maintained. The trial should be protected from fire by establishing fire lines around the test.

Diseases and insects should be controlled as per standard protocols. Thinning may or may not be done in the progeny test. If thinning is carried out, proper records should be maintained. The measurement of height, diameter etc. in the trial is done periodically. Data should be recorded accurately.

5 SEED ORCHARDS

Seed orchard is a plantation, in isolation, of genetically superior trees to reduce pollination from outside sources. It is established by setting out clones or seedling progeny of trees selected for desired characteristics and intensively managed to produce frequent and abundant seed crops.

Now a days establishment of seed orchard is being taken up as a regular forestry activity as it guarantees reliable production and steady supply of quality seeds. Seeds from seed orchards have produced substantial genetic gain in terms of growth, tree form, adaptability, disease and pest resistance. and wood qualities whenever the activity was taken up seriously with detailed knowledge about the genetics and reproductive biology of the species and consequences of inbreeding and other genetic phenomenon.

SEED ORCHARD AND SEED PRODUCTION AREAS

A ‘seed orchard’ produces seed that is improved whereas seed production areas produce seed more closely related to the parent population. The source material for seed orchards is selected on the basis of desired traits or characteristics. Individual plants in the orchard are identified and those that do not exhibit the desired traits or characteristics may by thinned to ensure the production of ‘better’ seed than the original parents.

The important difference between the two is that seed orchards are established to alter the genetic base to favor a particular set of genes. In seed production areas the genetic mix can remain representative of the original population(s), although it is still possible to manipulate the mix through time by selective removal of plants. Seed orchards can be established from seedlings (seedling seed orchard) or planting stock propagated through cloning, such as cuttings (clonal seed orchard).

TYPES OF SEED ORCHARDS

Seed orchards are of two types:

- Clonal seed orchards: Orchard established with vegetative propagules such as grafts, cuttings or tissue culture raised plantlets is called clonal seed orchard. Such orchard established with untested clones is known as first generation orchard. Clonal orchard developed with genetically tested clones (elite clones) is called advanced generation orchard.
- Seedling seed orchards: Orchard established with seedling progeny (half-sib or full sib) followed by rouging of inferior families as well as inferior individuals within family is called seedling seed orchard.

ESTABLISHMENT OF CLONAL SEED ORCHARD

Production of Clonal Material

Organization undertaking such activities should have expertise to undertake production of clonal materials by different techniques. Commonly used vegetative propagation techniques are grafting, cutting, air-layering, tissue culture etc.

In case of grafting two individuals, rootstock and scion are involved. These may interact positively or negatively. Negative interaction results in graft-incompatibility and grafting may fail anytime during development of the grafted tree. The selected tree with desired characters is called scion which donates bud material which are grafted on rootstock. To avoid the problem of graft-incompatibility, the worker should be allowed sufficient time to study root stock-scion interaction. In case of severe graft-incompatibility, rooted cuttings are used.

The selected tree with desired characteristics which donates bud material is also called ortet. A group of individuals produced by vegetative means from a single tree is called clone and each member of a clone is called ramet.

Selection of Orchard Site and its Preparation

- Area for orchard should be easily accessible and near to main/regional station.
- Area which can be diverted for some other purpose like construction of road, market, dam, etc. in future should be strictly restricted.
- Orchard area should be scattered to reduce risk of damage or total loss due to natural calamities.

Orchard site having favorable edaphic and climatic conditions for profuse flowering and fruiting should be preferred. Conditions of severe drought, wind and frost may have adverse effect on the orchard trees particularly on flowering and seed setting. Land with below average or poor fertility is unfavorable for clonal seed orchard development.

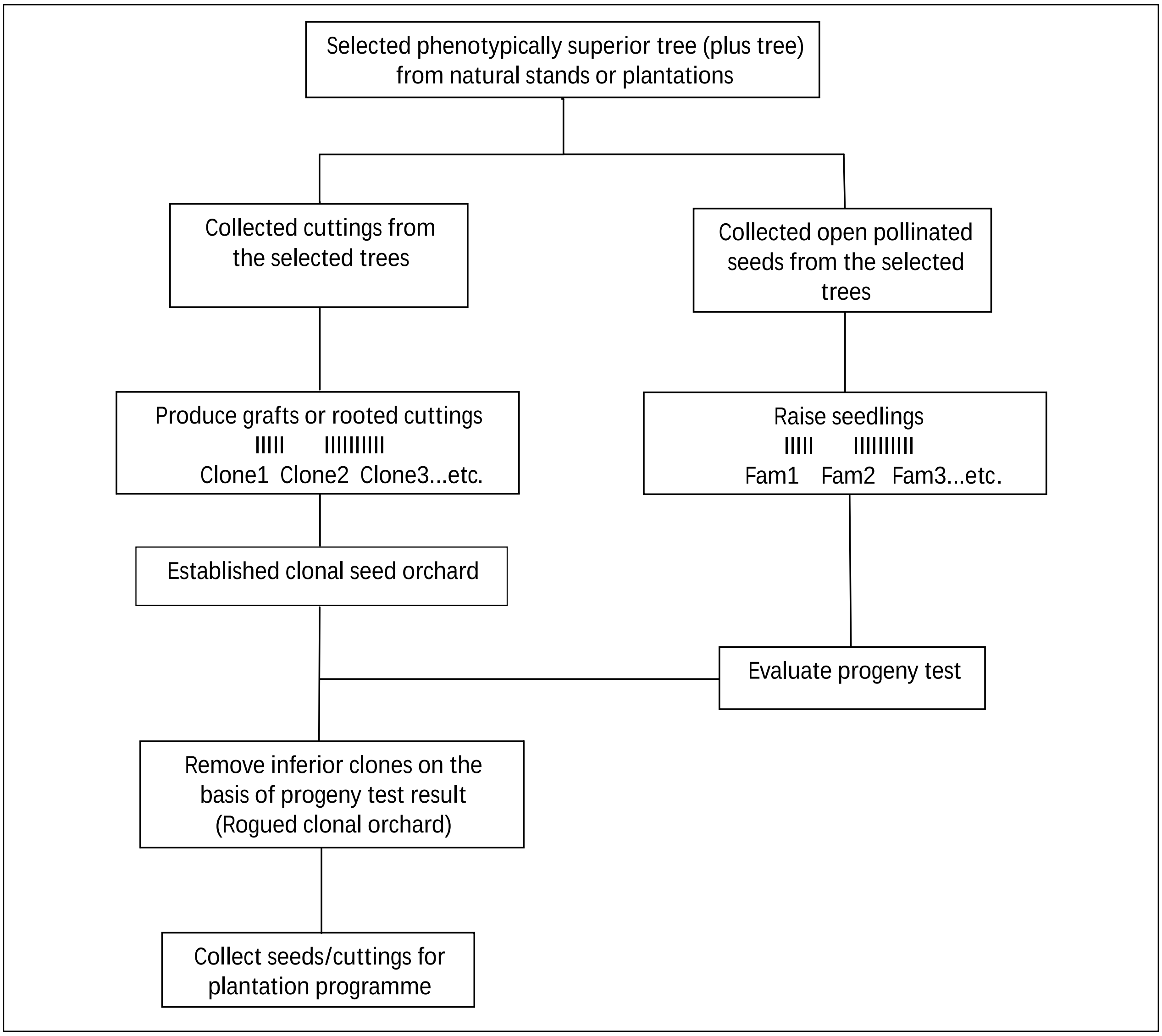


Fig 4.1. First generation clonal seed orchard

- Abandoned agricultural lands with average fertility are the best suited for orchard establishment. Highly fertile land often delay flowering because of heavy vegetative growth.
- Site having square or rectangular shape should be preferred for ease of management and proper clonal dispersal.
- Flat land having good drainage is highly suitable for orchard development. Very sloppy land poses management difficulties and should be avoided.
- Do not establish orchard outside the natural range of the species without prior testing. The orchard should be established in the main portion of the geographic range of the species.

- Remove all weeds and other bushes. Plough the orchard site and level properly. Gently sloping land needs some sort of soil conservation measure. Fence the area properly before field planting clonal materials.
- Dig pits of optimum size, the size of the pits will vary (0.5x0.5x0.5 to 0.8x0.8x0.8 m^3) according to the soil type. Fill the pits with good soil, sand and FYM in the proportion 2:1:2.
- Field plants the grafts in a particular design during rainy season. Label all plants for proper identification at a later date. Use plastic or aluminium tag. Replace these tags with bigger size as the trees grow.

Size of Orchard

- The actual size of orchard depends on the total seed or seedling requirement. The other factors affecting orchard size are location, importance of the species, availability of land in a particular locality and facilities (fund, personnel, irrigation, mechanization, etc.) with the organization.
- In most cases the minimum size of the orchard should be 2.5 to 5 hectares. This helps in planting minimum/optimum required number of clones and ramets of each clone to minimize related mating and also to have broad genetic base.
- The cost per unit of seed produced decreases with increased orchard size. Smaller orchards for specialty purposes (say, production of hybrid) may be established as part of a large orchard complex.
- Determining optimum size of orchard is difficult and the required size may vary 2 to 3 fold depending on the factors discussed above.

Clonal Deployment in Seed Orchard

Proper deployment of clones in an orchard is highly essential to minimize selfing, relatedness among the progeny and to increase the chance of complete panmixis. These objectives are difficult to achieve however, this can be kept to a minimum level by proper spacing and planting optimum number of clones and ramets.

- The actual spacing between ramets of different clones for most of the tropical species varies from 4 x 4 m^2 to 8 x 8 m^2. The spacing also depends on the fertility level of the soil.
- Lower seed yield from initial wide spacing is more economical than to systematically thin out expensively raised grafts at a later date. Wide spacing also helps in keeping size of the tree smaller than by crown pruning.
- Square or rectangular arrangement of ramets is preferable for machinery access between rows.
- Sufficient number of clones and ramets of each clone should be present in each clonal seed orchard to ensure broad genetic base even after rouging of inferior clones on the basis of genetic test results.
- First generation clonal orchard should be established with 40 to 50 untested clones. Thereby, these will reduce to 20 or so by rouging of inferior clones indicated by the poor combining ability. The experience with genetic test results indicate that about 1/2 to 1/3 clones will be rogued out from the orchard after testing. It is suggestive to not plant uneven number of ramets of different clones. At least 20 clones and 20 ramets of each clone should be planted in the first generation orchard.

- Advanced generation orchard may be composed of even less than 10 clones. Specialty orchards designed for the production of hybrids may be composed of two best general combiners with complementary characteristics.
- Genetic gain from first generation seed orchard with large number of untested clones will be less because of low selection differential.
- A number of field designs ranging from simple to most sophisticated computer designs are available for clonal deployment in the orchard.
- A good seed orchard design must have flexibility for the improvement of genetic quality of the orchard by genetic rouging as well as to minimize the chance of inbreeding.
- Systematic seed orchard design helps in easy establishment and movement from one ramet of a clone to another at the time of seed harvesting or giving special treatment to clones.
- The orchard manager should have minimum basic knowledge of statistical designs and their analysis. Some of the commonly used designs for clonal dispersal are as follows.

Pure Rows : This design is based on 'planting pure rows of individual clones. It increases the risk of inbreeding within clones and results in uneven and wide spacing when undesirable clones are removed. This design is, however, rarely used.

```
----*----*----*----*----*----   1
----*----*----*----*----*----   2
----*----*----*----*----*----   3
----*----*----*----*----*----   4
```

1-4 indicate four rows of four different clones.
* indicate ramets within each clone

Chessboard: This design is generally used for specialty orchard such as production of hybrid between two elite clones. A chessboard arrangement is simply done by alternating the two selected clones in each row and column of the orchard.

C1	C2	C1	C2
C2	C1	C2	C1
C1	C2	C1	C2
C2	C1	C2	C1

C1 and C2 are two genetically tested (elite) clones.

Completely Randomized Design: The basic principle of randomized design is that no two ramets of the same clone are planted in adjacent positions within rows or column, or that at least two different ramets must separate ramets of the same clone. Such restrictions are imposed by manipulating the positions of ramets.

A	B	C	D	E	F	G	H	I	J
C	D	E	F	G	H	I	J	A	B
F	G	H	I	J	A	B	C	D	E
I	J	A	B	C	D	E	F	G	H
C	D	E	F	G	H	I	J	A	B
G	H	I	J	A	B	C	D	E	F
A	D	F	E	C	G	I	H	J	B
H	J	B	I	D	A	C	F	G	E
B	C	D	E	F	G	H	I	J	A
D	E	I	J	A	C	B	G	F	H

A to J are 10 different clones
Each clone is randomized 10 times.

The complete randomization of all ramets of all clones between all planting positions is achieved by the process of randomization.

This design is simple in principle and use. It, however, poses some: practical management difficulties associated with planting and relocation of individual ramets when the orchard contains more number of clones and ramets.

Randomized Complete Block Design: In this design, the whole area is divided in equal blocks each sufficiently large to contain all the ramets of all clones. All ramets are completely randomized within each block, and also each block is randomized independently. This design is also simple to use and preferred commonly, but it requires large area because of making blocks.

A	B	C	D	D
C	D	E	A	B
E	A	B	C	D
B	C	D	E	A
D	E	A	B	C

Block-I

A	B	C	D	D
C	D	E	A	B
E	A	B	C	D
B	C	D	E	A
D	E	A	B	C

Block-II

A to E are 5 different clones. Each clone is randomized 5 times

Fixed Block Design: In this design a systematic layout is replicated over the whole area as a fixed block. The major limitation of this design is that its size, total number of ramets and clones, and their arrangement are fixed.

A	B	C	D
E	F	G	H
I	J	K	L
M	N	O	P
Q	R	S	T

A to T are different clones

Rotating Block Design: In this design the limitations of the fixed block design are removed by systematic shifting of the clonal arrangements within each replication of the block. However, this design provides only limited changes in the composition of neighborhood around each ramet.

A	B	C	D
E	F	G	H
I	J	K	L
M	N	O	P
Q	R	S	T

Original block

P	A	B	C
T	D	F	G
E	I	H	K
J	M	N	L
O	Q	R	S

First repetition with first systematic shift

A to T are different clones

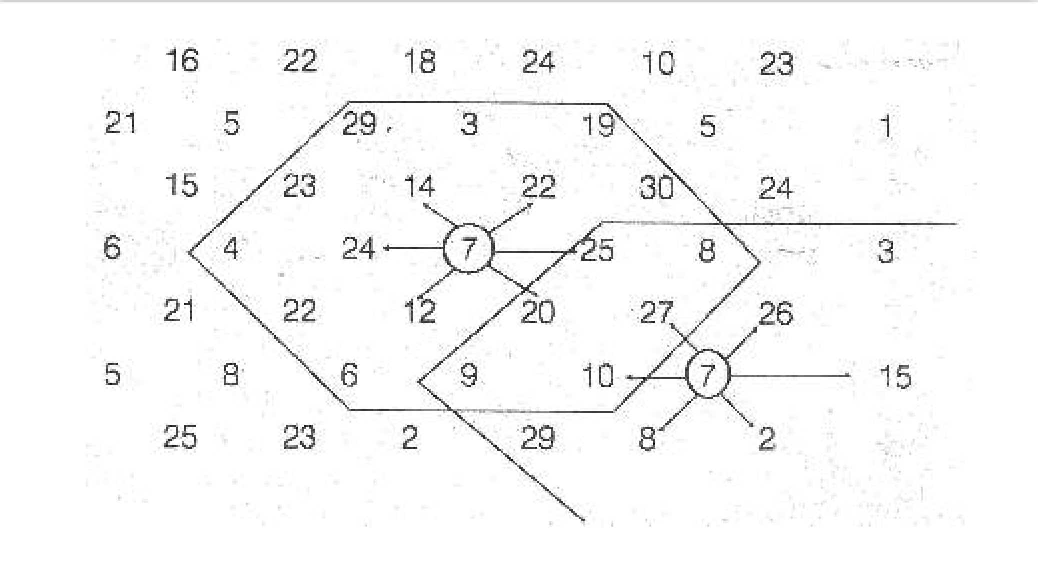
Reversed Block Design: In this design paired block with a reversed sequence of clones within them and with a different randomization for each block pair is used. This design is suitable for self- sterile species which does not require isolation between ramets of the same clone.

G	K	D	C	B	A	
F	L	E	G	J	H	F
E	L	F	I	E	E	I
D	K	G	F	H	J	G
C	J	H	A	A	B	C
B	I	I	B	K	D	K
A	H	J	C	L	D	L

A to L are 12 different clones randomized 4 times

Permutated Neighborhood Design: This design is the most difficult one and different clones and ramets can best be randomized with the help of computer only. This design is, therefore, expensive one. The limitations of the design are:

- There is a doubt ring of different clones to isolate each of the same clones, and
- Any combination of two adjacent clones should occur in any particular direction only. Theoretically the design can be constructed for r = t-1 which would ensure that every clone has the other clones as the neighbor at least once in each of 6 possible directions. Thirty clones would require 29 ramets of each clone. A small block of this design with the above numbers as designed by la Bastide is reproduced below.



Pollen dilution zone

Orchards should be protected from contamination by inferior pollen of outside sources. It is difficult to completely isolate the orchard as pollen moves with the wind and insects. It can be achieved either by establishing the orchard on sites where contamination by pollen of the same or related species is likely to be negligible or by creating a pollen dilution zone.

- The pollen dilution zone should be created by leaving 100-200 m wide open space or by developing 100-200 m wide strip by planting other species.
- Pollen dilution zone should also be created between orchards established with clones of different geographic origin and between advanced generation orchard and orchard established with untested clones.

Management of Clonal Seed Orchard

Seed orchard management is an extremely difficult and costly affair. Exact procedures will vary according to the location of the orchard, local conditions encountered and requirement of the species. Much of the benefit of the programme is lost if the orchard fails to yield seed to their maximum. Hence following should be kept in mind:

- Management procedures should be directed towards early establishment and healthy development of the clones and the promotion of sustained fruit yield.

- Normally orchards are established in good soil. But compaction (hardpans) of the orchard soil due to regular movement reduces growth and seed production, create drainage problem and may result in death of the trees due to root penetration problem. The orchard soil should be ploughed at least once in a year after the rains for loosening of the soil.
- Subsoil the orchard site to prune surface roots. This helps greater root penetration and proliferation and reduces surface water runoff.
- Subsoil two sides of the tree in the first year or depending on the establishment of the grafts. Repeat the process after two years at right angle to the original direction of subsoiling. Subsoil the orchard just before flower initiation.
- The floor of orchard should be protected from wind and water erosion using good ground cover. Fast-growing leguminous crop may be used to maintain adequate organic matter.
- Weeds should be removed to benefit the trees from fertilization and irrigation.
- Burning and grazing should be avoided in the orchard as these results in soil compaction and causes damage to grafts.
- Floor of the orchard should be kept levelled and clean for ease of collection of seeds.
- Preferably, organic fertilizers should be applied in the orchards for promoting growth and vigour of clones when young and to induce flowering at a later date.
- Nitrogenous and phosphorous fertilizer can be used to promote growth and flowering. Compound fertilizer like diammonium phosphate (DAP) will supply both the nutrients.
- Fertilizer should be applied immediately after rains by removing weeds and grasses around the tree preferably every alternate year from sixth year onwards.

If the site quality is good the orchard should start flowering at age of 5 or 6 years. Application of 1-2 kg (per tree) of fertilizer is suggested for full grown trees. The following general dose is recommended for the first five years.

Year of Planting				
I	II	III	IV	V
200 g	250 g	300 g	350 g	400 g

- Fertilizer should be applied around the periphery of the plant after proper soil working and should be followed by watering/irrigation.
- Application of fertilizer should be in split doses
- Proper irrigation has proved important during young age to maintain good growth and vigor in the clones. The timing of irrigation becomes crucial when the trees come to flowering. Moisture stress during the period just prior to flowering induces flowering.
- Diseases and pests problems are different for different species and locations. Insecticide and fungicide should be sprayed to control diseases and pests. An entomologist/pathologist should be consulted in case of severe problems of pests and diseases.

- Orchard should be protected from fire as may result in complete loss of orchard.
- In addition to general management practices discussed above, some special treatments may be given to improve or speed up flowering and seed production. Orchard manager should have thorough knowledge on the kind of effects of these treatments on the species before undertaking such activities.
- Shock treatments like root pruning, and partial girdling of stem may result in increased flower and fruit crops. But these should be avoided for orchards that are to be kept for long periods. Water stress can be imposed if water availability can be regulated by artificial watering. A brief drought during floral differentiation usually induces flowering. The watering should be re-continued after flowering.
- There are marked differences in flowering and fruiting behavior of different clones particularly in respect of flower production and synchrony in flowering time. Application of hormonal treatment particularly gibberellins induces flowering but is unable to change the clonal difference in flowering. Therefore, clones having similar behavior in flowering and fruiting should be used to establish orchard to avoid unequal gene transmission, if prior information on different aspects of flowering is available.
- Promoting pollination by insects by putting up beehives is widely practiced in fruit orchards and agriculture and the same is applicable to seed orchards also.
- Tree crown can be pruned to encourage development of a short, wide and bushy habit for ease of seed collection. Low height will also help in undertaking controlled crosses easily. It is suggested to undertake pruning at young age only.
- Dead fruiting inflorescence should be removed each year immediately after seed harvest.
- Sufficient spacing is recommended between orchard trees to encourage full crown development. Wide spacing prevents crown overlapping, allow more sunlight to penetrate, permit easy movement of equipment for undertaking cultural operations.
- Genetically inferior clones as evidenced from progeny test results should be removed from orchard. Also,it is recommended to remove very early and late flowering clones to achieve flowering synchronization for uniform gene transmission.
- Thinning may not be required in an orchard established with genetically tested clones (advanced generation orchard) if information already available on flowering, fruiting and crown development is taken care of, while establishing the orchard.
- Seeds should be harvested clone-wise and their identity should be maintained with suitable label indicating the name of the clone, date of collection of seed, and name of orchard/location.

Orchard Records

Maintain record on all aspects of orchard for taking present and future decisions on the orchard. Records may be maintained in the following formats:

i. Record on orchard site

1.	Range	--------------------	5.	Soil type	--------------------
2.	Block	--------------------	6.	Topography	--------------------
3.	Compartment	--------------------	7.	Site quality	--------------------
4.	Area	--------------------			

ii. Record on site preparation

1.	Ploughing	------------------	5.	Fertilizer/manure applied	------------------
2.	Levelling	------------------	6.	Quantity applied	------------------
3.	Pit size	------------------	7.	Method of application	------------------
4.	No. of pits	------------------			

iii. Record on clonal materials

1.	No. of clones	------------------	5.	Tested/untested clones	------------------
2.	No. of ramets	------------------	6.	Methods of clonal propagation	------------------
3.	List of clones	------------------			

iv. Record on planting

1.	Date of planting	------------------
2.	Design used	------------------
3.	Spacing	------------------

v. Record on orchard management

1.	Subsoiling	----------------	8.	Date of irrigation	----------------
2.	Date of subsoiling	----------------	9.	Pest incidence	----------------
3.	Fertilizer type and dose	----------------	10.	Type and dose of insecticide/ pesticide	----------------
4.	Method of application	----------------			
5.	Date of application	----------------	11.	Pruning	----------------
6.	No. of irrigation	----------------	12.	Thinning date	----------------
7.	Date of irrigation	----------------	13.	Name of clones removed	----------------

vi. Record on flowering and fruiting

1.	No. of clones flowered	------------------
2.	Date of 50 % flowering	------------------
3.	No. of clones fruited	------------------
4.	Date of 50 % fruiting	------------------
5.	Clone-wise seed yield	------------------

Advanced generation clonal orchard

Clonal seed orchards are commonly named by generation, that is, first generation, second generation, third generation etc. depending upon the cycle of advancement they represent.

First generation orchards are established with untested clones which results from selection of plus tree from natural stands/plantations (Fig. 4.1). The genetic worth of such selected trees is unknown at the time of establishment of orchard. Simultaneously, genetic tests are carried out with half-sib seeds from the selected plus trees. On the basis of genetic test results, genetically inferior trees (clones) or poor genera combiners are rogued out from the first generation orchard which becomes rogued first generation orchard.

Fresh orchard is established with the good general combiners (elite trees) which is called the second generation orchard (Fig. 4.2). Progeny tests are again established with seed from rogued out first generation orchard. The genetic information obtained from such test is utilized to manner and finally only few best clones are selected for specialty orchard. The method of establishment and management remains same as discussed earlier.

ESTABLISHMENT AND MANAGEMENT OF SEEDLING SEED ORCHARD

The basic principles and methods of establishment of seedling seed orchard are same as clonal seed orchard. Therefore, seedling seed orchard will not be described in detail, except one or two vital points. While reading the sections on establishment and management of clonal seed orchard (section 5.3) replace the terms 'clone' and 'ramet' with 'progeny' and 'family', respectively, for seedling seed orchard.

The process of 2nd cycle is repeated to select 2 to 5 best clones for use in specialty orchard remove inferior clones from second generation orchard. The process is repeated in a cyclic open pollinated seed (half-sib) from selected plus trees in their original locality or from clones of these trees assembled in a first-generation orchard should be collected, maintaining identify of seed lots by individual tree/clone. Each lot will represent a family.

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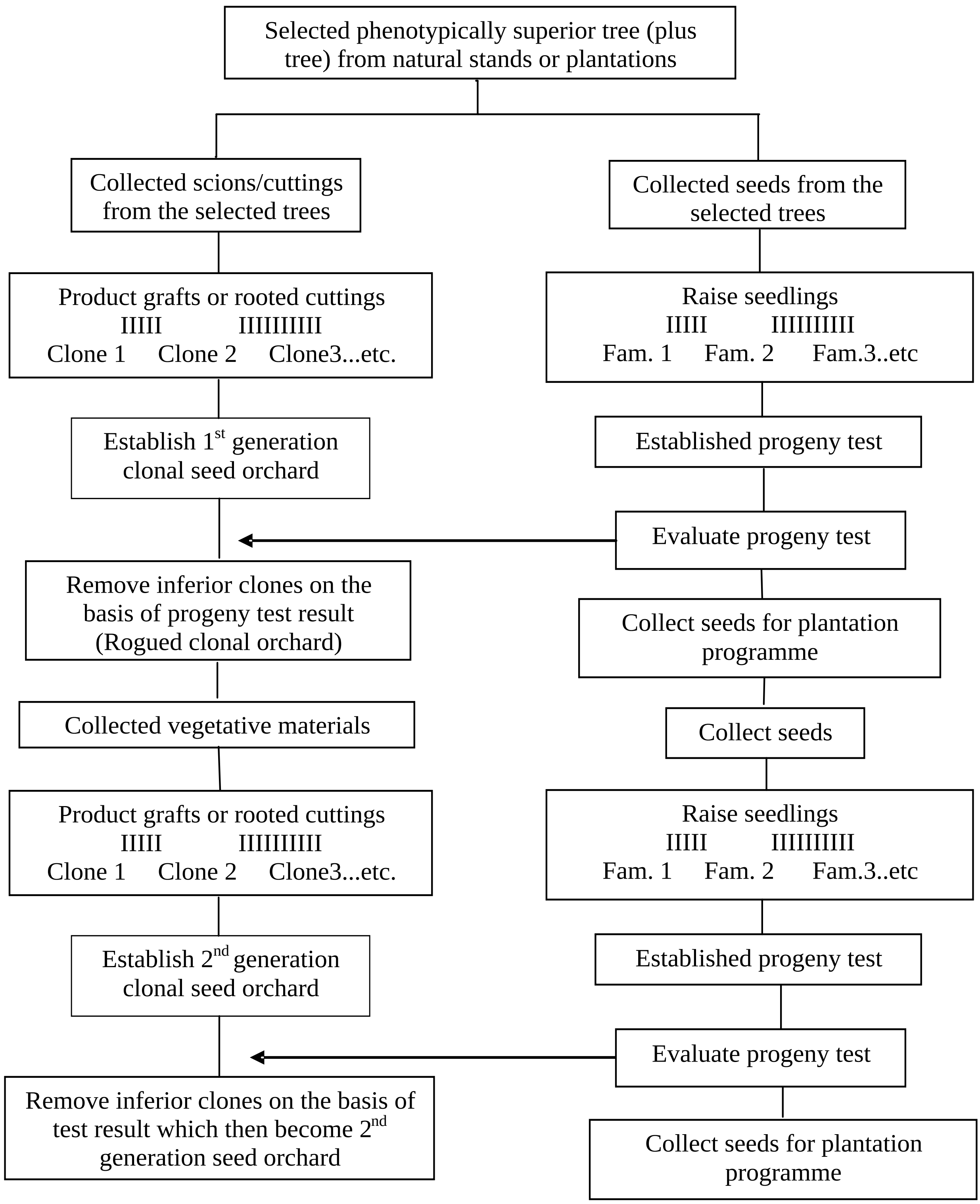


Fig 4.2. Advance generation clonal seed orchard

- The process of 2nd cycle is repeated to select 2 to 5 best clones for use in specialty orchard remove inferior clones from second generation orchard. The process is repeated in a cyclic Open pollinated seed (half-sib) from selected plus trees in their original locality or from clones of these trees assembled in a first-generation orchard should be collected, maintaining identify of seed lots by individual tree/clone. Each lot will represent a family.

- Progeny test plantation may be converted into seedling seed orchard provided the plantations have been raised in an area which favors good seed production (Fig. 4.3 and 4.4). In most cases progeny tests are conducted in areas typical of those that are to be reforested with improved trees. Genetic tests are carried out at narrow spacing with strong competition, whereas seedling orchard requires wide spacing.

- Follow the same methods of maintenance, management, seed harvesting, and record keeping as described in case of clonal seed orchard.

COMPARING CLONAL AND SEEDLING SEED ORCHARD

- Clonal seed orchard is a costly proposition than seedling orchard.

- Clonal orchard flowers and fruits early than seedling orchard. However, in species which flower early, seedling seed orchard is advantageous.

- If there is graft incompatibility or flowering and root deformation problem in rooted cuttings, seedling orchard is beneficial.

- More number of families can be accommodated in seedling orchard as compared to number of clones in clonal orchard. Thus, seedling orchard has wider genetic base but less selection differential which increases the probability of inclusion of inferior families.

- The chance of related mating and danger from such mating are same in both orchards if the ramets of individual clone and families are not properly spaced.

- Genetic gain from clonal seed orchard is higher than seedling seed orchard.

GENERAL REMARKS

- Since seed orchards represent an advanced step in tree improvement programme, the establishment of orchard should be planned 2 to 3 years before. It requires many years of careful planning and execution.

- The management of seed orchards for sustained production often requires use of special silvicultural practice other than conventional ones.

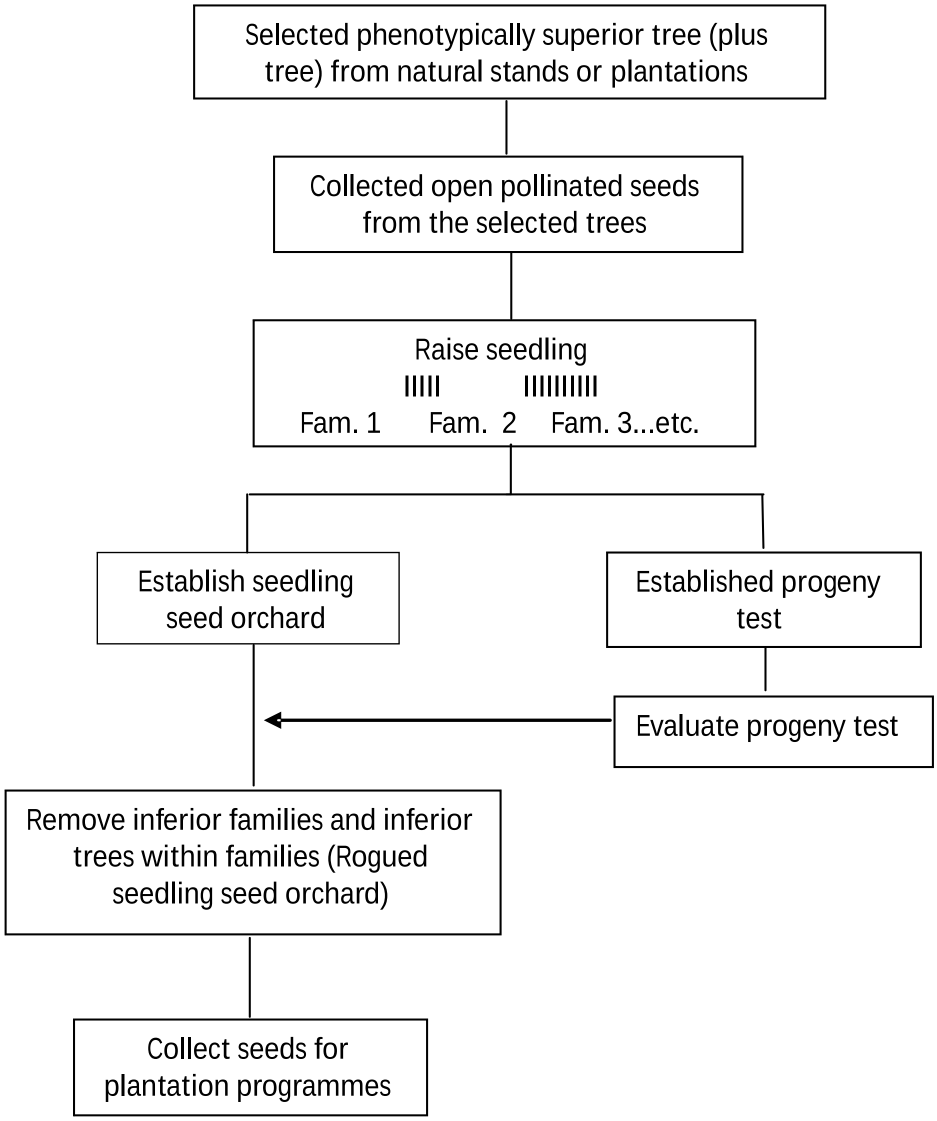


Fig. 4.3. Seedling seed orchard with separate progeny test

- Seed orchards are important components of tree improvement programme as they function both as production population and breeding population.
- Establishment of clonal seed orchard requires the skill of vegetative propagation (both macro-and micro propagation) and thorough knowledge of genetics and breeding.
- Seed orchards are established with a number of biological assumptions, e.g. reproductive synchrony, no differential fertility, random fusion of gametes, no inbreeding, and no contamination by non-orchard pollens which are rarely fulfilled. The forest manager should have knowledge on the effect of the non-fulfilment of the assumptions on the productivity of plantations raised from seed from such seed orchards.

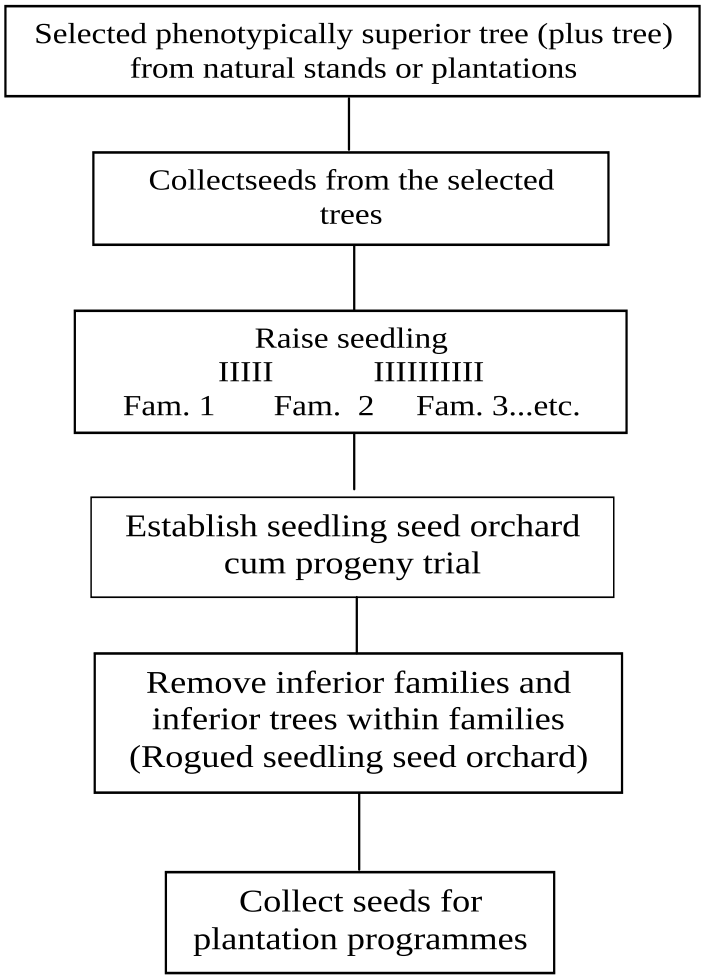


Fig. 4.4. Seedling seed orchard cum progeny test

- Depending on the urgent need for large quantities of quality seeds some shortcuts must be followed to obtain seed as early as possible.
- The cost of development, maintenance and management of seed orchards must be balanced against the gain of implementation. The economic gain from using seed from clonal seed orchard and seedling seed orchard as compared to seed from unselected stand is to the tune of 20 to 30 and 10 to 20 per cent, respectively.

TERMS AND DEFINITION

Clone

A of genetically identical trees (individuals) obtained by vegetative propagation (or asexual means) from a single tree.

Cutting

Detached portion of branch or any other plant part which when rooted produces a full plant.

Family

A group of genetically dissimilar individuals that have one or both parents in common.

Genetic Gain

It is the difference between the mean genotypic value of the selected trees and the mean genotypic value of all trees in the population.

General Combining Ability

It denotes the average performance of a genotype in a series of crosses.

Grafting

Method of uniting parts of different individuals by matching their tissues so that their union can occur when scion is joined with a rootstock.

Graft Incompatibility

The failure of the scion and the rootstock to form or maintain union on grafting.

Ortet

The donor plant from which vegetative parts/propagules are obtained.

Progeny Testing

It is the method of selection of parent trees based on the performance of their progeny.

Ramet

Individual member of a clone or individual propagule from ortet.

Rootstock

It is the plant on which the graft is made.

Rouging

Systematic removal of inferior individuals.

Scion

It is the aerial vegetative parts obtained from the ortet and grafted onto rootstock.

Selection Differential

Percentage of population saved to raise next generation of crop.

APPENDIX- V

ITEM OF WORK AND APPROXIMATE MANDAYS REQUIRED TO ESTABLISH CLONAL AND SEEDLING SEED ORCHARD

S. No.	Item of work	Man days/ha
1.	Preparation of grafts/raising of seedlings	5
2.	Fencing of orchard site	300
3.	Removal of weeds/bushes	10
4.	Ploughing by tractor	1
5.	Digging of pits	10
6.	Filling of pits with FYM, etc.	8
7.	Transportation of grafts/ seedlings to orchard site	2
8.	Randomized placement of grafts/seedlings	3
9.	Planting of grafts/seedlings	2
10.	Casualty replacement	1
11.	Weeding and soil working	6
12.	Fertilizer application in split doses	8
13.	Irrigation (3 times)	6
14.	Recording of measurement of height, girth, crown size, disease and pest incidence, flowering and fruiting	2
15.	Harvesting, processing and storing of seed	20
16.	Fixing of signboards	1
17.	Watch and ward	1

6 VEGETATIVE MULTIPLICATION GARDEN

The vegetative multiplication garden (VMG) may be defined as a collection of superior genotypes maintained juvenile by regular hedging for perennial production of vegetative propagules for clonal multiplication. Superior genotypes may come from sources like selection from natural stands/plantations, selection from half-sib/full-sib families, hybrids, etc. Hence, for the production of large-scale quality planting material, vegetative multiplication garden (VMG) are established and consists generally of tested clones. The clones planted in VMG are not allowed to attain much height, trimmed so as to have eased in accessibility, more vegetative material, hence the reduced cost of propagation.

VMGs are also referred to as hedge orchards, cutting orchards or clonal multiplication area. Establishment of these orchards is imperative for obtaining sufficient number of cuttings, buds or scion to prepare large scale clonal planting stock. VMGs established from the best genetic source (for example, controlled pollinated seeds derived from best progeny–tested parents) helps in rapid vegetative multiplication of planting stock, which is otherwise difficult to achieve from this scarce seed source. Thus, they are ideal source of cutting material conferring following benefits:

- The history and identity of each stockplant can be determined accurate.
- The health status can be controlled and the plants can be maintained in the proper degree of nutrition and vigor.
- Evenly graded batches of cutting material are assured during a given period by culturally maintaining uniformity of rooting is high.

A VMG, thus, helps capture the total sum of juvenility of the trees and facilitates their clonal propagation. Apart from providing sustained supply of juvenile material for clonal propagation of selected superior trees or developed superior hybrids, VMGs or hedge orchards also act as ex situ conservation areas, where, germplasm of endangered, threatened or rare species can be raised, continuously multiplied and easily clonally multiplied. Girouard (1972) suggested that ‘clonal bank’ in the form of hedges should be established to preserve the juvenility of propagation material and to provide quality cuttings. In VMGs, hedges are maintained productive for a long period that varies species 10 species, during which each ortet is form-pruned to yield a maximum number of cuttings from a compact-shaped plant. Permanent stock plants grown in field conditions in VMGs have following advantages:

- There is greater opportunity to keep the identity of donor plants as the propagator can return to the initial clonal material each time cuttings are required.
- Systematic pruning, fertilization, pesticide application and removal of cutting material encourage uniform growth of cuttings. Uniform cuttings mean less grading before sticking, more even rooting and thus, improved grades of planting stock.
- It is relatively easy to ‘manipulate’ the plants to improve number of cuttings at the desired stage of growth by using specific pruning techniques, growth regulator application or increase/decrease of light.
- Unskilled labor, properly supervised, can often be used to collect the cuttings.

Fig 6.1. A view of VMG of teak at TFRI, Jabalpur

Fig 6.2. Hedge garden of *Bambusa vulgaris* at TFRI, Jabalpur

A large-scale clonal forestry programme is not regarded realistic until maturation problems are resolved through effective rejuvenating techniques. Limited number of juvenile propagules may be obtained from nursery seedlings or seedling stock plants. Maintenance of VMGs by regular hedging of stock plants is only practical option for the large-scale and regular supply of juvenile propagules. Performance of seedlings from hedged stockplants in VMGs generally remains good as the hedges become chronologically older. In *Picea abies*, clones chronologically as old as 17 years have been managed as hedged cutting orchards and perennially propagated without any problem with regard to rooting or growth habit (Bentzer, 1993). Cutting production from hedged ortets is as superior as that of serial propagation for maintenance of juvenility, but has distinct advantage of being much more efficiently managed. These benefits prompted us to establish VMGs of teak (Fig.6.1) and bamboos (Fig.6.2).

ESTABLISHMENT OF VMG

Basic Planning

Planning is required at every level, i.e. national, regional and local level important factors, which must be considered while planning to set up a VMG, may be categorized as below:

- Species specific biology, growth habit and importance
- Location and area specific
- Stock plant specific - Origin and number
- Propagation procedures and Infrastructure specific

The actual area of land required for establishment of VMG largely depends on species growth habit, degree of mechanization and number of potential plantlets needed. Information is scarce on the number of stock plants required to provide a known quantity of cuttings. Goh and Monteuuis (1997) have calculated number of propagules available from a certain area of stockplant plantation. In teak, according to them, a single stockplant can provide 40 rooted cuttings that correspond to six hundred rooted cuttings / m^2. However, estimation must be made on the basis of published record and field experience. The planting of stockplants well beyond expected requirements must be avoided, particularly for easy to root species. The entire area should be clearly demarcated and proper recording of source of plant, planting dates and exact location in VMG should be done.

Location

Location for establishment of VMG should be carefully decided, giving due consideration to many factors. Selection of appropriate site for VMG will ease the management during and arm establishment. Accessibility of site and its proximity to propagation is the most important. Site access limitations and long distances from the propagation facility may Increase travel and labor cost and influence the timing and success of propagation. VMGs are established for production of superior albeit uniform planting stock for commercial plantation. Therefore, existence/ development of vegetative propagation infrastructure such as mist chambers, low cost polyhouses,shadehouse, hardening facilities, clonal multiplication laboratory in near vicinity will be immensely useful. A VMG associated with a well-developed nursery works well.

In general, following points deserve to be taken into account while selecting site for VMG establishment:

- Geo-edaphic location should be conducive for good establishment, growth and development of stock plants
- Site should also be easily accessible for establishment, protection, management and transport of vegetative propagules.
- Site of VMG should be exceptionally favorable for early, abundant and regular production of orthrotropic shoots. This happens generally in natural geographical range of species.
- VMG should be established in a flat or slightly undulating area since such areas are homogenous in soil structure and fertility
- A site with good fertility should be preferred. Less fertile soils, however, may be improved with fertilizer application.
- Being a labor-intensive task, both in terms of operation and administration, a central place, i.e. near to local administrative office or nursery should be chosen.
- Protection of area against strong winds, fire, illegal fuel wood collection and grazing is also desired.
- The legal rights to use the site for the purpose should be clearly stated and rest with the managing authority.

Site and Soil Preparation

Good site preparation before planting is essential for future management. Establishment of VMG on land that has not been properly prepared will result in poor growth and high plant loss. Good soil preparation is important, as these plants will provide the foundation for economic revenue in the years ahead. In general, the site should possess:

- Topsoil with good depth.
- Good drainage system.
- Protection against cattle, fire and wind.
- Appropriate pH and soil type depending on the species being grown.
- Irrigation facility especially sprinkler system that will assist plant establishment and provide water need during dry summers.

The ideal place is a completely clear area, free from shrubs, stumps and big stones. If the VMG is to be established on forestland, all trees should be cut and removed or burnt on the site. If the site has been previously grazed for several years, site cultivation is required. Attention must also be given to control perennial weeds to avoid competition with the stockplants. General purpose translocated herbicides such as glyphosate, for perennial grasses and broad-leaved plants, are useful for this purpose. After complete weeding, cultivation by ploughing or harrowing should be done, employing tractors or any other effective measure. Mechanical cultivation improves soil structure and consequently water holding capacity and drainage.

Proper soil preparation improves the establishment and growth of stock plants. A soil analysis of pH and nutrient status is required so that imbalances can be corrected by soil amendments. A basal fertilizer (NPK + micronutrients) application may be considered to raise fertility level. Soil fumigation using metam, chloropicrin, methyl bromide or dazomet is advised on sites having possible soil-borne diseases and pests. Cost of this operation may be reduced by treating only the sections (pits, beds) where plants are grown.

Layout Design

Layout design for the stockplants should be carefully chosen for ease of their maintenance. Sufficient space among stockplants should be allowed for their luxuriant growth and development. This will also help In Identification and collection of vegetative propagules. Several types of designs are followed to fulfill specific requirements. The general requirements in VMG designs are:

- Simple and easy establishment and management.
- Accommodation of maximum number of clones/families.

Pure rows, completely randomized design, and randomized complete blocks are the most commonly used designs. Randomized complete block design, where the area is divided into equal sized blocks sufficiently large to include one ramet of each clone or one individual of each family, is the best option. The area of block, the number of plants in a block may differ depending upon availability of clones.

Stock Plant Selection

VMG is established with stock plants raised from various procedures, which include:

- Bud grafts/ rooted cuttings/ tissue culture raised plantlets obtained from superior mature trees.
- Superior seedlings obtained from open pollinated seeds of advanced generation clonal seed orchards based on progeny tested clones.
- Hybrids between parents selected for complementary characteristics.

Whatever be the origin, the selection of Individual stock plant depends on following criteria:

- Known identity, i.e. clone, family or provenance.
- Good health status, freedom from Insect and disease.
- Proper physiological condition promoting easy clonal propagation.

Additional criteria may include specific project requirements. Sources may be restricted to specific geographic locations, elevation, soil and habitat type or any other criteria.

The number of stock plants needed for plantation reflects production demand and some anticipated level of rooting success based on experience and/or results of clonal trials. However, margin of error should include potential losses of stock plants.

Planting

- The time of planting depends on the climatic conditions of the area. Stock plants should be planted in suitable planting season,
- Proper spacing for establishment and development should be provided between rows of and between stock plants in a row. The spacing will depend on growth habit of the species and ease of management operations. In general, the trees in VMG are maintained at less spacing than those in plantations to maximize the utilization of available land resources. For most tropical broad-leaved tree species, spacing of 2 m x 1 m serves well. Spacing of 1 m x 0.5 m has been recommended for dipterocarps. It is convenient to have a fixed spacing between the rows, to assist mechanization.
- Extra cuttings can be obtained during early years of stockplant establishment by doubling the intensity of planting within rows. A closer initial spacing allows for initial losses.
- Normal silvicultural practices are employed according to preferred design and plan so that the identity of individual plant is maintained. A plan of VMG design should be presentat site clearly showing trees of different clones/ families.
- Individual plants should also be distinctly marked/ numbered.

Post Establishment Care

During first few years of establishment, special care should be accorded to the plants.

- Weeding is necessary during first and second year to discourage weed competition.
- Proper irrigation should be provided during dry periods for optimal growth of stock plants.
- Irrigation combined with fertilizer has a tremendous positive effect on their growth.
- Stock plants should also be protected against natural calamities, insect and disease and can be protected in three stages by following measures:

  Soil fumigation against soil-borne pests and diseases.
  Routine sprays for normal pests and diseases affecting the stock plants.
  "Tumble shooting sprays" for a sudden localized buildup of a pest or disease.

  A soil analysis prior to planting of stock plants is suggested and near to neutral pH and deficiency of mineral elements should be taken care. However, after the establishment, a regular fertilization programme is necessary to ensure vigor and to encourage balanced growth for obtaining quality cuttings/propagules.

DOCUMENTATION OF VMG

- A well-managed VMG must be clearly and accurately labeled. The identity of each stock plant should be maintained and properly recorded.

- As a safety measure, there should be two copies of a plan documenting the layout and individual species/ clones/ families.

Fig. 6.3 shows a single stock plant in teak VMG and Fig. 6.4 provides a flow chart of producing rejuvenated vegetative propagules via establishment and management of VMG.

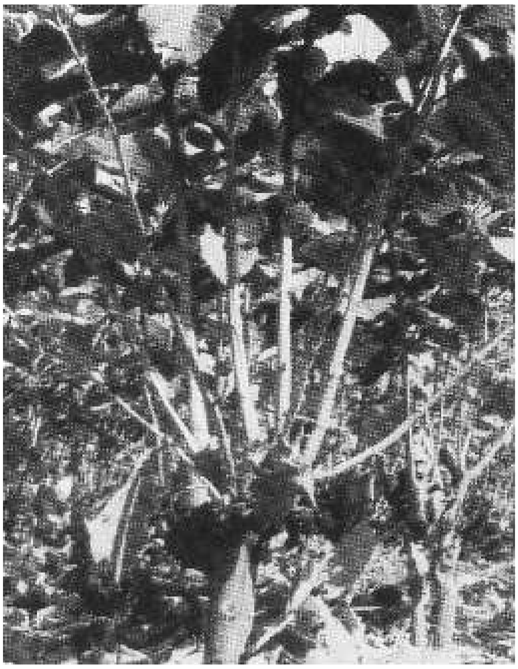


Fig 6.3. A single hedge stockplant of teak

Seasonal Effects

Rooting ability and sensitivity to applied auxins of shoot cuttings varies considerably with the annual growth cycle of tree. Seasonal variation in the rooting ability of woody cuttings taken from stockplants grown in natural conditions is due to fluctuations in temperature, light intensity and/ or interaction between irradiance and photoperiod. The period of the adventitious rhizogenesis differs from species to species.

Best rooting season for many tree species has been identified and in some cases the window of opportunity may be as little as two weeks, e.g. Chinese fringe tree (Stoutemyer, 1942). In general, properties that induce dormancy, promote adventitious bud formation or promote flowering in stock plants, inhabit or delay, adventitious rooting in their cuttings (Moe and Anderson, 1988). Usually, long day (LD) treatment of stock promotes rooting while short day (SD) treatment inhabit rooting (MacDonald, 1969).The seasonal variation in the rooting ability indicates that physiological status of the stock plant at the time of cutting excision is of utmost importance for the rooting process and helps in the development and management plan of VMG of a particular species.

Nutritional Requirement

Stock plant nutrition has been found to influence the quality and rooting of shoot cuttings in herbaceous plants. In general, stock plant nutrition at a level that is suboptimal for shoot growth is best for rooting (Moe and Anderson, 1988}. Evidence suggests that other elements such as P, Ca, Mn and Zn are also important for root initiation (Blazich, 1988).

Traditional recommendations for moderate level of stock plant nutrition, particularly nitrogen, whose deficiency of may reduce rooting is reported. Fertilization programme should ensure that the plant receives balanced fertilizer. Excess nitrogenous fertilizer should not be applied towards the end of growing season which can inhibit rooting. Nitrogen is required at the beginning of the growing season to encourage maximum shoot growth.

Water Status

It plays important physiological role in vegetative propagation. Successful rooting in cuttings depends to a considerable extent on maintaining a satisfactory water balance in the tissue. Proper water status of stock plant at the time of shoot harvesting helps in maintenance of turgor in the cuttings to achieve good rooting.

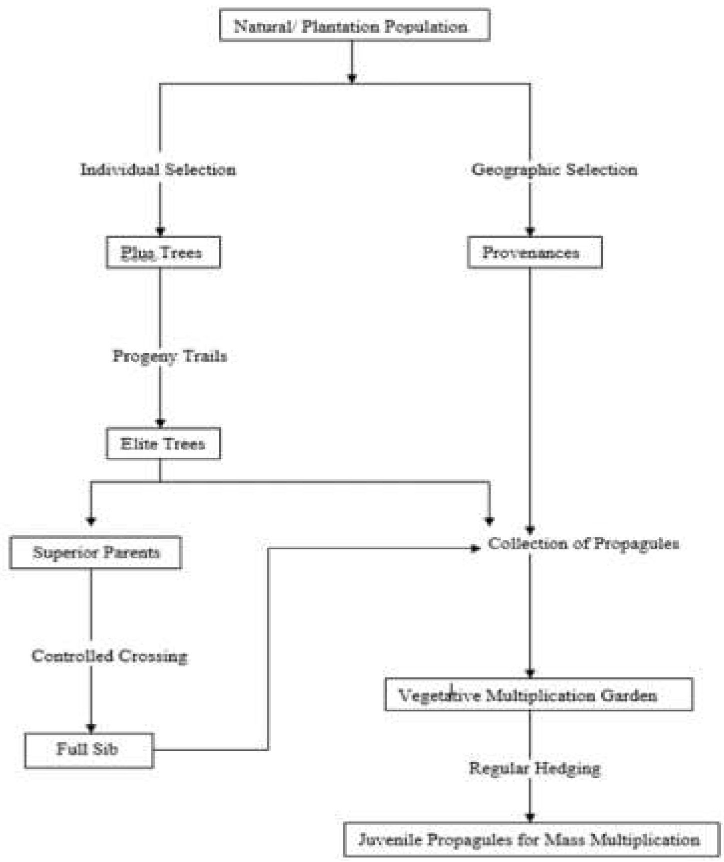


Fig 6.4. Establishment and Management of VMG

Persistent water stress seriously affects the growth and development of stock plants (Fig. 6.5).Thus, irrigation of stock plants must be ensured especially in drier period of year. Frequency of irrigation will depend on local climatic conditions. Irrigation schedule should be chalked out on the basis of soil moisture content. However, it should be provided at least fortnightly in hot summer month. The quality of water used for irrigation of stock plants should be free from infection, impurities and excess of salts.

Fig 6.5. Wilting signs due to water stress in teak stock plants

Hedging

Hedging of stock plants is the most essential part of VMG management (Fig. 6.6). The appropriate hedging of stockplant in VMGs provides continuous supply of orthrotropic shoots with high rooting potential for vegetative/ clonal propagation. Species dependent and need specific hedging schedules deserve to be standardized. Hedging schedule has a bearing on the number of coppice shoots per stock plant and number of nodes per coppice shoot. Intensive hedging increases the number of coppice shoot per stock plant but may result in crowding of weak coppice shoots with poor rooting potential. Excessive crowding of coppice shoots on a stock plant decreases their regenerative quality due to their diminutive size with less food reserves (Menzies, 1992). Thus, an effective hedging schedule should optimize production as well as the rejuvenility.

Fig 6.6. Hedged stockplants in teak VMG

In teak, the management of VMG by two hedging to stock plants per year has been found suitable for production of quality vegetative propagules. In tropical conditions hedging of stock plants should start in the third year of establishment or when the plant has attained a height of 1m. The severity of pruning during hedging is generally determined by the growth pattern/ habit of individuals in the VMG and the ease with which cuttings can be collected from the stock plants. Generally, hedging is done twice to thrice a year. Hedging should be avoided in peak summers (May-June) and rainy season (July-August). During summers young bud sprouts may die due to excessive heat while a rainy season hedging invites infection at exposed cut ends.

At the time of hedging the splitting of stems should be avoided, using a good quality saw. Detopping the plant by a slanting cut about 50 cm from the ground is often recommended. After hedging, all diseased and dead material should be removed to discourage infection to healthy stock plants.

Cutting Harvest

The dominant/ larger shoots are harvested first, allowing the growth of suppressed shorter shoots for some time. The shoot cuttings are collected early in morning or in the evening as it checks sudden moisture loss. Very tender or hard lignified coppice shoots are not suitable for vegetative propagation. Coppice shoots of fine round outer appearance should be preferred over quadrangular ones.

In teak, a single hedged stock plant provides around 25-30 single node cuttings of desired characteristics. However, it varies with species and stock plant management.

Management Schedule

The management of stock plants in VMG needs a well-planned schedule which incorporates soil working, weeding, fertilizer application, irrigation and hedging frequency and is based on growth behavior of species, best rooting season and overall requirement of plantlets.

7 NURSERY RAISING OF QUALITY PLANTING STOCK

Success in the establishment of plantations depends on good seed, quality of planting stock and on planting technique appropriate to the climate and site. Though large-scale planting is undertaken in the country every year yet the survival is often poor. This suggests that there must be some fundamental practices being overlooked. Hence there is a growing need to provide information on basic nursery and plantation technology to all those associated with tree growing activities.

SEED

Good quality seed is essential for the success of plantations. It costs almost the same to establish a plantation from poor seed, as it does from seed of high genetic potential. However, differences in the quality of plants produced and economic returns can be great and vast.

Seed Quantity

The quantity of seed to be collected depends on the number of plants required, germination percentage of the seed lot, loss in pricking out, mortality in seedling containers or transplanting bed and cull loss. Estimation of seed quantity for raising nursery stock is explained with the following example:

Suppose 10,000 plants of babul are required for planting.

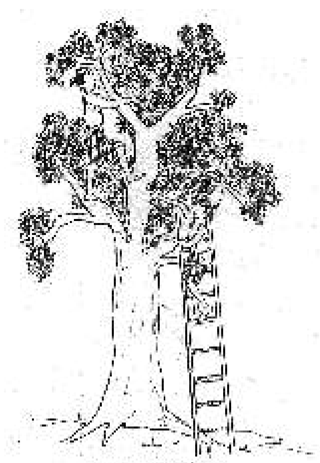
Number of seeds per kg	-	9000		Survival
Germination percentage	-		70 %	70 °/o or 0.70
Loss during pricking	-		15 %	85 % or 0 85
Mortality in containers or transplant bed	-		10 %	90 % or 0.90
Cull loss	-		20 %	80 % or 0.80

The survival factor is 0.7 x 0.85 x 0.9 x 0.8 = 0.43.

It is therefore necessary to have {(10,000 X 100)/ 43} or 23256 seeds or 2.6 kg of babul seed.

Seed Collection

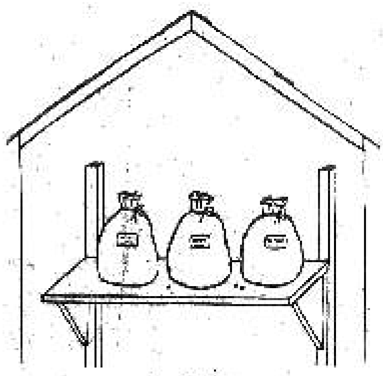
- Seed should be collected only from healthy, vigorously growing trees of desirable form and shape. Seed collection from isolated trees should be avoided.
- Collection of seed should be made from the branches growing in the sun.
- Only ripe seed should be collected.
- Seed collection methods depend on size and nature of seeds and height of trees.


Seed Collection

- Seed fallen on the ground should be avoided as it could be rotten or filled with insects. However, big mature seed or fruits which fall on ground can immediately be picked up.
- Other collection methods include hand picking from lower branches, collection by using long handled tools and ropes in case of higher branches and by climbing very tall trees.
- Seeds after collection should be cleaned up to remove unwanted parts of huh and other impurities before sowing or storage.

Seed Storage

- Seeds should be shade dried to bring down the moisture content (8 -12 %) and should then be stored in a dry and cool place.
- The three important factors to keep seeds viable during storage are temperature, humidity and aeration.
- Seeds tend to germinate with higher temperature and humidity.
- Lack of aeration may kill the seeds by suffocation.
- Seeds should never be stored on the ground. The seeds can be stored in gunny bags, paper cartons or cloth bags. The plastic bags should not be generally used either for seed collection, transportation or storage as the seed may rot inside the bag. Only well dried hard seeds like albizia, acacia, cassia, leucaena, eucalyptus and casuarina can be stored in plastic bags.
- If seeds are to be stored for longer duration, they should be treated with seed dressing fungicides like captan, thiram or agrosan. For treatment of 1 kg of seeds, 4-5 g of fungicide is generally sufficient.



Seed Storage

- The stored bags of seed must be labeled with the name of species, location, date of collection and name of collector etc.

Seed Treatment

Seeds contain tiny, fragile plants that live under the hard seed shell. One must be careful not to damage the newborn plant inside. Seeds need water to germinate. Some seeds have such a hard shell that water cannot easily enter the seed to help it sprout. In such cases, seeds are to be pretreated to help them absorb water and germinate. There are many methods to treat seeds and the important ones are described below:

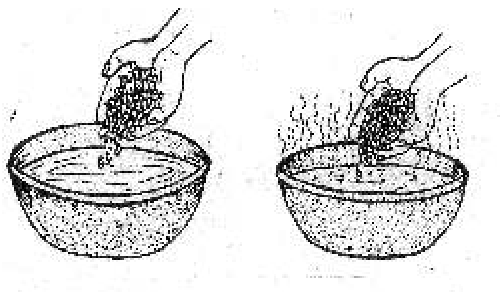
Cold Water Treatment

Some seeds need lots of water so that they germinate at the same time. Others have certain chemicals inside the seed, which must be removed before the seed can germinate. The cold-water treatment is a good method to treat such seeds. The seeds of pine, aonla, kachnar, kala siris, khair etc. can be treated in this way.

Method: Put the seed in a volume of water five times that of volume of the seed. Let the seed soak for 1-2 days, changing the water every 12 hours. Discard any seed that floats to the top. All swollen seed are fit for immediate sowing.

Hot Water Treatment

This method is used for the treatment of seeds with hard seed coat such as fascia, sesbania and albizia.



Method: Boil a volume of water five times the volume of the seed. Let the water cool for ten minutes and soak the seed in hot water. Discard any seed that heats to the top. Keep the seed in this water for two days or until most of the seed have swelled. Change the water every day with cold water. Once the seed swell, sow them immediately.

Boiling Water Treatment

This method is applied to the seeds that have a very hard seed coat, such as acacia and prosopis species.

Method: Boil a volume of water five times the volume of seed. Take the pot of water off the fire and soak the seed immediately. Leave the seed in water for only one to two minutes. After two minutes replace the hot water with cold and let the seed kept soaked in the cold water for 2-3 days or until the seed swell, changing the water every day. Once the seeds swell, sow them immediately.

Wet and Dry Treatment

This method is applied only for teak.

Method: Soak the teak seed in cold water for 48 hours. Spread them in the sun thereafter to dry at least for 48 hours. Repeat this process 5 to 8 times before sowing in the germination beds.

Acid Scarification

Very hard coated seeds like prosopisand certain acacias can also be treated with acid to break the hard testa (seed coat).

Method: Soak the seed in 20 % sulphuric acid for one hour. Drain acid and wash seed thoroughly three to four times with clean water. The seed can be sown thereafter. Proper precautions should be taken while handling the acid

Seed Sowing

Seed should be sown neither too deep nor too shallow in the soil. A seed sown too deep may rot and never germinate. On the other hand, sowing too shallow may cause it to either dry out or splashed out of' the container or germination bed during watering. Sowing depth depends on the seed size. Larger seeds are to be sown deep in the soil whereas small seeds less deep. The depth of sowing should be two to three times the thickness of the seed. This covering keeps the seed moist and warm. Always sow seeds in the shade and at proper time. Time of sowing of some seeds in nurseries is given in (Table: 7.1)

Table 7.1. Time of sowing of seeds in nurseries

S. No.	Period	Species
1.	January to March	*Casuarina equisetifolia, Grevillea robusta, Eucalyptus camaldulensis, E. tereticornis, E. citriodora, E. hybrid, Leucaena leucocephala, Melia azedarach, Acacia auriculiformis, Anthocephalus chinensis, Jacarunda mimosaefolia*
2.	April to June	*Acacia catechu, Albizia lebbeck, A. procera, Aegle marmelos, Bauhinia purpurea, Bombax ceiba, Cassia fistula, C. javanica, Dalbergia latifolia, D. sissoo, Kigelia pinnata, Lagerstroemia parviflora, Ceiba pentandra, Pongamia pinnata, Terminalia alata, T. arjuna, Spathodea campanulata, Bamboosa arundinacea, Tectona grandis*
3.	July to September	*Alstonia scholaris, Anogeissus latifolia, Azadirachta indica, Bauhinia variegata, Delonix regia, Syzygium cumini, Cassia siamea, Gmelina arborea, Hardwickia binata, Mangifera indica, Morus alba, Madhuca indica, Dendrocalamus strictus, Shorea robusta*
4.	October to December	Direct sowing in polythene bags in case of *Casuarina equisetifolia, Eucalyptus* spp. and other species

Sowing techniques vary with the size, weight and type of seed. Seed can be divided into four classes depending on their size:

i. Very small, light seed

These may either be sown in germination trays or beds and then pricked out into the containers. Seeds of eucalyptus and casuarina fall into this category which should be sown covering them with thin layer of soil. Watering should be lightly done using fine rose-can to avoid splashing them out of soil.

ii. Medium sized seed

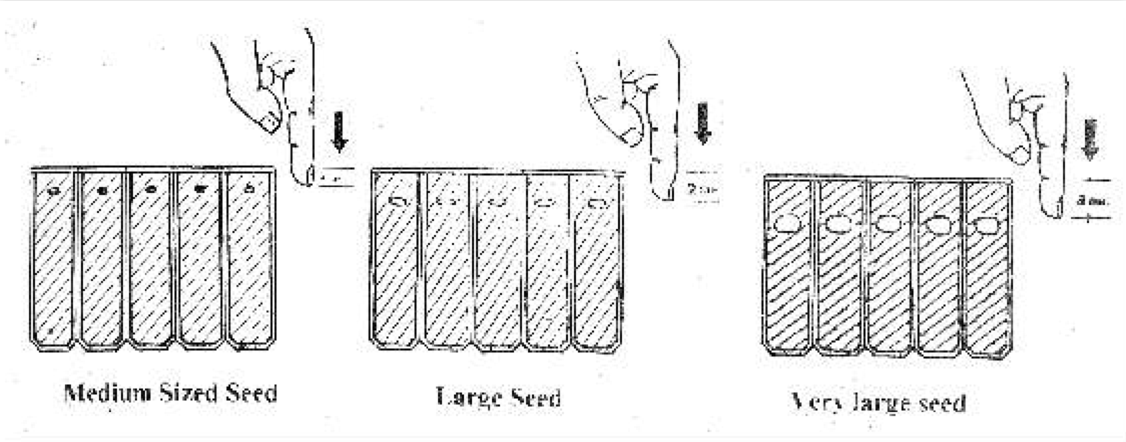
The seeds of acacias, cassia, albizia and prosopis fall in this category and they should be sown about one centimeter deep.

iii. Large seed

The seeds of azadirachta, tamarindus, samanea and erythrina come under this category and such seeds should be sown about two centimeter deep.

iv. Very large seed

The seeds of tectona, ziziphus and sweetened fall under this category and these should be sown about three centimeter deep.



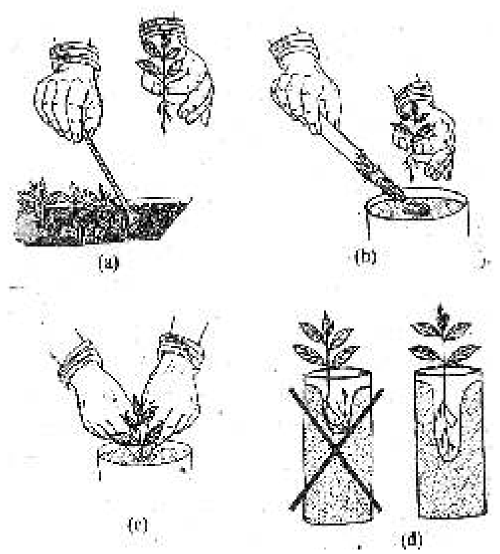
Germination beds

Seeds can be sown directly into the containers. Seedlings that are directly seeded grow faster and have fewer disease problems. However, germination beds or trays are preferred due to following reasons:

- Germination bed is used to provide a reserve of seedlings which can be used to replace direct seeded plants that did not germinate or that died.
- Germination bed is used for the seed which germinate slowly and unevenly.
- Germination bed is used when the quality of seed is not known.
- Germination bed is used for very small seed such as eucalyptus.

Sowing mix for germination

- Sowing mix used for germination of seeds should be low in organic matter and allow good water drainage.
- It should either be coarse grade river sand or an equal mixture of river sand and sandy loam soil.
- The sowing mix should be sterilized by making a foot high heap in the open sun covered with a polythene sheet and kept for seven days.



(a) Loosen soil and take out seedling (b) Make a hole larger than tap root length
(c) Press the soil firmly (d) Never bend the roots

Pricking and transplanting

PRICKING OUT AND TRANSPLANTING

Pricking out is necessary when seeds are sown in germination beds/trays.

Pricking is preferably done when the seedlings have just two leaves. Successful pricking out and transplanting involves the following steps.

Pricking out

- Water the seedlings thoroughly before pricking out.

- Hold the seedling between thumb and forefinger by the leaves or just below the first pair of leaves.
- Do not squeeze the stem too hard, it is very fragile.
- For best results use a small tool to loosen the roots before pricking out.

Transplanting

- The transplanting should be done in a hole longer than the tap root length made by inserting a wooden stick in the container.
- Never bend the roots to force them to fit into the hole. If the roots are too long, cut off the root tips or make the hole deeper and wider.
- Press the soil firmly around the seedling before watering it.
- Always transplant seedlings in shade.
- Keep the seedlings in shade at least for one week after transplanting.

SEEDLING CONTAINERS

Polybags

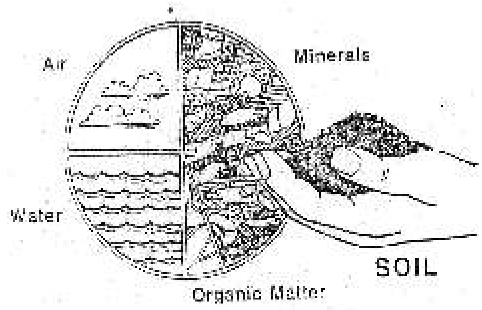
- Most of the tree species are raised in polybags which are cheap and well adapted to the forest nursery systems.
- Polybags of size 22 x 12 cm and of 200-gauge thickness are generally used. These should be gusseted, black in color and with at least 6-8 holes in the lower half.
- Seed is either directly sown into polybags or the seedlings is transplanted from germination beds or trays. Polybags are filled with soil, sand and farmyard manure in adequate proportion to give a light textured, loamy potting mixture with a pH between 6 and 7 essentials for growth of tree seedlings.
- 33 g of 5 % aldrex for every one cubic meter of soil mixture should be mixed for best results.
- Polybags are then filled up with this well mixed and sieved potting mixture and are placed in rows and columns in multiples of 10 for easy counting.

Root trainers

Root trainers are increasingly being used to deal with the disadvantages of polybag seedling production system *viz*. poor root growth and root deformation. These rigid containers are usually tapered with a drainage hole at bottom and with 4-5 vertical ribs to prevent root coiling. The containers are raised off the ground to allow air pruning of roots. Root trainers require lesser inputs and have fewer weed problems. Roots are trained vertically downward and there is more fibrous root formation. These containers are made from high density polyethylene. These are available in various designs, shapes and sizes. Most common among them are Hiko Pots.

Seedlings raised in root trainers (Hiko Pots)

SOIL MIX FOR CONTAINERS



Elements that form soil

Tree seeds needs good soil so that roots can grow well. Soil is not a solid mass rather it has small spaces that are tilled with air and water. The roots take the air and water from these spaces and help the plant grow. Other two elements that form the soil are minerals and organic matter. For good growth of a seedling in a container, soil mix must meet the given requirements:

- It must be light in weight.
- It must be well drained.
- It must be free from insects, and pathogens.
- All organic matter must be fully decomposed.

The soil mix can be of various types depending on the availability of its constituents. Two such soil mixes are described here:

(i) Bagasse mix

Bagasse mix is a soil made of decomposed sugarcane bagasse, rice hulls and soil. Bagasse mix is prepared using well decomposed bagasse, rice hulls (whole) and fine soil (silty-loam) in the ratio of 7:1.5:1.5, respectively. Well decomposed bagasse is brown to black in color and greasy when squeezed between the fingers. Bagasse mix can have fertilizer included in the mix and used in root trainers.

(ii) Local soil mix

Local soil mix can be made with well decomposed manure from animals and composted farm or garden wastes. In order to prepare such a soil mix, 2 parts of compost are mixed with one part each of well decomposed animal manure, fine soil and coarse sand.

COMPOST

Compost is made from decomposed and rotten organic materials. It is very fertile with large amounts of nitrogen and other nutrients. The ingredients to make compost are organic matter i.e. bagasse, tree leaves and twigs, grass and animal manure, leaves from nitrogen fixing trees and other ingredients such as wood ashes, water and air. Urea is also added for nitrogen enrichment.

Preparation of compost

- Cut and crush the organic materials into small pieces.
- Mix the crushed organic material with manure. nitrogen fertilizer and ashes.
- Mix the coarse materials with the finer ones to speed decomposition.
- Make a pile of 1.5 meters height on 2 m x 3 m area.


A compost pile

- Water the pile just enough to keep it moist.
- Turn over the compost pile every 2 or 3 weeks to make the materials decompose faster. For proper decomposition the inside temperature of the compost pile should be around 60°C which can be checked by putting a thermometer or even your hand into the center of the pile. If it is hot, the conditions are just right for decomposition. If it is cold, check and see if it is too dry or too wet and correct the problem.

MAINTENANCE OF SEEDLINGS

Irrigation

Nursery plants needs optimum amount of water for growth. Many diseases such as root rot and damping are caused by excess water. Always remember that all seedlings do not require the same amount of water. Small seedlings do not require much water whereas larger seedlings require more water, more often. Plants growing in sun need more water also, water requirement is more on windy days. Clean water should only be used to avoid plant diseases.

Weeding

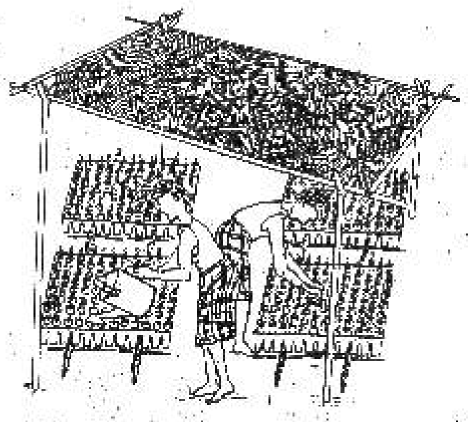
Removal of unwanted plants from the nursery beds or the seedling containers should be done as often as necessary. Hand weeding is most common. The weeds must be pulled when they are small and succulent before their root systems develop, Care should be taken not to disturb the roots of seedlings while pulling out the weeds.

Mulching

Mulching reduces water evaporation from soil, provides aeration in the root zone and reduces weeds. Adequate mulching can reduce the water requirement and boost the plant growth. Mulching can be done in many ways. One is to cover the soil between seedlings with straw, pebbles, sawdust or polyethylene. The second method is to cover the soil with pulled out weeds. However, while applying this method there is always a danger of introducing harmful pathogens in the nursery. The third method is to scarify the surface soil to break the capillaries responsible for soil evaporation. Mulching should be carried out when there is moisture in the soil.

Sun and shade management

Some shade is good for initial stages of seedlings, but too much shade can harm them. Plants growing in deep shade become tall, weak and can be very sensitive to sunlight. Seedlings should be hardened for sun slowly and gradually by opening up more and more light. Amount of natural shade in nursery can be reduced by pruning or removing trees surrounding it.



Seedlings kept under shade

Hardening of nursery stock

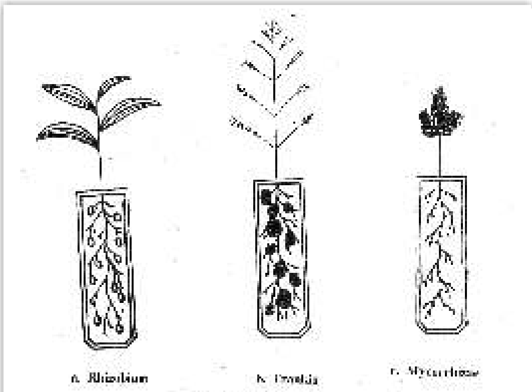
Plants in nursery receive all that they need to grow and be healthy. However, when planted out in the field, they may not have enough water or food. Therefore, seedlings must be made tough to survive under harsh conditions. This can be achieved by hardening of the seedlings i.e. to habituate them to harsh field conditions before they leave the nursery. Hardening is done by restricting the irrigation two months before planting in case of polybag plants and one month before planting in case of root trainer plants. Once the irrigation is stopped the leaves show signs of wilting. Irrigation should be given at this stage. When wilting is noticed again, irrigation should be provided. The polybags should be shifted only one month before planting out.

BIOFERTILIZERS

Some micro-organisms cause disease and must be avoided. But other microbes are good for plants and help them to grow. Many tree species need these beneficial microbes such as rhizobium, frankia or mycorrhizae, commonly known as biofertilizers. In the present scenario, use of inorganic fertilizers and pesticides is brought with the danger of aggravating the already grim environmental situation; use of environment friendly biofertilizers is greatly desired.

- Rhizobium: It is a microbe that lives in the roots of leguminous trees and fixes nitrogen for the plant. Seedlings with rhizobium are healthier and grow better. It is visible as little balls or nodules growing on the roots. Rhizobium is needed for acacias, sesbanias, albizias, prosopis etc. The use of rhizobium is species specific and one has to make sure the use of right kind of rhizobium for the species to be raised. Rhizobium is sold as fine black powder packed in plastic bags and must be stored in a cool and dry place.

- Frankia: It is another microbe that can fix nitrogen for the seedlings. It is found in the roots of species like alnus and casuarina and can be located by digging up 15-30 cm deep until some roots are visible. Brownish red colored large (1-5 cm diameter) nodules which are still solid and firm should be located and should be removed and dried in shade. Pound the dry nodules to fine powder and store in a plastic bag under dry and cool conditions. Casuarina and alnus seedlings in nursery must be treated with frankia.


Biofertilizers

- Mycorrhizae: Most tropical tree species develop symbiotic relationship with mycorrhizal fungi. The vesicular arbuscular mycorrhiza (VAM) fungi are widely distributed in all types of soils. VAM association's helpthe plants in increased nutrient uptake, increase plant resistance to harsh conditions such as drought, frost and soil acidity. Its applications have been observed to increase the growth and development of plants substantially Also. VAM inoculated plants exhibit much better survival. The inoculum of VAM consists of rhizosphere soil, root bits and spores which are cultured in the root zone of mane and other species in sand and soil mix.

Inoculation methods

- Seed inoculation: After the seed pretreatment, discard the water and mix 1 or 2 tablespoons of cooking oil and some rhizobium powder with the seed. Mix thoroughly until seed is completely covered with black powder and sow them immediately.

- Seedling inoculation: Mix 1.5 teaspoons of rhizobium powder in 10 liters of water in a rose can which can inoculate about 1000 seedlings. Water the leguminous tree seedlings requiring rhizobium inoculation and keep on shaking the can to prevent settling.

To inoculate casuarina or alnus, mix 2 table spoons of frankia powder into 10 liters in watering can. Water the seedlings requiring frankia inoculation. This mixture is sufficient for inoculation of 1000 seedlings. Always keep on shaking the mixture to prevent frankia from settling.

The inoculation of seedlings with VAM is done all around the root zone of seedlings in a 4-6 cm deep circle. About 10 g of inoculum is used per seedling. Watering is done immediately after inoculation. Sometimes seeds are sown directly on the inoculum so that roots get infected before transplanting.

PESTS AND DISEASES

Considerable damage is caused by pest and diseases in the nursery, resulting in poor planting stock, upsetting planting programmes and causing financial losses. Pest and disease control are necessary whenever symptoms of attack by virus, bacteria, fungi or insects are noted first of all it is necessary to identify the problem before treating it.

Pests

Observe the leaves carefully for insect droppings, insects or places where the insect fed on the leaf. Insects can attack leaves, stem and roots. The feeding pattern may help to identify the insect. The common insects causing damage in forest nurseries are grubs, cutworms, termites. crickets and grasshoppers. White grubs feed on roots or decaying vegetable matter. Cutworms live on or just below the soil surface and cause damage to young seedlings by cut the seedlings at the collar and eating the leafy part during the night.

Table 7.2. Common insects and fungi damaging forest nurseries and their control measures

S.No.	Type of Pest	Control Measures
1	White grubs	Application of thimet 10 g @ 200 g per bed in split doses, first at the time of preparation of bed and second after one month of germination.
2	Cutworms	Treatment of soil with 5 % sumicidin dust @ 60 kg per ha is an effective protection against insect damage.
3	Termites	Termites Application of 5 % sumicidin dust @ 60 kg per ha is an effective control.
4	Crickets and grasshoppers	I. Application of malathion (0.25 %) water emulsion spray is effective in controlling the pests. II. Spray of thiodan 35 EC @ 1 liter per 100 liters of water is also effective.
5	Defoliators	Foliar spray of Endosulphan 0.05 % (1.5 ml per liter) or malathion 0.1% (2.4 ml per liter) water emulsion is an effective method of checking the damage.

Termites live in colonies and are sub-terranean in habit. They cause damage to the roots by removing the bark of the tap root, thereby killing the seedlings. Crickets and grasshoppers feed on foliage of young seedlings and low shoots. Defoliators are foliage feeding beetles and caterpillars. They feed on entire leaf tissue and skeletonize the leaves.

Fungal Diseases

Each disease has a pattern of damage which can be used to identify it. Some diseases make spots on the leaves; others attack the stem or the roots of the plants. Damping off is the most serious disease of nursery seedlings caused by a number of soil saprophytic fungi. The common fungi causing damping off belong to pythium, rhizoctonia and fusarium species. Mortality in the seedlings may occur at three stages during their growth, i.e., pre-emergence damping off, post-emergence damping off and root and collar rot in older seedlings. A variety of pathogens attack foliage parts of seedlings causing rusts, blights and leaf spots.

Table 7.3. Common diseases damaging forest nurseries and their control measures

S.No.	Disease	Control Measures
1	Damping off (Pre and post emergence)	Controlled by seed and soil treatment with chemicals. Seed treatment: Systemic infection can be controlled by dip treatment of seed in 01 % water solution of emisan for 15 minutes and keeping the seeds for 24 hours before sowing. Pre-emergence damping off can be controlled by treating the seeds with a slurry made by mixing 140 g of Thiram or Captan in one liter of water. Soil treatment: The chemicals are applied into the top 15 cm of soil, one day prior to sowing. Some of the chemicals and their dosages per sq.m. captan- 24.50 g, zineb- 31.10 g and biltox- 23.08 g.
2	Collar rot	Drenching of soil mixture with 03 % water suspension of any copper-oxychloride fungicide containing 50 % active ingredient. Drenching may be repeated after 3 weeks if disease persists.
3	Root rot	I. Fusarium root rot diseases are controlled by drenching the soil with 0.2 % water suspension of thiram or captan. II. Rhizoctonia root rot is controlled by drenching the soil with 0.2 % solution of brassicol
4	Foliage diseases	Foliage pathogens are controlled by spray of 0.2 % suspension of dithane M45 or 0.2 % water solution of bavistin.

There are four ways to prevent pests and disease problems in the nursery:

- Sanitation: Nursery site must be kept clean of all discarded material, grasses and weeds. The diseased plants must be kept far away and isolated to avoid any further spread of the disease. Never let water stand anywhere in the nursery.
- Air circulation: Air must circulate freely in the nursery. Good air circulation can be maintained by pruning branches of large trees that prevent air from circulating or that create too much shade. Containerized seedlings can be kept at least one foot above the ground to facilitate air circulation.
- Watering: Soil that has too much water lacks air and roots cannot breathe well, resulting in weak plants. Watering in root rot and collar rot prone seedlings should be done only when the soil is almost dry. Soil should not be dry otherwise the plants will get burnt. Such plants become week and are easily attacked by insects and diseases.
- Sun and shade management: Always put the plants in sun as soon as seedlings are few inches tall. Early sun helps them to grow faster and healthier.

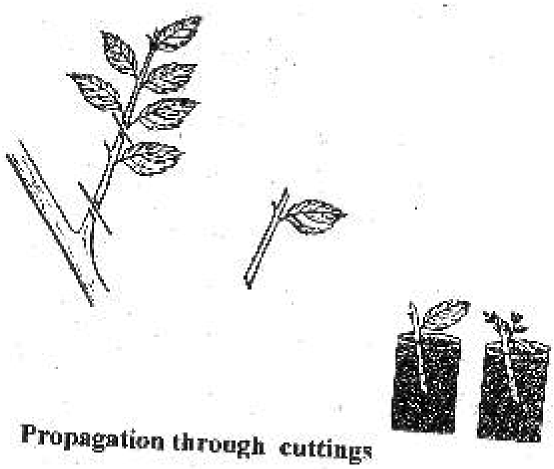
VEGETATIVE PROPAGATION

Normally forest trees are planted through seeds. Most tree species are cross pollinated seedlings. Therefore, show variation in growth and other features. Vegetative propagation is employed in many tree species for multiplication of an individual tree of outstanding characteristics. The resultant plant is similar to the donor tree and therefore inherits all the outstanding characteristics such as more yield, better wood quality, straight stem etc. Most commonly used vegetative part for multiplication is stem or branch cuttings.

Propagation through cuttings

Rooting of stem or branch cuttings are the most commonly used method of vegetative propagation.

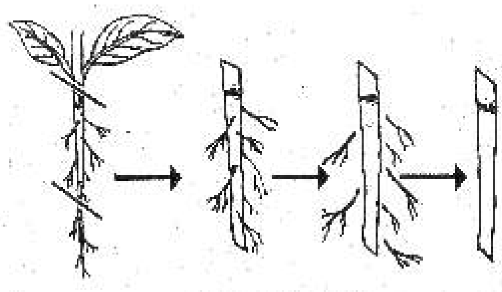
- Cuttings should be collected from healthy, vigorously growing young trees and never from very old or malformed trees. Cuttings from very old trees are not usually successful. One-year old nursery stock can also be used for making cuttings.
- The best season for getting the cuttings is winter when the growth rate is slowest or when the trees are usually leafless.
- Cuttings should be of around thumb thickness and about 22-25 cm in length.



Propagation through cuttings

- Cuttings should always be made with a sharp tool so that the cut is clean. Blunt knives or cutting axes can damage the cuttings by rupturing or splitting the ends. The end cuts should be slanting with 15-18 mm length.
- There should be at least 3-4 nodes in a cutting of species like poplar and willows which requires no treatment before planting in beds. Other species like neem, sissoo, karanj and bamboos require hormonal treatment with gibberellic acid, IBA, IAA etc. for better rooting.

Stump preparation


Stump making

Stumps i.e. root-shoot cuttings are prepared for planting in case of species like sissoo and teak.

- The stumps should be made by digging up 1-2 year old plants from raised beds. The length of the root is about 20-25 cm and the length of shoot is about 5 cm. The collar should be of around thumb thickness.
- The cutting of stumps must be done with a sharp tool so that the plant is not damaged. The cutting tool should be frequently sterilized with rectified spirit to avoid possibility of transferring disease from one plant to another.

Planting

- The preparation of planting site begins at least one year in advance. It involves survey for topography, aspect, gradient and drainage.
- Type of soil, soil depth, structure and fertility is also recorded along with existing vegetation if any. Data on rainfall and temperature should also be collected. A detailed soil testing to know the status of available nutrients such as N, P, K and pH is required to be carried out. This will decide the type of species to be planted, need and amount of fertilizer application and type of soil working to be carried out.
- Prior to the planting of seedlings in the field, the planting site is cleared of bushes etc., and layout of pits is carried out at a suitable spacing depending on nature of species, purpose for which it is grown and site conditions.

Soil working

Pit size of 45 x 45 x 45 cm3 is appropriate for good soils and 60 x 60 x 60 cm3 is required for poorer soils. However, in usar areas deeper pits of 90 cm depth are made and to replace with good field soil. ‘Kanker pan’ in such soils exists 60-90 cm below the ground surface which must be broken so that roots are able to penetrate the pan. In areas prone to water logging, planting is done on mounds 60-90 cm high. In dry areas and ravines, trenches of 45 x 45 cm2 cross section and length varying from 2 to 3.5 m are dug. The spacing between the trenches is kept 3 m and soil is piled up on the berm to form a ridge. Sowing of seeds can also be done on the ridges. Soil working should be done at least one month before planting.

Spacing

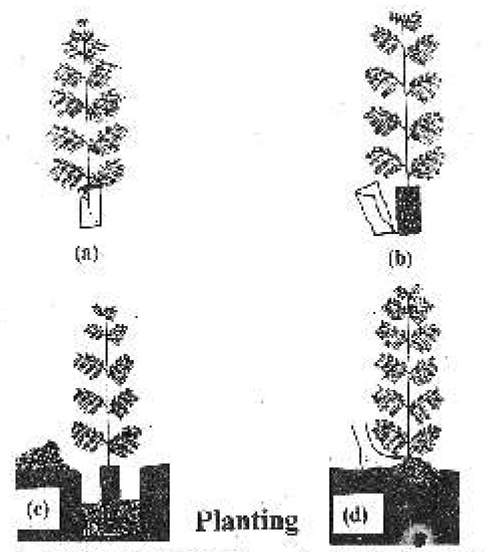
The most common spacings adopted are 2 x 2 m2, 2 x 3 m2, 2.5 x 2.5 m2, 3 x 3 m2, 4 x 4 m2, 4 x 5 m2 and 5 x 5 m2 depending on the species, type of soil, site etc. Close spacings are used for growing short rotation fuel wood/ pole crops and wider spacings are used for sawn wood species.

Planting of seedlings

- Field planting is done with healthy and vigorously growing seedlings during rains.
- The plants should be transported in the morning and only as many plants should be taken as can be planted on the same day.
- Care should be taken not to disturb the root system while transporting the polybags. In case of bare root planting,

the roots should always be kept moist and should not be exposed to light during transportation.

- The planting pit should be half filled with the excavated soil, mixed with compost, and 15-20 g of aldrex per pit.
- While planting, polybag should be removed and plant should be held in a vertical position by the collar in the centre of the pit. The collar should be kept about 10 cm above ground levelso that when soil is pressed, it does not go below the ground level.
- The soil should be well pressed so that the roots buried are in complete contact with the filled soil. During bare root planting precaution must be taken so that the buried roots are in their natural position.
- The soil should then be consolidated again first by hands and then by feet thoroughly so that it is well pressed leaving no interspaces inside. The test of good planting is that the seedling once planted cannot be pulled out easily.

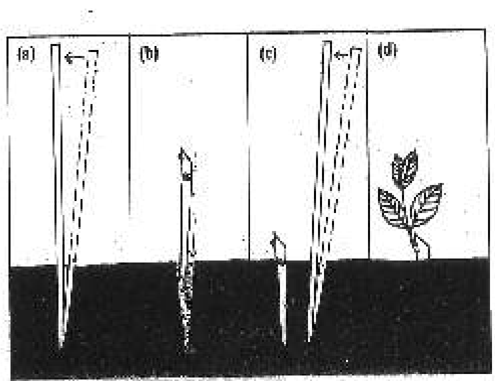


Planting

a. A healthy polybag seedling b. Removal of polybag
c. Placement of seedling d. Consolidation of soil

Stump Planting

- The stumps are planted in the field in holes made by crowbar, or in pits of size 30 x 30 x 30 cm^3. Crowbar holes should be made only in lighter soils and the hole should not be deeper than the length of the root.
- The stump is held by the collar which is kept one cm above the ground and the root portion is put inside the hole.
- The earth is tilled in from all sides and pressed so that no empty space is left. Some extra soil sloping should be used to cover the stump up to the collar.
- When a pit is made, it is tilled with the soil while holding the stump in the same manner and the soil is compacted fairly well.



Stump planting

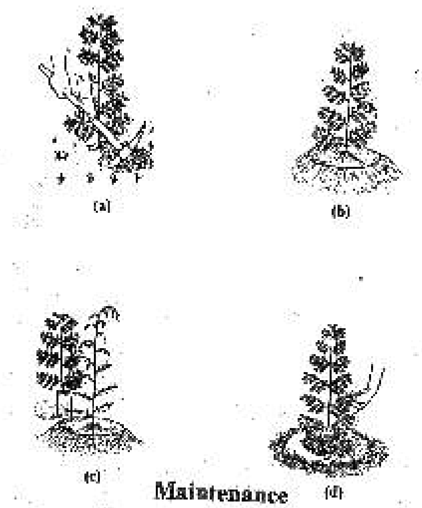
a. Make hole with crowbar b. Place the stump upright
c. Compact soil with crowbar d. Sprouted stump

- The test of good stump planting is that the stump should not come out when pulled with ordinary force.

MAINTENANCE OF PLANTATIONS

First Year

After about two weeks of planting, weeding should be done around the plant in a circle of' one meter. The soil should be loosened to a depth of 10-15 cm. In case of dead plants, the replacement with a new plant should be done at the same time. Fertilizer application should be done one month after planting, by loosening of soil 15 cm around the plant and mixing the fertilizer @ 20 g per plant. Second weeding and hoeing operation is done in the same way after two months of planting. Third weeding and hoeing should be done only when required. Mulching is a desirable method of weed control and moisture conservation. The weeds pulled out during weeding and hoeing operation can be used for mulching. In areas prone to termite attack, endosulphan 0.1 % (3 ml per liter) should be applied in the month of October-November. If termite attack is observed, endosulphan should be applied again in January-February. Endosolphan water emulsion should be applied m 500 ml per plant.



Maintenance

Second year

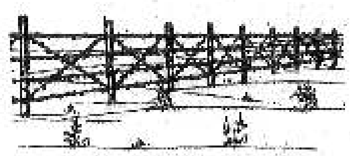
Two weeding and hoeing operations are generally carried out in the month of August and October respectively. Casualty replacement is also carried out by planting of healthy plants. Pruning of lower branches is carried out in case of fast-growing species.

Third Year

Only one weeding and hoeing operation is generally done in the third year. Pruning of branches up to one third height of the plant is done to have more height growth and straight stems.

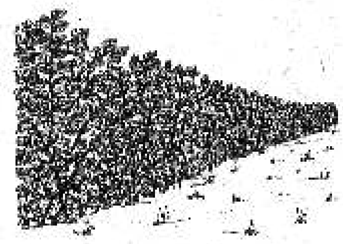
IRRIGATION

Irrigation of plantations is not always possible. In most cases young plantations have to pass through prolonged dry and hot periods resulting in considerable casualties especially in arid and semi-arid regions. Watering must be done in areas where possible, during the first 2-3 years of planting in the dry and hot periods. Irrigation ensures better survival and growth of the plants.


Barbed wire fencing

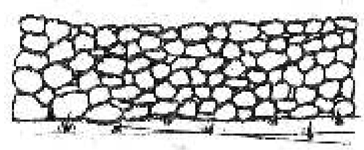
MULCHING

Mulching is of vital importance in dry regions. Any material which is used at the soil surface to reduce evaporation losses is termed as mulch. Usual mulching materials are plant residues, manure, soil and stones etc. Mulching is beneficial for suppression of weeds and conservation of moisture. Organic mulch also contributes to enhance nutrient availability and improvement of soil structure.


Live hedge

PROTECTION

Almost all young plantations are vulnerable to browsing and trampling damage by domestic cattle. Any planting without protection, sooner or later is bound to be a failure. The protection can be done with barbed wire fencing, cattle proof trenches, stone walls or by live hedges. The barbed wire fencing is costly and carried out generally for departmental plantations.


Stone wall

8 SELECTION OF SITES AND SPECIES

Increasing the productivity of natural forests and plantations though mandated with the forest department, involvement of local people and common masses to contribute to increase the green cover of the country is equally important. As the area under very dense forests in the country is witnessing a decline, involving people in afforestation activities and promoting cultivation of indigenous species in scrub forests, waste and degraded lands and area outside forest can help increase the acreage.

Promoting planting of fodder and fuel wood species on farm bunds as per its applicability can help increase the green cover and increase the carbon sink. Quite often, there are a number of roles (such as fuel wood or fodder production) which, through careful planning, can be combined to achieve multiple benefits. This section of the manual describes the site and species selection for forest plantations.

SITE RECONNAISSANCE

The more the information available about the considered plantation site conditions, the better are the chances of selecting the tree and shrub species best suited to the area. Information most commonly included in site reconnaissance is:

- Climate - temperature, rainfall (amount and distribution), relative humidity, and wind.
- Soil - depth of soil and its capacity to retain moisture, texture, structure, parent material, pH, degree of compaction, and drainage.
- Topography - important for its modifying effects on both climate and soil.
- Vegetation - composition and ecological characteristics of natural and (when present) introduced vegetation. On areas which have not been degraded by man, the vegetation can provide an indication of the site. The sites where the vegetation has been disturbed and is no longer a reliable indicator of potential planting sites, site selection should be based on soil surveys.
- Other biotic factors - past history and present land use influences on the site, including fire, domestic livestock and wild animals, insects and diseases.
- Water table levels - knowledge of the depth and variation of the water table levels in the wet and dry seasons is valuable and can be crucial in determining the tree and shrub species that can be grown. Water table levels can be estimated from observations in wells or by borings made for this purpose.
- Availability of supplementary water sources - ponds, lakes, streams, and other water sources.
- Distance from nursery.

Apart from the above biophysical information, socio-economic factors also play an important role. Among these factors are:

- The availability of labor.
- Motivation of the local population.
- The distance of the forest plantation to the market and consumer centers.
- Land ownership and tenure.

SELECTION OF THE PLANTING SITE

Where to plant is generally a collective decision made by policy makers, foresters, and the planting crews, based on information obtained in the site reconnaissance. The key is to select the site that, when planted, will lead to the establishment of a successful forest plantation. Often, the choice of the planting site is limited to lands which are not suited for agriculture or livestock production; when this is the case, the site reconnaissance information gains importance.

The boundaries of the planting site, once the area has been chosen, should be marked with boundary posts. When there is a danger of trespassing and damage by grazing animals, a boundary fence should be established. Fencing is costly and, therefore, should only be built when other means of protection are not effective. Once a forest plantation is well established and the trees are sufficiently tall, the fences can be removed and reused at another planting site.

When roads and other passageways traverse the planting site, they should also be contained with fences. In many instances, tree and shrub planting is undertaken to protect fragile sites from degradation. However, in some situations, the fragile sites should not be planted; it may be better not to disturb the soil in these areas. Where gullies have been severely degraded by erosion, protective measures other than the planting of vegetation (such as building small check dams) may be necessary.

SPECIES SELECTION

When the best possible information has been collected on the characteristics of the site to be planted, the next step is the selection of the tree or shrub species to plant. The aim is to choose species which are suited to the site, will remain healthy throughout the anticipated rotation, will produce acceptable growth and yield, and will meet the objectives of the plantation (fuel wood production, protection, etc.).

Choice of species deserves thoughtful consideration as it controls the success of artificial regeneration. A minor error in the selection of species may result in the failure of the plantation which will lead to a huge loss of money, time and energy. Important factors to consider are site factors, purpose of plantation, silvicultural characters and economic factors.

Table 8.1. Suitable species for different climate types

Rainfall (mm)	Climate	Examples of suitable species
Less than 250	(a) Hot desert	*Prosopis juliflora, P. cineraria, Acacia tortilis, A. senegal*
	(b) Cold desert	*Salix* spp., *Populus, Juniperus* spp., etc
250-750	(a) Tropical semi-arid	*Prosopis juliflora, Acacia tortilis, A. nilotica, A. auriculiformis, Tecomella undulata, Eucalyptus camaldulensis, Ziziphus* spp., *Albizia lebbeck, Azadirachta indica*
	(b) Temprate semi-arid	*Populus* spp., *Salix* spp., *Juniperus* spp., etc
750-1200	(a) Dry-tropical and temprate	*Eucalyptus camaldulensis, Albizia lebbeck; Ailanthus excelsa, Cassia Siamea, Hardwickia binata, Acacia nilotica,* etc.
	(b) Dry sub-tropical and temprate	*Pinus roxburghii, Acacia* spp., *Cupressus* spp., *Robinia* spp., *Cedrus deodara, Juglans regia, Grewia optiva,* etc.
1250-2500	(a) Tropical semi-humid	*Eucalyptus* spp., *Tectona grandis, Gmelina arborea, Dalbergia latifolia, D.sissoo, Dendrocalamus strictus, Casuarina equisetifolia,* etc.
	(b) Temperate semi-humid	*Populus alba, Robinia pseudacacia, Pinus* spp. and *Cedrus deodara*
More than 2000	Tropical humid	*Eucalyptus* spp., *Terminalia* spp., *Syzigium cumini, Casuarina equisetifolia, Pterospermum* spp., *Michelin champaca, Chukrasia velutina, Artocarpus* spp., etc.

9 PLANTATION TECHNIQUES

Proper plantation of a tree can significantly favor the success of a plantation. Properly planted tree or shrub require comparatively less management and is more tolerant of adverse conditions. Planting technique impacts various requirements of the plant, minimizing and fulfilling its water, fertilizer and pesticide demands. Before planting the plant from nursery, it is important to gather prior knowledge of plant's nursery conditions like its soil type, drainage characteristics, availability of irrigation water etc. To have a successful plantation, the site should be specifically amended.

PREPARATION OF THE PLANTING SITE

Plantation site should be prepared before the seedlings of tree or shrub arrives from the nursery to ensure that planting can proceed without delay and have higher success rate of establishment. Site preparation is directed to give the seedlings a good start with rapid early growth. In general, the methods used to achieve site preparation will vary with the type of vegetation, amount and distribution of rainfall, presence or absence of impermeable layers in the soil, the need for protection from desiccating winds, and scale of the planting operations. Additionally, the value of the tree or shrub crop to be grown is important in determining the amount of expense that may be justified in plantation establishment. Generally, preparation of site should be done with the objectives to:

- Remove competing vegetation from the site.
- Facilitate soil moisture by captivating maximum water and rainfall and reduce surface runoff.
- Provide good rooting conditions, sufficient volume of rootable soil and eliminate hardpans for success planting.
- Create conditions to minimize danger from fire and pests.

METHODS OF SITE PREPARATION

The methods of site preparation largely depend on the size of plantation areas and availability of funds. For relatively small-scale plantations, sites can be prepared by labors by manual working the soil and clearing the competing vegetation. Animal-drawn ploughs and harrows can also be used according to requirement and economics for small-scale operations.

Mechanical soil preparation is common for in large-scale planting programmes and for soils demanding deep subsoiling and the breaking up of hardpans

Pitting: Pits for planting should be prepared well in advance. Planting pit (of an appropriate size) is dug to aerate and loosen the soil in which the plants will grow. These planting pits should not be left empty with the excavated soil but should be refilled immediately to prevent drying of the soil by sun and wind.

Planting should be done while the ground still has some moisture in it and so is soft and easy to dig. Hence, planting should preferably be done soon after the monsoon .

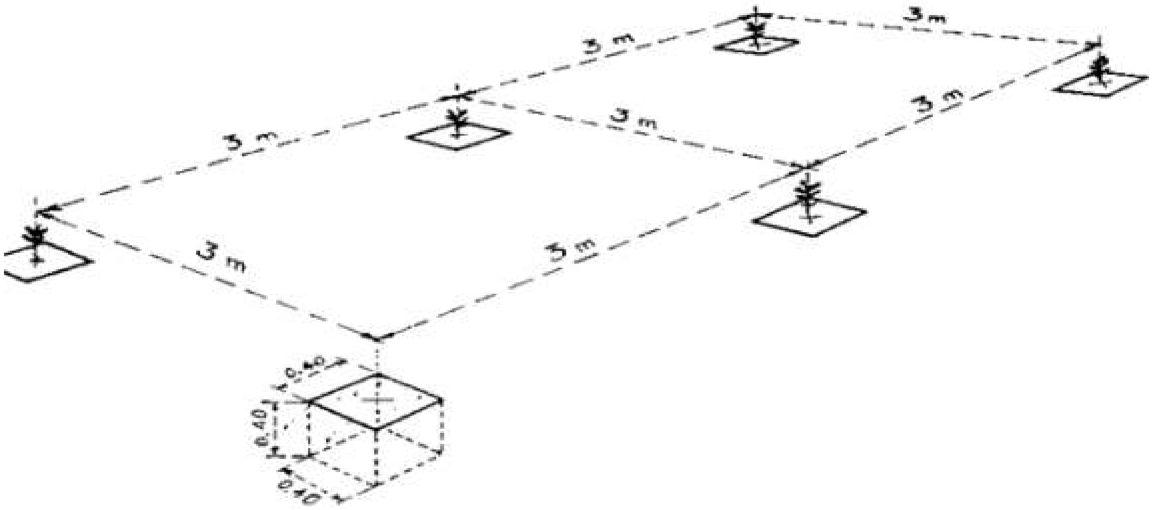


Fig 9.1. Planting holes 0.4 m x 0.4 m x 0.4 m at a density of 3 m x 3 m

The top-soil of up to 15 cm should be dug up and placed to one side of the pit, separate from the sub-soil from below 15 cm.

Soil preparation can be carried out in patches, strips, or by complete cultivation. Complete cultivation is necessary for tree and shrub species, which are intolerant of competition from grass, forte, and woody growth (such as most eucalyptus species). Sometimes, spot preparation may be sufficient, but the spots should be large (for example, 1 to 1.5 meters in diameter). Other methods of soil preparation by hand are the ash-bed method, tie-ridging, contour trenching and terracing, and the "steppe" method.

The ash-bed technique consists of piling the debris from harvesting or clearing the land into long lines or stacks. After drying, the debris is burned and vegetation is planted in the ash patches. Sometimes, the lines or stacks of debris are covered with "clods" to obtain a more intense heat when burning. Advantages of this method are that the burning kills the competing vegetation, the area remains free of this vegetation for an appreciable period, and the ash provides a useful fertilizer for the planted trees or shrubs.

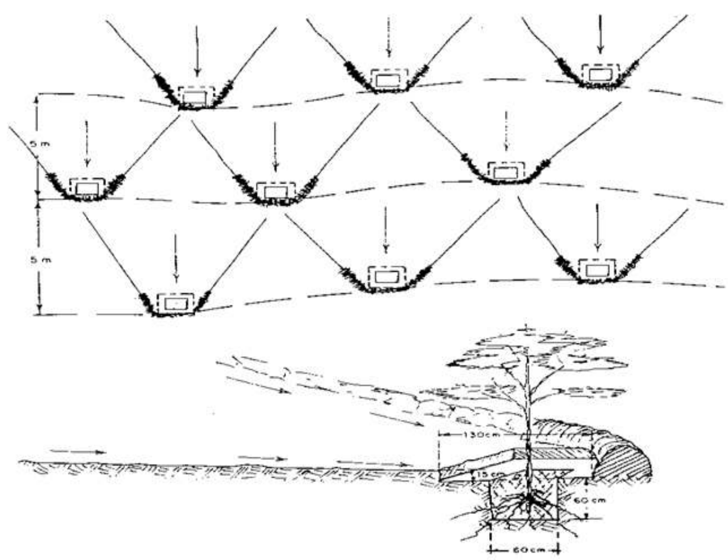


Fig 9.2. Herring-bone technique for soil preparation

The tie-ridging technique involves the cultivation of the entire area and establishment of ridges at specified intervals. The main ridges, aligned along the contours, are joined by smaller ridges at right-angles to create a series of more-or-less square basins which retain rainwater and prevent erosion. The ridges are generally 3 meters apart. The trees and shrubs are planted on the ridges. This method is suitable for flat or gently sloping ground and can be combined with an agricultural crop during the initial years of plantation establishment.Trenching techniques along the contours are used in site preparation in hilly country. The trenches can be continuous, divided by cross banks, or consist of short discontinuous lengths, arranged so that the gaps between the trenches in one row are opposite those in the next row; in this latter instance, runoff from rainfall is caught. Trenches are formed manually or mechanically. On gently sloping ground, the herring-bone technique can be used. Terraces, which are wider and flatter than trenches, can be either manually or mechanically formed on the side of a hill by digging soil from the uphill side and depositing it on the downhill side. Usually, the bottom of the terrace is made to slope into the hillside. The purpose of terracing is to retard and collect water runoff between the terraces. Because of the improved soil moisture conditions, the terrace provides improved conditions for plant growth. Planting is done on the ridge of soil, at the base of the ridge, or in patches at the bottom of the trench, according to moisture conditions. Terraces are used widely on moderate to severe slopes. Terraces can be 2 to 3 meters or several hundred meters in length (Fig. 9.3). If short, they can be staggered on the hillside wherever convenient. Sometimes, crescent-shaped terraces are constructed with the two tips of the crescent pointing uphill.

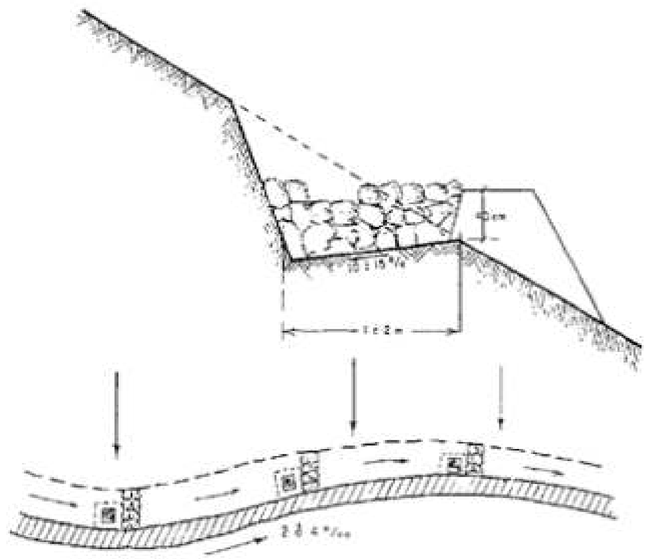


Fig 9.3. Soil preparation technique on steep slopes

The steppe method of site preparation is designed to promote growth of trees and shrubs of extremely dry areas. In this method, the surface of the soil is modified by breaking-up and stirring the deep layers of the soil with rooters, rippers, or large discs, and then building widely-spaced, parallel ridges following the contour. Ridges are built with the topsoil, and trees or shrubs are planted on the lower half of the ridges facing the slope; here, the depth of moist soil is greatest, due to accumulation of water after rain. The purpose of the "steppe" method is to maintain a reserve of moisture in the deep layers of the soil. Spacing between ridges is greater with lower rainfall, as the catchment area between the ridges is increased.

TIME OF PLANTING

The planting season generally coincides with the rainy season. Sufficient precipitation for planting must be judged on the basis of local knowledge. Planting can also be initiated when the soil is wet to a specified depth (approximately 20 centimeters).

A common mistake is to start planting too soon. On the other hand, if planting is started too late, it may be difficult to complete a large planting programme in the scheduled time, and the plants will lose the maximum benefit of rains after planting; this can be a serious matter where the rainfall is low and erratic.

PLANTING OF CONTAINERIZED STOCK

Planting of containerized stock is usually done in holes that are large enough to take the containers or the root-balls when the plants are removed from the containers. It is essential that the surrounding soil is firmed down around the plant immediately after planting to avoid the formation of air gaps which can lead to root desiccation.

A good practice for the preparation of planting holes is to surround the planting pit with a small ridge (15 to 20 centimeters in height) of soil, to obtain a small basin (about 80 centimeters in diameter); this is especially helpful when the plants are watered individually after planting. The small prepared basin can also be covered with a plastic sheet (held in place on the ground with stones or earth), with an opening in the center for the plant, as illustrated in Fig.9.4. The plastic sheet impedes evaporation of ground water from the planting hole; also, dew collects on its surface and runs to the central opening of the sheet to irrigate the roots. Through conservation of soil moisture, plastic films facilitate more rapid establishment and growth of trees and shrubs during the initial and most critical years. Another benefit of opaque plastic films is that they inhibit weed growth by reducing light penetration. With the suppression of weeds in the immediate vicinity of the plants, labor also can be saved.

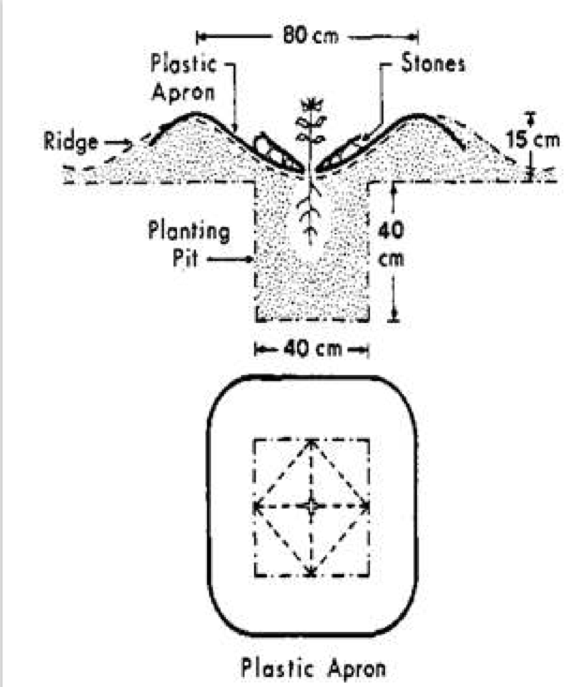


Fig 9.4. A planting hole with plastic apron to impede evaporation of ground water.

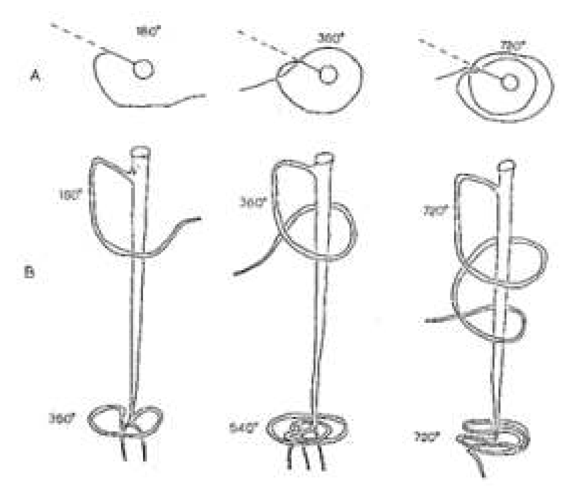


Fig 9.5. A Illustration showing the most common type of root doiling (one lateral root and the main root)

A threat to newly-planted trees in arid zones is the high rate of transpiration. Unless the plants can establish themselves quickly and compensate for the transpiration by taking water through their root systems, they will wilt soon after planting. This explains why even a single watering immediately after planting can be useful. In general, containerized seedlings have a distinct advantage over bare rooted seedlings, in that the earth ball surrounding the roots provides protection during transport and enables the plant to establish itself quickly and easily. The restriction of lateral root extension, a result of using containers, can cause root malformation, coiling, and spiraling (Fig. 9.5). In extreme cases, the coiling can lead to strangulation of the roots and the death of the plant. In other situations, it may reduce wind-firmness or lead to stunted growth. Unfortunately, the symptoms may not become apparent until 4 to 5 years after planting.

To reduce the damage of root malformation in containerized plants, a common practice is to remove the container from the soil cylinder before planting and make two or three vertical incisions to a depth of one centimeter with a knife to cut "strangler" roots. As a further precaution, the bottom 0.5 to 1 centimeter of the soil cylinder can be sliced off. Care must be used to ensure that the soil does not disintegrate and expose the roots to desiccation.

SPACING OF PLANTINGS

By observing trees and shrubs growing under natural conditions, it is often found that plants grow widely apart in low rainfall areas. Therefore, wide spacing of plantings in arid zones generally should be practiced to avoid competition for soil moisture.

The amount of water available to a tree or shrub in a plantation is proportional to the stand density. On dry sites, it is necessary to plant widely apart and to remove all competing ground vegetation; this increases infiltration of rainwater and decreases water losses through transpiration by plants and evaporation from the soil. When irrigation or mechanical cultivation is practiced, it is necessary to adjust spacing to the width of the machinery used and to ensure that plants are placed in straight rows. Actual spacing varies with species, site, and the purpose of the forest plantation. In fuel wood plantations, for example, one might prefer closer spacing's than employed in other kinds of plantations. Seldom can a spacing of less than 3 x 3 meters be applied.

PLANTATION TECHNIQUES OF SOME IMPORTANT SPECIES

1. *ACACIA AURICULIFORMIS* (Akashmoni)

Family	:	Mimosaceae
Uses	:	Wood is a good fuel, also used as pulpwood and is a cheap timber.
Seed collection time	:	February-March
Seeds per kg	:	35,000 - 40,000
Seed viability	:	Up to 12 months
Germination percent	:	50 -60 %
Seed treatment	:	Hot water treatment is given and seed soaked for 24 hours before sowing.
Nursery technique	:	Sowing is either done in germination beds or trays in February. Germination starts in 7 days and completes in 30 days. Seedlings are pricked out after a month's time in polybags and maintained until rains.
Plantation technique	:	Seedlings are transplanted in field in July at a spacing of 2x2 m. Wider or closer spacings could be adopted as per the objectives of plantations. Pit size is kept at least 30 x 30 x 30 cm.
Suitability	:	It is capable of growing on very poor soils. It can be successfully raised under different climatic conditions. Grows well on wide range of soils viz. from sand dunes to laterite soils but grows poorly on heavy soils and is frost tender.

2. *ACACIA NILOTICA* **(Babul)**

Family	:	Mimosaceae
Uses	:	The wood is used as small timber for making tool handles, carts and agricultural implements. It is an excellent fuel wood and good fodder. Gum is used in paints and confectionary and bark is used as tannin.
Seed collection time	:	April-June
Seeds per kg	:	7,000 - 11,000
Seed viability	:	1- 2 years
Germination percent	:	80-90 %
Seed treatment	:	Fresh seeds are sown directly whereas stored seeds are pre-treated with boiling water.
Nursery technique	:	Seeds can directly be sown in February March about one cm deep in containers filled with potting medium. Pricking out of seedlings from the soil is avoided due to sensitiveness of the tap root.
Plantation technique	:	Healthy seedlings 30-40 cm tall are planted out in well prepared pits of at least 30 x 30 x 30 cm at 2 x 2 m spacing.
Suitability	:	An important species for afforestation in tropical and sub-tropical regions with dry and climate. It is also suitable for alkaline areas.

3. *ALBIZIA LEBBEK* **(Kala siris)**

Family	:	Mimosaceae
Uses	:	Excellent fodder, wood used for furniture, internal decoration, paneling, agricultural implements and carving. Leaves can be used as green manure and bark as tannin.
Seed collection time	:	December-February
Seeds per kg	:	8,000-10,000
Seed viability	:	2-4 years
Germination percent	:	60-70 %
Seed treatment	:	Seeds treated with hot water i.e., soaked for 24 hours before sowing.
Nursery technique	:	Seed sowing is done in February-March in lines, 15 cm apart with 2-3 cm space between seeds. Sowing depth may vary from 1 to 1.5 cm. Germinated seedlings are pricked out in polybags and maintained until planting. Seeds can also directly be sown in polybags.
Plantation technique	:	Planting is done in June-July at a spacing of 5 x 5 m, in pits of size 45 x 45 x 45 cm.
Suitability	:	It can grow on a variety of soils and climate. It is also planted on road sides. It can be grown successfully even in saline and alkaline soils. Its characteristic climate is a long, hot summer and cold winter with annual rainfall from 600 to 1600 mm.

4. ***AZADIRACHTA INDICA*** **(Neem)**

Family	:	Meliaceae
Uses	**:**	Leaves are systemic insect repellent and antiseptic. Bark is used for fevers and skin troubles. Neem extracts serve as important biopesticide and seed oil cake is used as fertilizer. Timber is termite proof and used for construction. It has wide ranging medicinal properties and used in soap making.
Seed collection time	**:**	July-August
Seeds per kg	**:**	4,000-4,500
Seed viability	**:**	2-3 weeks
Germination percent	**:**	50 -70 %
Seed treatment	**:**	No treatment required but better germination reported in depulping the fruits before sowing.
Nursery technique	**:**	Fresh seed are sown in Polybags at a depth of 2 cm. Germination starts within one week and seedlings are planted out next year. Seed can also be sown in seed beds 15 x 3.5 cm apart, maintained and pricked out at 15 x 15 cm when two months old and planted out with ball of earth.
Plantation technique	**:**	One-year old seedlings are planted in July in pits of size 45 x 45 x 45 cm and at a spacing of 5 x 5 m.
Suitability	**:**	It is a hardy tree having a wide edapho-climatic adaptability. It grows in all parts of the country, particularly in drier regions but is not found on higher elevations. It is also planted as an avenue tree.

5. ***CASUARINA EQUISETIFOLIA*** **(Saru)**

Family	**:**	Casuarinaceae
Uses	**:**	Used as fuel wood. pulpwood and poles. Bark is used for tanning and dyeing.
Seed collection time	**:**	June-December
Seeds per kg	**:**	8-10 lakhs
Seed viability	**:**	8-12 months
Germination percent	**:**	50-60 %
Seed treatment	**:**	Seeds are either mixed with ash or gamaxene powder to ward off red ants which feed on these seeds.
Nursery technique	**:**	Seeds are sown in raised mother beds covered with sand or hay. Seedlings pricked out in polybags when 10 cm tall. Seedlings are sensitive to drought and excessive moisture.

Plantation technique : Planting is done in the pits of 45 x 45 x 45 cm filled with sandy pulverized soil at a spacing of 2 x 2 m.

Suitability : Extensively cultivated as a fast-growing species in coastal regions. It grows well on loose sand, in the close proximity of the sea. It does not grow on clayey soil or badly drained soil.

6. *DALBERGIA SISSOO* (Sissoo)

Family : Papilionaceae

Uses : Timber is used for high class furniture and cabinet work, musical instruments and carvings. Leaves used as fodder; small wood as fuel wood and for making charcoal.

Seed collection time : December-January

Seeds per kg : 50,000 - 55,000

Seed viability : 2-3 years

Germination percent : 90-95 %

Seed treatment : Not required but seeds can be soaked in cold water for 24 hours for faster and uniform germination.

Nursery technique : Broken pieces of pod, each containing one seed are sown in drills in properly worked up soil in February-March. They are covered with a layer of earth and too much watering is avoided. Pricking of two leaf stage germinants are done in polybags. In case of stump planting the seedlings are pricked out when 5 cm tail to transplanting beds at a spacing of 15 x 22 cm and maintained for 12-16 months.

Plantation technique : One-year old sturdy seedlings are transplanted into pits of size at least 30 x 30 x 30 cm at a spacing of 3 x 2 m. Stumps are planted with crowbar in 20 cm holes.

Suitability : Grows well on porous, alluvial soil with adequate moisture. It does not tolerate compact clayey soil or badly drained site. It is drought tolerant and adaptable to localities with average rainfall from 200 mm to 700 mm.

7. *DENDROCALAMUS STRICTUS* (Male bamboo, Bans)

Family : Poaceae

Uses : It is poor man's timber, used for basket making, house construction and as a raw material for paper pulp

Seed collection time : March-May (Flowering occurs both sporadically and gregariously)

Seeds per kg : 28,000-30,000

Seed viability : Up to one year

Germination percent : 30-70 %

Seed treatment : No pre-sowing treatment is necessary. However, cold-water treatment for 24 hours can give better results

Nursery technique : Drill sowing at a distance of 75 cm is done in September month. Seed should be covered lightly with fine soil or sand. The entire bed is then covered with straw and profusely watered with a tine rose can. The germinants are pricked out in polybags before November end and kept under shade for few days before shifting them to open sun

Plantation technique : Planting is done only when rains have set in adequately. The size of the pit should be 60 x 60 x 60 cm and spacing 5 x 5 m

Suitability : It grows well in well drained alluvial soil but also thrives well on slopes, rocky and impoverished sites

8. *PONGAMIA PINNATA* (Karanj)

Family : Papilionaceae

Uses : Seed oil used in soap and tanning industry and as a lubricant. Seed cake is used as manure. Wood used for making ploughs, cart-wheels, rafters, furniture and small turnery articles. Leaves valued as fodder in arid regions.

Seed collection time : March-May

Seeds per kg : 1,200 -1,500

Seed viability : Up to one year

Germination percent : 80 %

Seed treatment : Seeds should be given cold water treatment for 24 hours before sowing.

Nursery technique : Sowing can either be done in germination beds or directly in polybags in March-August. Germination begins in 10 days and completes in 30 days. The seedlings are maintained in nursery for 6-12 months.

Plantation technique : One-year old seedlings which are about 50-60 m tall are used for planting. Spacing is kept 4 x 4 or 5 x 5 m for block planting and 8-10 m for avenue planting. The pit size should be at least 30 x 30 x 30 cm.

Suitability : It grows on a wide range of soils. It is planted as avenue tree, and in wastelands for fuel and oil seed. It has been successfully raised on bhata land, bauxite mined over areas and on coal mine overburdens. The species is drought resistant.

9. *EUCALYPTUS TERETICORNIS* (Nilgiri)

Family : Myrtaceae

Uses : Excellent wood for pulping, for paper and rayon. The wood is also used as timber and poles. It is a good firewood and used for making charcoal.

Seed collection time : October-November and May-June

Seeds per kg : 3-4 lakhs

Seed viability : 1-2 years

Germination percent : 50 % - 90 %

Seed treatment : Pre-sowing treatment is not required as the germination is very quick.

Nursery technique : Seed can be sown in February-March either in germination trays or in the germination beds and pricked into polybags when the germinants attain two leaf stage. The roots may be very long at the time of pricking and may be trimmed.

Plantation technique : The planting is done in the month of July, when the seedlings are 60-70 cm tall, in pits of at least 30 x 30 x 30 cm at a spacing varying from 1 x 1m to 2.5 x 2.5 m depending upon the purpose of planting.

Suitability : The species prefer fairly rich alluvial soil, sandy loam or deep sandy soils with moderate moisture. It also grows well on mined over areas of bauxite and coal mine overburden dumps. The areas receiving rainfall of 500 to 1500 mm are suitable for this species.

10. *PINUS ROXBURGHII* (Chir-Pine)

Family : Pinaceae

Uses : Source of oleo-resin chiefly used for paints and varnishes. It is also used as a timber, pulpwood and fuel wood.

Seed collection time : February-April

Seeds per kg : 9000-10,000

Seed viability : 2 years

Germination percent : 85 %

Seed treatment : No pre-treatment is usually necessary except cones are winnowed to remove wings. Soaking of seeds in ordinary water for 18 hours can give better germination. The seeds should be dressed with diathane M-45, before sowing.

Nursery technique : Seeds are sown in germination beds of sand in September at 2 x 2 cm spacing. Germinated seeds are pricked out in polybags filled with the soil mixture inoculated with mycorrhiza. Seedlings of around 25-30 cm height are obtained in 9 months for field planting.

Plantation technique : Seedlings are planted in already prepared pits of at least 30 x 30 x 30 cm at a spacing of 2 x 2 m. Young seedlings are prone to damage by grasshoppers, rats and porcupines.

Suitability : It can be grown all along the Himalayas at 500- 1500 m elevation. It is frost and drought resistant however young seedings are damaged by fire..

11. *PROSOPIS JULIFLORA* (Mesquite, Vilayati Babul)

Family	:	Mimosaceae
Uses	:	Excellent fuel wood and makes superior quality charcoal. Wood is hard and durable and is used for fence posts. The pods are eaten by livestock
Seed collection time	:	November-December and April - June
Seeds per kg	:	8,000-20,000
Seed viability	:	Around 18 months
Germination percent	:	80-90 %
Seed treatment	:	Seeds require hot water treatment or soaking in 20 % H2S04 for 1 hour.
Nursery technique	:	Treated seeds are sown directly in polybags in March. Two seeds per polybag are sown. Seedlings maintained up to rains and then planted out.
Plantation technique	:	It can be grown by direct sowing at the plantation site. Polybag planting is done in difficult, rocky and saline areas. It is generally planted at 3 x 2 m spacing in pits of size 30 x 30 x 30 cm.
Suitability	:	Planted in rocky hills, sandy and saline patches up to a pH of 11.5. It is also grown in shifting sand dunes and coastal sands. It does not tolerate waterlogged conditions.

12. TECTONA GRANDIS (Teak, Sagwan)

Family	:	Verbenaceae
Uses	:	Wood very durable, used for construction of all kinds, furniture making, carving, very suitable for boat and ship making. Plywood, chip board and fiber board are also made.
Seed collection time	:	December-January
Seeds per kg	:	1,800-3,200
Seed viability	:	Up to two years
Germination percent	:	20-30 %
Seed treatment	:	Seed pretreatment is done to soften the woody endocarp. Alternate soaking and drying for 48 hours each for 12 to 15 days or placing the seeds in cow dung paste for few days give better germination.
Nursery technique	:	Pretreated seeds are sown in May in germination beds and watered copiously every day. Germination takes place in 10-20 days. Plants are uprooted during the next rainy season and stumps are prepared.
Plantation technique	:	Stumps are planted in crowbar holes during the rains. Sprouted stumps in polybag may also be planted in 30 x 30 x 300 m pits for better results. The spacing of 2x 2 m is generally followed.
Suitability	:	It prefers deep, well drained loamy soil, however, can be grown on variety of soils. It is sensitive to drought and frost.

10 MAINTENANCE OF PLANTATION AREAS

The success of plantation largely depends upon the maintenance of the plantation area as trees species take time to establish. This necessitates ensured supply of quality planting stock. The budgetary provisions for maintenance need to be provided according to the site conditions and requirement of the species. The meticulous planning and execution of afforestation activities in the right earnest can help increase the green cover of the country.It will be necessary to protect the plantation against weather, fire, insects and fungi, and animals. A variety of cultural treatments also may be required to meet the purpose of the plantation.

TREATMENTS ACCORDING TO VARIOUS FACTORS AFFECTING THE PLANTATIONS

Weather/ edaphicfactors

Damage to the plantations by weather is usually unpredictable and little can be done to protect forest plantations against the damage.

Such damage can only be minimized to a limit by planting tree and shrub species resistant to the detrimental effects of local weather patterns, or locating the stands of trees or shrubs in sheltered areas. Selection of species resistant to wind currents for high windy areas, creating wind breaks and shelterbelts, planting shade bearing species over shade loving species etc. can reduce or create conditions for better survival of the plantations. Salt and water tolerant species can be used for planting in belts along water bodies to protect other less tolerant species forming the main plantation and reduce horizontal seepage.

Fire

Fire damage can impose serious threat and can be a major consideration from the early stages of plantation development. The risk of fire is generally high in the dryer climatic regions. Although relatively moist or high rainfall areas may undergo warm and dry spells instigating incidences of fire in the plantation. Most of the reported fire incidences were anthropogenic but fires can also originate from natural causes, such as lightning. Fires in plantation can start from adjacent farmland on the perimeter or it can also be caused due to activities of hunters/ poachers. Various fires are also started by forest dwellers to ease the collection of NTFPs like mahua flowers and tendu leaves etc., burning by herdsman to improve livestock grazing can also spread forest fires. There have been instances of deliberate burning to create employment (in the fire suppression and subsequent replanting) or to show disapproval of forest policies. It is not possible to prevent a climatic build-up of fire hazard conditions, but much can be done to minimize the risk of fire through public education and involving local people in forestry.

A main principle in reducing risk of fire is to reduce combustible material that can increase spread of ground fire. Fire lines/ firebreaks should be made and low vegetative growth should be maintained to check instances of fire. Annual or periodic burning of vegetation through control fire can be practiced after the leaf fall or post summer season to reduce incidences of fires and damage caused to the plantation.

Insects and fungi

Most of the forestry insects and fungi are host specific. In their natural environment, trees and shrubs normally attain a state of equilibrium and show association with indigenous pests. However, plantation of exotic trees and shrubs can introduce exotic pests that can often adapt themselves well to their new habitat as against to the planted species which are weak in their initial stages. The risk of damage from pests is generally higher when the plants are physiologically weak due to planting on unsuitable sites, improper site preparation, inefficient planting, adverse climatic conditions, neglect of weeding and other maintenance operations. Thin-barked species are more susceptible to damage and subsequent attacks by insects or fungi than are other species. Even healthy trees and shrubs are attacked at times and for many insects and fungi, no control measures are available.

Before raising the plantation, surveys should be conducted to ensure the status of indigenous pests and insects harmful to the plantation species. Controlled experiments can be initiated before developing large-scale planting programmes. To reduce the impact of pests on the plantation, it is suggested to plant pest resistant tree and shrub species or varieties that are suitable to the climatic and soil conditions of the site.

Careful establishment and maintenance operations during initial plantation years can increase the resistance of plantation against insects and fungi. Periodic surveys of plantations conducted to investigate attacks and evidence of pest attack and its causes should be identified. Various available silvicultural, chemical, biological, or mechanical control measures should be used in case of an attack.

Various silvicultural operations like thinning, elimination of poor and suppressed stems, lopping etc should be carried out to maintain the plantation in a thrifty and vigorous growing condition. Prompt removal and destruction of infested trees and shrubs can be effective in preventing the spread of the pest attacks to the rest of the plantation in young plantations.

Mixed species plantation can also be considered a silvicultural control measure where a threat of infection is known to exist. However, subsequent forest management can be complicated in a mixed planting which can be avoided by planting alternate blocks or wide belts with different tree or shrub species, forming barriers to the spread of a pest or disease from the initial point of infection.

Appropriate chemical insecticides or fungicides can be applied to check insects and fungi usually available as liquids (or wettable powder), dusts, or smokes. These can be sprayed with hand-operated spray guns or portable mist-blowers to control attacks in young plantations. In bigger plantations, due to canopy closure, aerial spraying and dusting or smoking can be more effective. Only previously tested and environmentally sound insecticides and fungicides should be used.

Biological control of insects can be employed with success in some situations. The greatest success in biological control is usually achieved after the problem has grown to epidemic proportions. Plantation of shrubs or herbs hosting parasite or insect detrimental to that of the plantation should be planted around the plantation for biological control.

Mechanical control, either by physically removing and destroying the pests or by eliminating the alternative hosts should be used in the plantations.

Animals

Wild and domestic animals cause damage to the plantations by tree browsing or de-barking. Generally, rodents (rats, mice, and moles and squirrels); lagomorphs (hares and rabbits); and artiodactyls (deer, antelopes, pigs and buffaloes), sheep, goats and cattle are responsible for damage to the plantations.

Control measures to check damage by animals involves the use of fences, hedges or ditches, trapping and removal, and poison baits. Trespass by livestock can be controlled by guards.

VARIOUS CULTURAL TREATMENTS FOR MAINTENANCE OF PLANTATIONS

Cultural operations are required to promote favourable conditions for survival, subsequent growth and yield of the trees or shrubs in the plantation. They are mostly concerned with operations like weeding for preventing suppression of growth by competing vegetation, thinning to achieve a desired spacing among the trees or shrubs and periodic watering the plants.

Replacement of casualties

If seedlings mortality is high, these are replaced by planting healthy seedlings. This operation is called beating up or 'blanking' or in filling or re-filling. Seedling used for beating-up should be healthy, vigorous, robust and taller than average so that they catch up with initially planted seedling.

The time period of replacement is very important. The operation should be done within a month of planting out so that the seedling gets sufficient amount of rains for their establishment and growth. In case of fast-growing species such as eucalyptus spp., *Albizia falcataria, Anthocephalus chinensis, Leucaena leucocephala,* etc., this operation should be done within a fortnight of planting out. If casualty replacement is delayed, the replaced seedlings never catch up with other seedlings.

Before carrying out beating up operation, the reason for casualty may be ascertained and efforts should be made to remove or correct the reasons for mortality. Otherwise repeated failures may result. For example, if water logging is the reason for mortality, drainage conditions should be improved. Browsing, grazing, trampling, etc. are the common reason for seedling mortality and can be avoided by proper fencing. Beating up operation may be done only once. If plantation failure continues then choice of species, soil preparation, site condition, establishment conditions, protection measures, etc. need serious examination.

Weeding

Weeding is removal of undesirable vegetation that competes for light, water, and nutrients with plantation trees and shrubs. Weeding increases the availability of all or the most critical of these elements to the trees and shrubs to promote growth and development of the plantation crop. A main factor affecting the intensity and duration of weeding treatments is the relationship between the tree or shrub crop and the weeds. On some sites, the plantation crop eventually grows through the weeds, dominates the site, and becomes established. On such sites, the function of weeding is to increase crop uniformity and speed up the process of establishment and growth. While, on other sites, the type or density of the weed growth is such that, in the early stage of a forest plantation, it may suppress and kill some or all of the planted trees or shrubs; in such areas, the main purpose of weeding is to reduce mortality and maintain an adequate stocking of trees or shrubs.

The methods of weeding involve either suppression or elimination of the competing vegetation. Suppression of weeds can be done by physically beating down or crushing them, or cutting the weeds back at or above ground level. Weed elimination can be achieved by killing the weeds, destroying the whole plant either by cultivation or by the use of chemicals.

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. It is a tending operation carried out in a crop beyond the sapling stage and up to the beginning of regeneration period. In thinning, a forester tries to salvage the inherent mortality and produce a crop of better growth and quality. Thinning of forest plantations, particularly those established for wood production, may be required to obtain the desired spacing between the trees. In general, this spacing is a compromise between a "wide" spacing to reduce planting costs and inter-tree competition in times of drought, and a "close" spacing to attain early canopy closure, the suppression of weeds, the reduction of weeding costs, and natural pruning of branches through shading.

In "first-rotation" forest plantations, the thinning objective is frequently to adjust the initial spacing among plants, so that the size and type of tree or shrub required is attained on a short rotation, without secondary thinning treatments. Where a tree or shrub of larger size and higher quality is required, closer than final spacing is often prescribed in an initial thinning; usually, some form of secondary thinning is necessary as a subsequent treatment. The element of selection in thinning should ensure that the increment growth of the final crop is concentrated on the best stems.

Regardless of the purpose of the thinning operation, it should follow closely the timing and spacing requirements that are outlined in a prescribed thinning schedule for the area.

Improvement fellings

Improvement felling has been defined as 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 stocked groups along with clearing and general assistance to young growth of valuable species.

The operation is usually carried out in mixed forests beyond the sapling stage for improving the composition and character of the crop. The trees of inferior species and form are removed in favor of valuable species and trees of better form. Improvement fellings are usually prescribed in forests which are in poor condition because of uncontrolled excessive grazing. The improvement fellings vary greatly in their prescription depending mostly upon the present condition of the crop and locality. The following operations are usually prescribed in improvement felling:

- Removal of dead, dying and diseased trees.
- Removal of unsound and over mature trees which are not likely to survive up to next felling provided such trees are silviculturally available.
- Removal of unsound and badly shaped trees provided their removal can benefit the trees of better form and species.
- Thinning out crowded groups of trees, poles and saplings. The trees of larger diameter class should not be removed so that such trees may yield revenue in next felling.

- Cutting back badly shaped or injured saplings and advance growth in order to obtain better coppice shoots.
- Removal of plants of inferior species which are having or likely to have adverse effect on the regeneration of important species.
- Removal of trees of inferior species, which are having or likely to have adverse effect on growth of valuable species.
- Cutting or uprooting of climbers.

The improvement fellings are regarded as interim system of management and are usually adopted in poor quality forests in India.

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. Pruning occurs naturally when the crop is dense enough particularly in younger stage. The process of natural pruning completes in three stages; namely (i) killing of branches, (ii) shedding of dead branches and (iii) healing over of the branch stub.

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. The retention of under-storey trees may also lead to effective natural pruning. The simplest method of obtaining natural pruning is to develop and maintain dense stocking in the main crop. This may decrease the rate of diameter increment. Therefore, it is necessary to reduce the crop density as soon as natural pruning is achieved.

For a successful planting, performance data may have to be extrapolated from one locality to another. Results from a locality where a tree or shrub species is growing (either naturally or as an exotic) strictly apply only to that locality; their application in another locality involves the assumption of site comparability, an assumption which may or may not be justified. When reliable information shows a close similarity between the site to be planted and that on which the species is already successful, it is generally possible to proceed to large-scale planting with confidence.

In practice, the above data are seldom available, and planting on the new site becomes (in effect) experimental and should proceed on a small scale; when this occurs, detailed performance records should be maintained throughout the experimental planting period.

The selection of tree or shrub species through the use of analogous climates is important as a first step but this must be amplified by an evaluation of localized factors which can be more important (for example, soil, slope, and biotic factors). However, the ability to match closely a planting site and a natural habitat may not preclude the need for species trials, since climatological or ecological matching may not reveal the adaptability of a species. It cannot be emphasized too strongly that, without such trials, the choice of tree or shrub species is (in most cases) a risky business.

Watering

Forest plantations in arid regions need at least periodic watering during the first growing season to obtain a satisfactory survival rate. Watering should begin after the cessation of rains, when the moisture content of the soil has fallen to near the wilting coefficient; then watering should be repeated at intervals until the onset of the next rainy season. Before each watering, the area around the tree should be cleared of weeds, and a shallow basin should be made around the stem of each tree or shrub to collect as much water as possible.

Watering can be expensive operation, especially on terrain too steep or too rough for the passage of tank vehicles. Pack animals may be required to carry drums of water to the plantation site. Watering can be uneconomic for large forest plantations, particularly when the source of water is a long distance from the plantation, but it may be justified in the case of small plantations or for establishing roadside avenues.

In some instances, regular cultivation and weeding, especially during the first growing season, are sufficient measures to conserve soil moisture for satisfactory survival of the plants, eliminating the need for watering.

Staking

Staking in established plantation is providing support to the plants. Staking is usually provided in road sides and private plantations to protect the plants which are bending. Bended plants are usually propped up with the help of stakes and tied with some materials like rope, etc.

Singling and re-spacing

Singling is an operation under which forked or multiple stems are reduced to a single stem to improve the form of the planted tree. It is usually done in small scale plantation aged 2-3 years to remove forking and multiple stem condition.

Re-spacing is an operation in which competing plants of the same or similar species are removed to provide proper growing space. It is required when initial spacing is too close or the plantation is done through seed sowing. This operation is needed during second or third year of planting out.

Mulching

The practice of applying a layer of dead vegetative materials, such as straw, hay, dried grasses, organic matter, farm yard manure, paper and other artificial products, etc. in order to assist soil productivity is called mulching. The surface mulch can have important effects on surface layers of the soil. Mulching has been found useful in improving the growth of some species in plantations. Organic matter mulching has been found to improve the growth of plants in saline alkaline soils.

The practice of mulching around horticultural trees has been prevalent for a very important effect on the soil condition particularly in the surface layer. The beneficial effects of mulches are: i) conservation of moisture by decreasing runoff and evaporation and increasing infiltration rate, ii) prevention of soil erosion, iii) providing thermal insulation, iv) maintenance of soil structure by reducing the effect of rain drop, v) increase in microbial population, vi) improvement of physicochemical properties of surface soil and vii) decrease in weed growth.

Thus, soil mulches keep surface layer of soil cooler, even in high temperature, moist and more permeable to water. These conditions may be very useful in arid zones.

In dry and refractory areas, mulches assure greater success in plantations. Organic mulches are widely used in plantation crops, e.g. tea and coffee because they provide nutrients after decomposition and also improve various soil properties.

HARVESTING OPERATIONS

Forest plantations that are established for purposes of wood production, trees and shrubs are harvested once they attain the "optimum size" for the desired wood product. From a biological standpoint, trees and shrubs should not be cut until they have at least grown to the minimum size required for production utilization. Beyond attaining the minimum size, the question of when to harvest must still be answered, however.

Quite often, the average annual growth rates of a forest plantation can be used as a guide in determining when to harvest wood. In general, the average annual growth of trees and shrubs increases slowly during the initial years of plantation establishment, reaches a maximum, and then falls more gradually, as illustrated in (Fig.10.1). Trees and shrubs usually should not be allowed to grow beyond the point of maximum average annual growth, which is the age of maximum productivity; foresters call this the "rotation" age of the forest plantation.

To determine the average annual growth rate of a forest plantation at a point-in-time, the volume and age of the trees or shrubs must be estimated; then the average annual growth (at the specified point-in-time) is determined by dividing the standing volume by the corresponding age. Again, careful measurements of volumes and known ages are necessary for this determination.

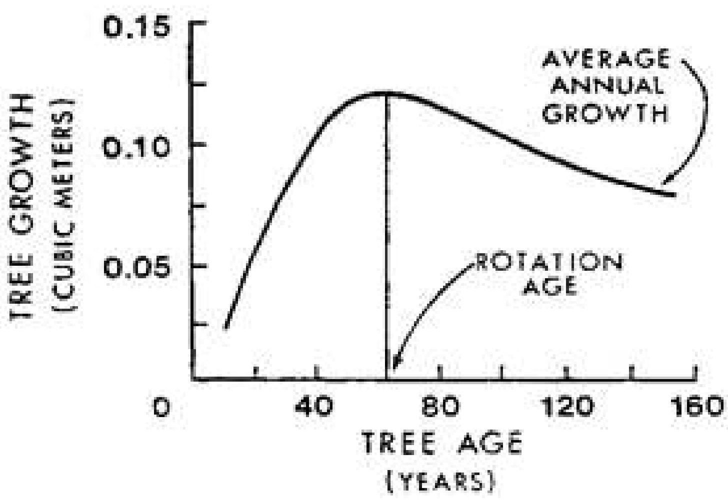


Fig 10.1. Relationship between tree age and tree growth indicating the rotation age

Economic considerations also help to determine when to harvest trees and shrubs for wood products. When based solely on market factors, the time to harvest is when the profit is maximized. Profit is maximized when the returns generated from harvesting and selling the wood minus the costs of harvesting and (when required) processing the wood into the desired products is the greatest.

The methods of felling trees and shrubs, cutting the stems and branch wood into the desired lengths, and removing the wood from the plantation site should be chosen to minimize degradation of the site. Axes, saws, wedges and sledges may be all that are necessary to fell the trees and shrubs and cut them into the desired lengths. Powerchainsaws are used in many instances; while their use makes harvesting easier, their high cost of operation can make then uneconomical.

Once the trees and shrubs are felled and cut into desired lengths, they must be carried or pulled to loading points for transport to processing sites or directly to a market place. When stem lengths are too heavy to carry, a simple drag or sled can be employed to move them, using an available power source, such as a domestic animal or a tractor. When residual trees or shrubs are left in the forest plantation, the harvesting operation should be carried out to prevent damage to this standing resource.

It is important that the methods of harvesting should be selected to "match" the skills of the people who will harvest the trees or shrubs. Once again, advanced planning will be necessary to ensure that the labour and required equipment will be available for use at the needed time (Mortlock, 1999).

11 INCREASING GREEN COVER IN DEGRADED LANDS

As per State of Forests Report, 2007,India has been able to preserve and expand its forest wealth in spite of tremendous anthropogenic pressure. India's forest cover increased to 7,08,273 sq km, or 21.5 % of the country's geographical area, as against 7,01,495 sq km two years ago. Although forests were cut down in some areas, there was net forest gain as the forests in other areas emerged. The tree cover outside forests also increased from 92,572 sq km to 93,815 sq km according to the report.

Massive deforestation of natural forests is posing a serious threat towards achieving the target of 33% forest cover. Between 1999 and 2013, India has lost close to 10.6 millions of forest cover. Reduction in growing stock because of degradation is very significant and hence is an important factor deserving attention in any carbon sequestration programme. Global concern over accumulation of greenhouse gases in the earth's atmosphere has simulated interest in land-use sector mitigation options. One mechanism, among many others that have been advocated to lower concentration of atmospheric CO_2 is to increase the forest biomass. The main arguments for this measure were that the tree biomass fixes large quantities of atmospheric CO_2 over long periods. Secondly, forest biomass can be used for energy purposes and thereby reduce the use of fossil fuel or can substitute for other materials such as aluminium or steel constructions whose production consume large quantities of fossil fuels. Finally, increasing the standing stock of forest biomass in many ecosystems may give several environmental benefits other than carbon sequestration.

Degradation refers to reduction in productivity and/or diversity of a forest due to unsustainable harvesting, fire (except for fire dependent eco-systems), pests, and diseases, removal of nutrients and pollution or climate change (TERI 1998). Subsequent to enactment of Forest Conservation Act, 1980, rate of diversion of forestland has declined drastically to around 0.021 million ha (Mha) per annum (ICFRE, 2000). Loss of natural regeneration, low growing stock and low productivity are important parameters indicating forest degradation.

Loss of natural regeneration is loss of future potential biomass. Over-grazing and repeated fires eventually affect relatively hardy species too and their ability to regenerate. Destruction of soil organic matter further reduces soil fertility. Forest fires also result in loss of natural regeneration. An FSI sample survey conducted in 1995 found that annually fires affect some 53 to 54 percent of forest areas. Majority of fires are deliberate to facilitate collection from ground of commercially important non-timber forest produce as 'mahua' (*Madhuca indica*) and *Shorea robusta* seeds. It also results in new flush of grass or *Diospyros melanoxylon* tendu used for rolling country made cigarettes (TERI 1998). As a consequence, natural regeneration is either absent inadequate in 53 % of the country's forest.

Effectiveness of the forest to sequester carbon is proportional to mean annual increment. High productivity, therefore, leads to high rate of carbon storage in biomass and wood-products. The productivity of Indian forest is also low. The current productivity of forest is 1.37 cu m/ha, calculated on the bases of net annual increment of 87.62 million cu m and forest cover of 63.7 Mha (FSI 1995), is low when compared with the global average of 2.1 cu m/ha/yr.

In such situation it has become all the more important to accelerate the task of increasing our national green cover. This will also help achieving our nationally committed target of carbon sequestration through forestry sector.

POTENTIAL OF INCREASING GREEN COVER IN DEGRADED LANDS

The gap between deforestation and afforestation can be narrowed down (Toky, 1992) and even exceeded through socio-biological rehabilitation by growing multipurpose trees and by adopting new land use systems. Degraded lands are present in various forms i.e. salt affected lands, waterlogged areas, shifting sand dunes in arid and semi arid regions, degraded hilly areas etc. There are about 130 million hectares of wasteland in India (Toky, 1992). These wastelands and other degraded lands provide ample opportunity to develop green cover and plantations as renewable source of fuelwood. Suitable trees and grasses may be grown at degraded sites using optimum management practices to sequester higher amount of carbon in these degraded soils (Vaidya *et al.*, 2017). Reclamation of degraded lands has huge potential for carbon(C) sequestration to counteract the climate change (Purakayastha *et al.*, 2016).

Potential of increasing green cover through afforestation and restoration of different degraded lands are narrated in the following section in the form of package of practice. These packages of practices are taken from the research works carried out at Arid Forest Research Institute, Jodhpur (Bahuguna, 2012).

RESTORATION OF DEGRADED HILLS

Description

Disturbances to the natural habitats through overgrazing, vegetation removal and mining is a common feature in most of the hilly dry areas throughout the world leading to the biological invasion and land degradation i.e., desertification. The Aravallis in north-western part of India is an ancient mountain and one of the oldest geological formations in the world and the home of many tribes. Mining activities, operation of stone crushers, pulverizers and removal of existing vegetation are disastrous causing environmental degradation in the region. Because of over-exploitation and overgrazing one can see barren hills devoid of vegetation throughout the Aravalli ranges. When put under protection from human or livestock interferences these disturbed habitat may take longer time to recover naturally. But the process of rehabilitation may be accelerated by afforestation and soil and water conservation. Such conservation measures including rainwater harvesting may provide a basis for environmental recovery by facilitating plant growth and vegetation cover because of improvement in infiltration rate, soil water and the availability of soil nutrients. The most effective method is to rehabilitated degraded hills are through integration of afforestation adopting rainwater harvesting and involving local people in the programme.

Hills of varying height with pediments near Gauapada villages in Banswara, Rajasthan (Fig. 11.1) were selected and taken up for evaluating efficacy of different rain water harvesting structures and afforestation technique in restoration of the degraded hills. The land is dry-subhumid with average annual rainfall 1050 mm from 1993 to 2010 with 53 numbers rain days. Seventy five plots were laid out in June, 2005 covering about 17 ha area in $<10\%$, 10-20% and $>20\%$ slope categories. Five rainwater harvesting (RWH) structures including a control were contour trenches (CT), box trenches (BT), V-ditches (VD) and Gradonie ditches (GD). The RWH structures were 30 running meters length in each plot except in the control. The excavated soils of the RWH structures were heaped towards the down slope. Thirty five seedlings per plots (@ 500 plants ha^{-1}) of *Zizyphus mauritiana, Acacia catechu, Azadirachta indica, Emblica officinalis, Dendrocalamus strictus, Gmelina arborea, Holoptelia integrifolia* and *Syzigium cumini* were planted under mixed plantation in August, 2005. Concrete tanks of 1000 liters capacity were constructed to collect one twentieth of run-off water to measure water and nutrient losses. Soil water, nutrients, soil organic carbon, plant growth, diversity of regenerated tree/shrubs and herbaceous vegetation and biomass of trees/ shrubs and herbage were recorded throughout the experimental period.

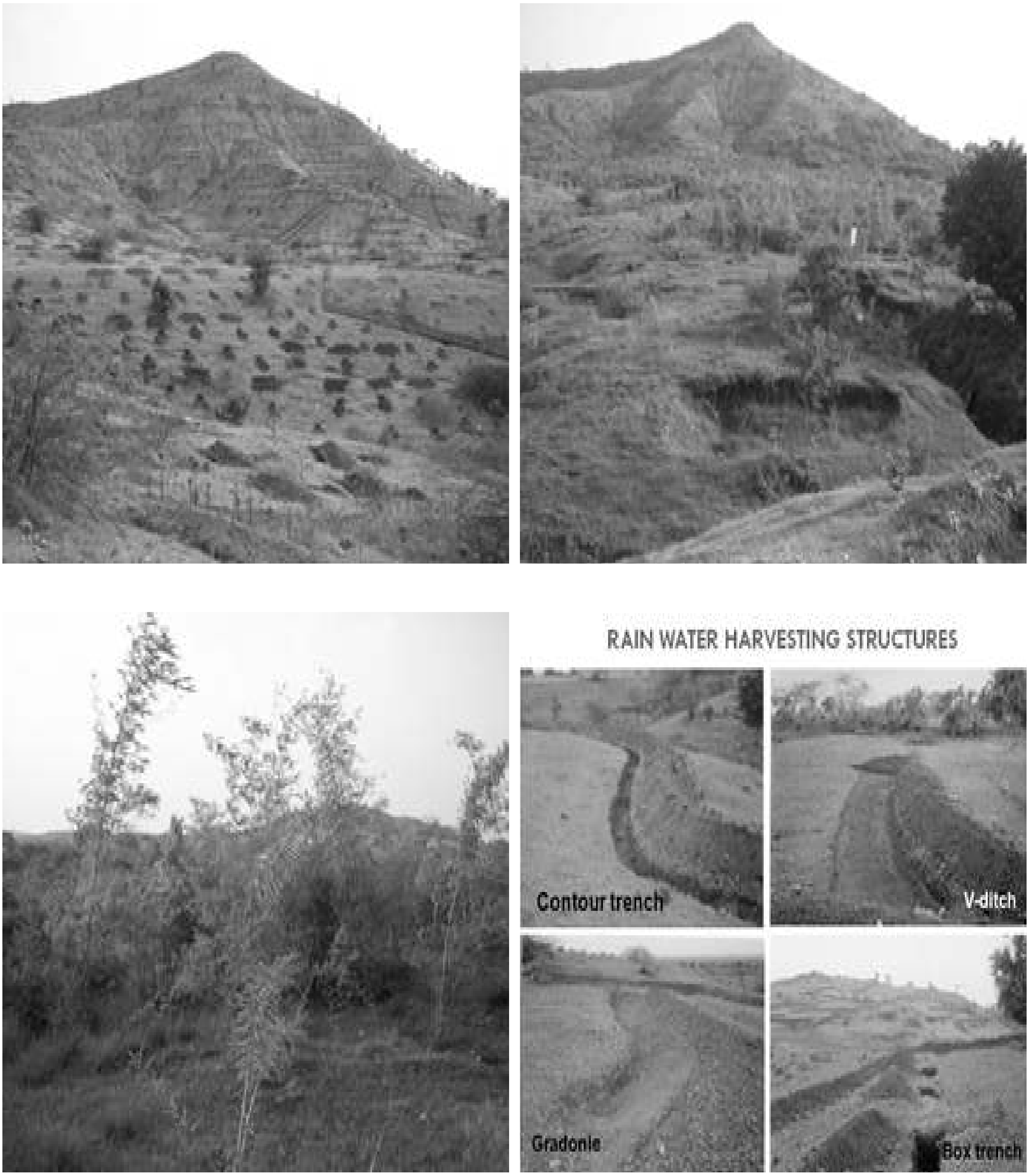


Fig 11.1. View of the site before and after intervention, Bamboo and Aonla plants and different rain water harvesting structures (anti clockwise from top left).

Relatively greater soil water availability in <10 % slope resulted in greater survival and growth of the planted seedlings in lower slopes than in the higher slopes. Despite of low SWC better performance of *H. integrifolia* in 10-20 % slope showed its preference to soil condition i.e., light soil. *A. catechu* performed best in <10 % as well as >20 % slope indicating its preference of clayey soil. Relatively better performance of *Acacia catechu* and *Z. mauritiana* in BT plots; *E. officinalis* and *H. integrifolia* in CT plots; and *A. indica* in VD plots indicated the suitability of these rainwater harvesting structures for the respective species. V-ditch and Box trench facilitated water distribution in upper soil layers for vegetation growth, whereas, contour trench facilitated water storage in deep soil profile that was utilized for the growth of tree seedlings.

Expected benefits associated with the package of practice

Adoption of improved water conservation and harvesting technologies contributes to increase in groundwater recharge, soil nutrients and biomass production and supports a higher number of plants, whereas afforestation under protection increases diversity and productivity and help restore these degraded hills along with the benefits of carbon sequestration. Gradonie and V-ditches enhance productivity of the grass/ herbaceous layer productivity and the best was V-ditch. Rainwater harvesting through different structures extended water availability in down slope wells up to February (instead of December) for domestic use as well as for livestock. Grass production increased from 15,000 pulia in 2005 to 36,000 pullia (1 kg each) at 5 years in collective harvesting (Fig. 11.2).

Fig 11.2. Head loads of grass (left) and fuel wood (right) from the restored area.

However, it was observed in January each year that about 10 persons were collecting fodder grass from the area each day i.e., 6,750 kg of grass. After grass cutting in November about 15 persons with an average head load of 10-20 kg were used to collect fuel wood of *Lantana camera* and *Prosopis juliflora* up to June each year. Thus, this restoration effort has benefited not only by restoring degraded hills by increased biological diversity, soil water and nutrient status and soil carbon storage but also enhanced the economy of the local people, who started purchasing milching animals due to increase fodder supply at place and sending their children to school for education, who were otherwise engaged for collecting fodder and fuel wood from a longer distance earlier.

Increased income through harvesting of fodder grasses (also from selling of grass), fuel wood and increased population of milk producing animals are some of the benefits related to development in livelihood status and human resource.

Table 11.1: Expected benefits associated with restoration of degraded lands

Environmental	Economic	Social
Increase in vegetation cover and production per unit area at the site as well as the adjoining agriculture area.	Increased landscape value and economic status.	Diversion to children in education.
Improvement in soil nutrient status and productivity.	Increased fodder and fuel wood supply at the nearest place and increase in population of milching animal.	Improvement in social status.
Increase in diversity of flora and fauna.	Increased income due to increased land productivity	Reduction in time of fodder and fuel wood collection
Reduction in soil and water loss at site and increase in water availability.	Reduced silting and soil loss in water storage dam/rivers.	Reduction in time in collecting/ utilizing water for animal drinking.
Increased soil carbon stock by 26.97 tones ha^{-1} by 2010.	Increased land productivity and its value.	Increased agriculture production and social status.

Lessons learned

- Rainwater harvesting improved soil water and nutrients status, facilitated rock disintegration to form soil and enhance vegetation diversity from 39 to 92 number of species in a 5 year period.
- Contour trench and Box trench were best for enhancing soil water plots.
- *Azadirachta indica* performed best in V-ditch areas, *E. officinalis, H. integrifolia* and *Z. mauritiana* performed better in contour trench and *A. catechu* in Box trench areas.
- This practice has enhanced the carbon stock by 26.97 tones ha^{-1} in 2010 compared to 2005. Rainwater harvesting increased water availability at site up to February (as compared to December, earlier) for drinking of the livestock.
- Participation of local people was in the form of labor during implementation of this practice, whereas, the area was maintained and utilized by village committee to get benefits of fodder and fuel wood.
- This practice can be replicated at local level, sub national level, sub regional and international level with some adaptation depending upon the requirement for fodder or fuel wood and the topographical conditions of the area.

- Forest department of Rajasthan has adopted this in many places, but it will be more appropriate to adopt it according to the efficiency of the structure for herbage yield/ plant biomass production.

Steps to be taken/operational procedure

- Protection of the area from wildlife, livestock and other anthropogenic disturbances by means of erecting fencing (ditch) fencing, stone fencing, barbed wire fencing etc. or by social fencing.
- Arrangement of saplings of suitable species or raising nursery.
- Establishment of soil and water conservation structures as per slope variations with excavated soils of the RWH structures heaped towards the down slope position (Fig. 11.2).
- As a thumb rule, 1,000 running meter contour trench of 45 x 45 cm^2 cross section per ha may be constructed (will depend on amount of rainfall in the area).
- Seeding/ direct sowing of seeds of different species like *Acacia Senegal, Acacia catechu, Jatropha curcas* etc. (locally growing species) on the heaps/ bunds.
- Digging of pits for planting (45 x 45 x 45 cm^3 size).
- Planting of suitable trees and bamboo species at 4 x 5 m spacing (in areas with 700-800 mm rainfall).
- Life saving watering in the plantation establishment phase.

RESTORATION OF WATERLOGGED LANDS

Description

Indira Gandhi Nahar Pariyojana (IGNP) is one of the most gigantic projects in the world aiming to check desertification and to transform desert wastelands of western Rajasthan into agriculturally productive area. In the canal command area, water logging and consequently salinity problems are increasing at an alarming rate. Kapoor and Denecke (2001) estimated 55,000 ha water logged area out of the total 18,60,000 ha command area in IGNP. Water logging has been a major problem in the irrigated belts. Canal command areas are increasingly being rendered unproductive and barren through water logging and consequent secondary salinization. Engineering solutions such as ground water pumping and surface drainage are too expensive. The best way is seen as an effective utilization of plants (in particular tree plantation), which remove the excess water through transpiration. Potential of using trees to control water logging and salinity is now a well-established fact. However, it is important to find out suitable tree species for a particular set of surroundings.

A number of species have been tried for the purpose of bio-drainage and their suitability for salt tolerance under water logged conditions. Eucalyptus was found to be the most useful for the purpose along with few other species (Hussain and Gul, 1991; Moezel et al., 1991). Karajeh et al. (1994) recommend cultivation of *Eucalyptus camaldulensis* tree as a management option for lowering water table. Thakur and Chhabra (1999) have recommended plantation of eucalyptus and bamboo to prevent water logging and salinity caused due to seepage in canal command area. Improvement in soil properties is observed in such plantations (Dass and Ahuja, 1998) along with other environmental benefits. However, information pertaining to canal command area particularly in arid zone of northwestern India is very few, compared to the gravity of the problem.

An attempt was made to remove excess water from the land through bio-drainage and to increase vegetation cover and productivity of a waterlogged area in Indian desert. Seeds of four tree species *viz. Eucalyptus* *camaldulensis* Dehnh.*, E. fastigata Deane* and *Maid., E. rudis* Endl. and *Corymbia tessellaris*(F. Muell.) K.D. Hill and L.A.S. Johnson, were procured from CSIRO, Australia. Raised bunds (60 cm high, 60 cm wide and 2 m apart) were prepared in waterlogged (inundated water of 15-25 cm) area to provide comfortable root zone for young seedlings. Seedlings were raised in the nursery and planted on the raised bunds at a spacing of 2 m in blocks after attaining average height of 30 cm. Observations on growth and physiological parameters recorded periodically. Transpiration and photosynthesis rates were recorded using ADC make LCi portable photosynthesis system. In February 2008, when the plants were four and half year old after transplanting, biomass estimation was made. Representative plants having dimensions equivalent to mean height and girth were felled in triplicate. Measurements on crown spread were recorded. Foliage, branches and stems were separated and their fresh weight recorded. Dry weight of each component was recorded after oven drying samples at 75 ^{0}C. Roots of each plant were excavated carefully to observe the pattern of root growth and depth of rooting under the influence of water logging and their fresh and dry weights were recorded. Ground water was monitored through observation pits in each species. Soil samples were collected initially and after wards at in February 2008 and were analyzed as per standard methods of Jackson (1973).

Area protection, soil working and plantation of *Eucalyptus camaldulensis, E. fastigata, E. rudis* and *Corymbia tessellarison* raised bunds, improved vegetation cover with simultaneous decrease in water table. Performance of *E. rudis* was best with respect to growth, biomass, transpiration rate and overall bio-drainage potential. *E. rudis* maintained uniform transpiration and photosynthesis rate throughout the year. Ground water level receded by 145 cm in *E. rudis* plot compared to 90 cm, 70 cm and 60 cm in *C. tessellaris, E. camaldulensis* and *E. fastigata* respectively within a period of four and half year. Soil organic carbon, electrical conductivity, NH_4 and NO_3 – N were high in *E. rudis* and low in *E. fastigata*. The results suggests that *E. rudis* has high potential to be used as an efficient biodrainage species for restoration of canal command waterlogged area. Apart from the planted species, *Prosopis juliflora, Tamarix dioica* and *Saccharum munja* also have come up in the area with recession of ground water table as natural succession and contributed significantly for further lowering of ground water table and increasing productivity. Soil working in the experimental area resulted in soil aeration, good contact of seeds from nearby trees with soil and regeneration of *E. camaldulensis*.

Agriculture land rendered out of production because of waterlogging could be restored by adopting this practice.

Expected benefits associated with the package of practice

The growth behavior, biomass accumulation by the plants and physiological parameters suggests that E. rudis has high potential to be used as an efficient bio-drainage species in Indira Gandhi Nahar Pariyojana (IGNP) command area with low salinity level. Apart from the planted species, *Prosopis juliflora, Tamarix dioica* and *Saccharum munja* also have come up in the area with recession of ground water table as natural succession and contributed significantly for further lowering of ground water table and increasing productivity. The result suggests that along with tree species shrubs and bushes can also play a major role in increasing productivity of waterlogged area. Soil working may be a viable option in assisting regeneration of local species growing nearby.

Lessons learned

- Area protection, soil working and plantation of *Eucalyptus camaldulensis, E. fastigata, E. rudis* and *Corymbia tessellaris* on raised bunds, improved vegetation cover with simultaneous decrease in water table in a waterlogged area in IGNP.

- *E. rudis* was best with respect to growth, biomass, transpiration rate and overall bio-drainage potential. It maintained uniform transpiration and photosynthesis rate throughout the year.
- Ground water level receded by 145 cm in *E. rudis* plot compared to 90 cm, 70 cm and 60 cm in *C. tessellaris, E. camaldulensis* and *E. fastigata* respectively within a period of four and half year.

(a) Plantation area before intervention

(b) *E. rudis* on raised bund

(c) Five and half year old *E. rudis* plantation

Fig 11.3. Water logged area in IGNP command area before and after restoration work

- Soil organic carbon, electrical conductivity, NH_4 and NO_3 – N were high in *E. rudis* and low in *E. fastigata*.
- Apart from the planted species, *Prosopis juliflora, Tamarix dioica* and *Saccharum munja* also have come up in the area with recession of ground water table as natural succession and contributed significantly for further lowering of ground water table and increasing productivity.
- Soil working in the experimental area resulted in soil aeration, good contact of seeds from nearby trees with soil and regeneration of *E. camaldulensis*.

Steps to be taken/operational procedure

- Protection of the area from wildlife, livestock and other anthropogenic disturbances by means of erecting fencing or by social fencing.
- Arrangement of saplings of suitable species or raising nursery.
- Soil working and preparation of raised bunds of size 60 cm width, 60 cm high and 2 m apart (for dense planting).
- Planting of saplings on raised bunds at 2 m spacing.
- If required, watering at the time of plantation for facilitating soil and root contact (usually not required because of waterlogging condition).

SAND DUNE STABILIZATION

Description

The soils of western Rajasthan are lesser in nutrients and experiences soil and water erosion of varying intensity. Community suffering from fodder and fuel wood scarcity in the region, whereas, high human and livestock population are leading to mismanagement of the sandy terrain causing reactivation of sand dunes and land degradation resulting of sand movement. This moving sand encroach productive agricultural fields, human habitation, canal, road, railway tracks and water body. Plantation of only tree species may not solve the problem. Involvement of surface vegetation may be one of the best techniques for effective control of sand drift and reducing reactivation of sand dunes. For this an experiment was laid out in a split plot design with three replications. Different plant species *viz. Acacia tortilis, Prosopis juliflora* and *Calligonum polygonoides* of about 20 cm, 40 cm and 15 cm in height, respectively were planted in September, 1996 at spacing of 5 m x 5 m and in a pit size of 45 x 45 x 45 cm^3. Species were considered as the main plot with 75 plants per species. 9.0 g of DAP (di-ammonium hydrogen phosphate) was spread in each pit as basal dose and about 20 g of BHC (y-hexachlorobenzene) was used by thoroughly mixing with the soil to protect the seedlings from termite attack at the time of planting. *Cassia angustifolia* (one meter away from the seedlings and at 60 cm interval between the tree rows i.e., six rows) under shrub and *Cenchrus ciliaris grass* (60 x 20 cm spacing and similar to *C. angustifolia*) were sown in the monsoon season of 1997 to provide surface vegetation. In addition to the *C. angustifolia* and *C. ciliaris* plots, there was a control plot. Thus, there were nine plots (three species x three vegetation type) in each replication, with 25 plants in each plot. *Calligonum polygonoides* was the most suitable species, which provided better micro environment and helped in developing effective surface vegetation to control sand drift. Combination of *C. polygonoides* with *Cassia angustifolia* was the best to control sand drift and to improve biodiversity and ecology of the arid areas. Introduction of under shrubs like *Cassia angustifolia* and grasses (i.e., *Cenchrus ciliaris*) along with the tree species provided beneficial effects in controlling sand reactivation and drift, particularly, at the time when planted seedlings attain the size of a tree facilitating free air movement under the canopy resulting in reactivation of sand drift. Further, dunes are also deficient in soil organic matter and nutrients, particularly nitrogen. This study suggests that the micro-windbreaks of *C. angustifolia* can be raised in advance or simultaneously with plantation during onset of monsoon to provide effective surface vegetation.

Expected benefits associated with the package of practice

A combination of *Calligonum polygonoides* with *Cassia angustifolia* was the best combination to control sand drift and increasing socio-economic benefits for the desert dwellers. At the age of 50 months, *A. tortilis produced* 5.2 tones ha^{-1} fuel wood as compared to 7.00 tones ha^{-1} from *P. juliflora* and 7.15 tones ha-1 from *Calligonum polygonoides*, *Cenchru sciliaris* produced green fodder of 1.22 tones ha^{-1} $year^{-1}$ with *A. tortilis*, 1.58 tones ha^{-1} $year^{-1}$ with *P. juliflora* and 2.23 tones ha^{-1} $year^{-1}$ with *C. polygonoides, Cassia angustifolia* produced dry leaves of 0.76 tones ha^{-1} $year^{-1}$ with *A. tortilis*, 0.96 tones ha^{-1} $year^{-1}$ with *P. juliflora* and 1.39 tones ha^{-1} $year^{-1}$ with *C. polygonoides* with market cost of Rs. 9,120, 11,520 and 16,720, respectively @ Rs 12 kg^{-1}. State Forest Department of Rajasthan and Ministry of Rural Development helped in funding as well as dissemination of this practice. The local people offered the labor required for the implementation of this practice.

Table 11.3: Expected benefits associated with sand dune stabilization

Environmental	Economic	Social
Improved soil nutrient and productivity.	Increased land value.	Improvement in social status.
Increased carbon stock by 3.72 tones C ha^{-1} with *A. tortilis,* 5.24 tones C ha^{-1} with *P. juliflora* and 5.66 tones C ha^{-1} with *Calligonum polygonoides.*	Increased production of leaves and fuel wood.	Reduced time indulgence in fuel wood and fodder collection and more diversion of children towards education.
Increased vegetation cover, diversity and land productivity.	Increased income by harvesting grasses and leaves of *C. angustifolia* for medicinal use.	Increase in social status.

Lessons learned

- Involvement of under shrubs and grasses as the surface vegetation along with the planted tree species provides beneficial effects in controlling sand drift and sand dune movement. *Cassia angustifolia* utilized as the surface vegetation is a medicinal plant.
- Increased income through harvesting of leaves of *Cassia angustifolia* and fodder from *Cenchrus ciliaris grass* and decrease in time of collections of fuel wood and fodder are some of the benefits related to development of livelihood and human resource.

- Environmental benefits and productivity enhancement from the agriculture land due to control of sand deposition are the additional benefits.
- Introduction of surface vegetation along with tree plantation improved soil nutrient status and increase in diversity and land productivity.
- Application of this practice increased carbon stock by 3.72 tones C ha^{-1} with *A. tortilis*, 5.24 tones C ha^{-1} with *P. juliflora* and 5.66 tones C ha^{-1} with *Calligonum polygonoides*.
- From C. angustifolia leaves a farmer can get Rs. 16,720 ha^{-1} $year^{-1}$ from *C. polygonoides* plot as compared to 9,120 ha^{-1} $year^{-1}$ from *A. tortilis* based system.

Steps to be taken/operational procedure

- Protection of the area from wildlife, livestock and other anthropogenic disturbances by means of erecting fencing (stone fencing, barbed wire fencing etc.) or by social fencing.
- Arrangement of saplings of suitable species or raising nursery (preferably *C.polygonoides*).
- Sowing of *Cassia angustifolia* seeds in advance to create micro-windbreak or during plantation time in between shrub/ tree rows.
- Add 9.0 g of DAP (di-ammonium hydrogen phosphate) in each pit as basal dose.
- If termite infestation is there then apply phorate granules or any other termiticide in the pit and mix well with the soil to protect the seedlings from termite attack.
- Planting of saplings at spacing of 5 m x 5 m and in pit size of 45 x 45 x 45 cm^3.
- Sowing of *Cassia angustifolia* seeds one meter away from the seedlings and at 60 cm interval between the tree rows i.e., six rows. Alternatively, sowing of *Cenchrus ciliaris grass* (60 x 20 cm spacing and similar to *C. angustifolia*) at the onset of monsoon to provide surface vegetation
- Life saving watering in the plantation establishment phase.

MICRO-CATCHMENTS FOR PLANTATION ESTABLISHMENT

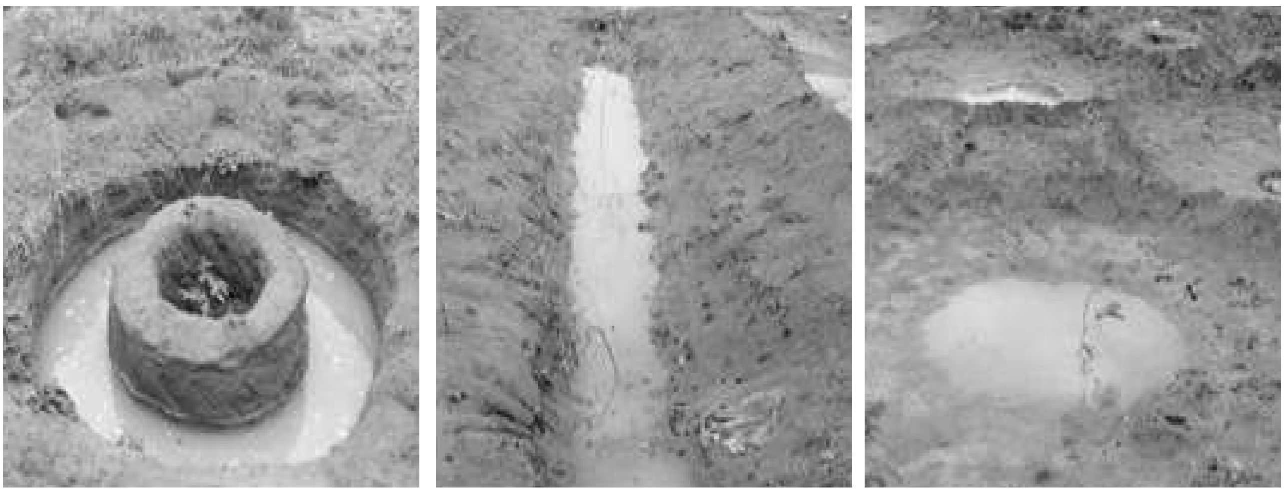
Description

The adversities of climate and soil prevailing in dry land areas result in a predominance of soil moisture deficit for most of the year, which challenges establishment and growth of trees. Because of paucity of ground water in the region tree planting primarily depends on rainfall. The rainfall too, besides low in quantity, has highly skewed distribution. Rains occur in a few showers of high intensity resulting, a high runoff which goes un-utilized and soil moisture storage remains poor. The stored moisture is further subject to unproductive losses by evaporation due to high potential evapo-transpiration (PET) in the region and as evapo-transpiration by weeds, which are abundant immediately after the first rain. These losses need to be reduced to utilize the scarce rain water, more effectively, for better growth and rapid establishment of trees. The use of suitable micro-catchment techniques to harvest field run off and the adoption of moisture conservation techniques such as mulching, tillage, weeding etc. have been the subject of considerable research for increasing yield of agricultural and horticultural crops.

Studies at AFRI demonstrate a dramatic impact of micro-catchments rain water harvesting technology on tree growth, which improved by 4 to 5 folds on micro-catchments when compared with control in case of *Azadirachta* *indica, Prosopis cineraria* and *Tecomella undulata.* The structures - ring pits, big saucers and trench and mound have been found beneficial. Based on growth, cost benefit analysis, employment and social conditions trench and mound and saucers of 2.5 m diameter have been recommended. The water harvesting techniques as they prevent runoff losses (30-50 %) maintain higher soil moisture regime and facilitate better tree establishment and growth owing to better development of root system, improved water use efficiency, improved nutrient use efficiency (4-7 times), thus give a good start to young plantations.

Expected benefits associated with the package of practice

The cost of preparing the micro-catchment rain water harvesting structures is about 21-50 % higher, whereas gain in biomass accumulation was 3 to 4 fold, just in an initial period of 26 months. The technique is labor intensive, thus generating additional employment of 85 man-days ha^{-1}. In Indian Desert famine relief works are quite frequent under Desert Development Programme, where forestry is the core activity. Therefore this technology not only economically viable but beneficial socially and more importantly it will help towards economic stability by reducing uncertainty of livelihood in arid ecosystem.



Ring pit Trench cum mound Saucer of 2.5 m diameter

Fig 11.4. Different rain water harvesting structures

Lessons learned

- The study demonstrates the usefulness and scope of rain water harvesting and conservation practice in improving tree growth in Indian Desert.
- The ridge and furrow technique, trench cum mound, ring pit and saucer of 3 m diameter were very effective and enhanced the soil moisture storage by as much as 42 % in the upper 75 cm layer alone after mild shower of 27.5 mm in January.
- Enhancement in moisture storage was much higher in monsoon season, particularly in deeper soil layers.

- This resulted a several-fold increase in biomass, profusely spreading and deeper root system (penetrating through the $CaCO_3$ layer which, due to better moisture condition, was less hard) and continuance of tree growth in the period of acute moisture deficiency (June).
- Trees in the treated plots experienced less moisture stress in terms of severity and length of period, with the result that the trees were taller, thicker and had straighter bole, denser and wider crown than in the control plot.

Steps to be taken/operational procedure

- Protection of the area from wildlife, livestock and other anthropogenic disturbances by means of erecting fencing (ditch fencing, stone fencing, barbed wire fencing etc.) or by social fencing.
- Arrangement of saplings of suitable species or raising nursery.
- Preparation of rainwater harvesting structures viz. ring pits, big saucers and trench cum mounds as per suitability (Fig.11.4).

Trench cum mound may be prepared by tractor mounted plough economically. Big saucers having 2.5 m diameter and ring pits may be prepared in situations demanding generation of employment.

- If termite infestation is there then applyphorate granules or any other termiticide in the pit and mix well with the soil to protect the seedlings from termite attack. Alternatively, drenching of pit soil with 0.3 % (active ingredient) Chlorpyriphos may be done.
- Planting of saplings at spacing of 5 m x 4 m and in pit size of 45 x 45 x 45 cm^3.
- Watering at the time of plantation to establish good soil-root contact if required and life saving watering in the plantation establishment phase if required.

MULCHING AND WEEDING FOR CONSERVATION OF SOIL MOISTURE AND ENHANCING PLANT GROWTH

Description

Global average of water evaporation is 410 mm whereas, the ratio of biomass to evaporation is 4 g kg^{-1} water evaporation with accumulation of 110 billion tonnes of carbon in land biota. Evapo-transpiration, the removal of water from soil in the form of evaporation and transpiration is driven by a tremendous drying force the atmosphere exerts on soil and plants affecting hydrological cycle.

The adversities of climate and soil prevailing in the Indian arid zone result in a predominance of soil moisture deficit for most of the year, which delays the establishment and growth of trees. Ground water in the region is very deep (100-300 m) and often brackish. Thus tree planting primarily depends on rainfall. The rainfall characteristics in the Indian Desert are such that besides being low in quantity, its distribution is highly skewed, with about 90 % of it falling between July and September. The number of rainy days annually varies from 10 to 15. Rains occur in a few showers of high intensity resulting, a high runoff which goes un-utilized and soil moisture storage remains poor. The stored moisture is further subject to unproductive losses by evaporation due to high potential evapo-transpiration (PET) in the region and as evapo-transpiration by weeds, which are abundant immediately after the first rain.

These losses need to be reduced to utilize the scarce rain water, more effectively, for better growth and rapid establishment of trees. The use of suitable micro-catchment techniques to harvest field run off and the adoption of moisture conservation techniques such as mulching, tillage, weeding etc. have been the subject of considerable research for increasing yield of agricultural and horticultural crops. However, research on these aspects has been scanty in forestry circle. Tree planting in arid region is being done in an unscientific manner, requiring very long period of establishment. Afforestation is the major development activity in the Indian Desert and needs to be done scientifically on high input, high return principles.

Moisture conservation practices such as mulching with local under shrub like *Crotalaria burhia*, soil tillage and intercultural operations in dry zones adequately demonstrate their utility in plantation establishment and early growth of trees by increasing plant height (24 %) and collar circumference (27 %) in *Azadirachta indica*. This impact is attributed to the prevention of evapo-transpiration losses and consequently high soil moisture regimes and moderation of thermal regimes (by 5 ^{0}C) in the vicinity of roots and consequently maintaining better microbial activities resulting in transformation and availability of nutrients.

Study on partitioning of water loss in a lysimeter study indicated that water losses from the *E. camaldulens* is plot (irrigated at the rate of 36.2 mm per irrigation) was 4.75 mm day^{-1} (19 lit day-1) during summer as compared to 3.45 mm day^{-1} (13.8 lit day-1) in *A. nilotica* and 2.62 mm day^{-1} (10.56 lit day^{-1}) in *D. sissoo* plot. The depletion in soil water from bare soil was 7.0 lit day^{-1} that contributed significant amount of water loss. Simple mulching with locally available *Crotalaria burhia* under shrub saved the water loss by 0.15 mm day^{-1}. In conclusion, surface evaporation contribute significant amount of water loss that can be reduced by weeding and surface mulching with locally available under-shrubs or grasses to enhance productivity.

The study amply demonstrates the usefulness and scope of rain water harvesting and conservation practice in improving tree growth in Indian desert. *Crotolaria burhia*, which is available in abundance from agricultural fields and other waste lands, could be profitably utilized as mulch to improve initial development and growth of trees in arid region. Mulching is known to reduce evaporative loss of soil moisture, moderate root zone temperature and improve microbial activities and nutrient availability. The additional cost of mulching is only 10 % compared to no mulch, whereas the additional biomass produced is 35 %. The study also highlights the necessity of weeding in arid zone plantations as it prevents unproductive loss of water and nutrients and allows their utilization by plantation thereby improving their growth. Weed clearing was found to conserve 20 % higher moisture, improve tree height by 26 % and double the biomass production in *A. indica* as compared to the control. A simple mulching with locally available material saved the water loss by 0.15 mm day^{-1} (1.5 tones of water ha^{-1} day^{-1}).

The results conclusively demonstrate that, use of *Crotolaria burhia mulch* and weeding are essential for maintaining better soil moisture regimes and for rapid establishment and development of forest plantations in the Indian desert.

Lessons learned

- The moisture conservation techniques like mulching and weeding in addition to micro-catchment rain water harvesting are very effective in boosting early establishment and growth of trees. Compared to control mulching improved the biomass accumulation by *Azadirachta indica* demonstrating its usefulness in arid climate. Weeding also enhanced biomass production in *A. indica*.

- Plant nutrition is primarily a moisture controlled process. Movement of nutrient ions in the soil-root system occurs predominantly through the water phase. Transport and uptake of soil phosphorous occurs predominantly by diffusion and is strongly influenced by the size of the root system. Favorable moisture condition, affected by moisture conservation practices like mulching and weeding, increases the rate of nutrient uptake by the plants.
- A simple mulching with locally available material saved the water loss by 0.15 mm day^{-1} (1.5 tones of water ha^{-1} day^{-1}). Thus, evaporation loss could be further reduced increasing depth of the mulching material.

Table 11.4: Expected benefits associated with mulching and weeding

Environmental	Economic	Social
Increase in production per unit area	Increased landscape value	Economic and social stability to famine struck desert region by not only overcoming the risk of plantation failures but also by generating employment for the desert dwellers and reduce nomadism.
Improvement in soil status	Increased land value	
Increase in carbon stock both in soil and tree	Increased fuel wood supply	

Steps to be taken/operational procedure

- Protection of the area from wildlife, livestock and other anthropogenic disturbances by means of erecting fencing (ditch fencing, stone fencing, barbed wire fencing etc.) or by social fencing.
- Arrangement of saplings of suitable species or raising nursery.
- Digging of pits (45 x 45 x 45 cm^3) for planting
- If termite infestation is there then apply phorate granules or any other termiticide in the pit and mix well with the soil to protect the seedlings from termite attack. Alternatively, drenching of pit soil with 0.3 % (active ingredient) Chlorpyriphos may be done.
- Planting of saplings at spacing of 5 m x 4 m and in pit size of 45 x 45 x 45 cm^3.
- Preparation of rain water harvesting saucers around the saplings.
- Collection of *Crotalaria burhia* or any other locally available under shrub and covering the area around the plants in the form of mulch.
- Watering at the time of plantation to establish good soil-root contact if required and life saving watering in the plantation establishment phase if required.
- Regular weeding and tilling of surface soil around the plants to break capillary action. This will reduce moisture loss by evaporation.

PROSOPIS CINERARIA BASED AGROFORESTRY FOR HOT ARID REGION OF GUJARAT AND RAJASTHAN

Description

Agroforestry systems are now recognized and become prevalent in the hot arid region forthe ecological and socioeconomic benefits including products for household and national economics like food, fodder and medicine. The systems include agri-silviculture, agrosilvopastoral, multipurpose tree systems and agri-horticulture. Trees integrated extensively in the crop and livestock production systems are *Prosopis cineraria, Tecomella undulata, Acacia nilotica, Acacia tortilis* and *Ailanthus excelsa*. Trees in agroforestry systems use water from soil that shallower plant roots cannot access. Benefits of tree species depend on efficient and judicious management of soil and water resources. Selection of appropriate combination of tree and crop species, adoption of appropriate spacing regime and suitable management practices (such as, trenching, pruning and thinning) are important aspects of field research. In the Indian arid zone, *P. cineraria, T. undulata* and *Ziziphus* spp. are the most preferred species fount integrated in agricultural land. *Prosopis cineraria* (L.) (Khejri) is the most widely grown tree in the Indian desert because both its leaves and fruits have high fodder and human food value, respectively. The increasing demand of fodder and fuel wood as a function of increasing human as well as livestock population in the region emphasized the need of more diversified production system. P. cineraria enhances productivity of soil and the associated crops and provides fruit and leaf for vegetables and fodder, respectively.

This case study is about using a practice developed by AFRI for different hot arid and semi arid regions of India facing the problem of land degradation. *Prosopis cineraria* was identified as most suitable for agroforestry as it does not compete with the main crops except at very high density. This tree has multipurpose uses hence it solved issues like scarcity of fodder and fuel wood, improved soil quality which in turn increased the productivity of land. State Forest Department of Rajasthan and Ministry of Rural Development helped in funding as well as dissemination of this practice. *P. cineraria* enhance productivity of agricultural crops when maintained at optimum tree density. Tree size, competition for resources at high densities and soil water deficit as a result of increase solar radiation at low tree density were the probable factors affecting crop production. Outputs of crop yield and tree growth and biomass suggested that optimum tree density, which provided highest crop production decreased with tree size/ age i.e., 417 trees ha^{-1} (4 m x 6 m), 278 trees ha^{-1} (4 m x 9 m) at 6 and 7 years, 208 trees ha^{-1} (8 m x 6 m) at 10 year and less than 208 trees ha^{-1} at 11 year of age and above. The result indicated bio-economic benefits of optimum tree density of traditional practices of integrating trees in farming system in arid zones.

Farmers sow ‘kharif’ as well as ‘rabi’ crops depending upon the availability of irrigation facility in the area. In the rain-fed areas only ‘kharif’ crops are taken. Main crops are *Vigna radiata, Panisetum glaucum, Cymopsis tetragonoloba, Sesamum indicum* etc. during 'kharif'-rainy season and *Brassica* spp. in 'rabi'-winter season. The crops are grown in the interspaces of the trees. Facilitating effects are observed on the crop yield because of increased nutrient availability and a balanced resource sharing between the tree and associated crops. People of the Indian desert worship the species and the state government has declared it as the state tree owing to its importance in sustainable livelihood of the local people.

In general people of Indian desert do not plant *P. cineraria* on their farmland rather protect and take care of randomly growing tree or seedlings regenerated on their farmlands. Maintaining optimum densities of 833 tree ha^{-1} (2 m x 3 m) at 2-3 years, 417 tree ha^{-1} (4 m x 6 m) at 4-6 years of age, 278 trees ha^{-1} (4 m x 9 m) at 6-7 and 7 years, 208 trees ha^{-1} (8 m x 6 m) at 11 year and < 208 trees ha^{-1} at 12 years of age or above increased crop yields as compared to the sole crop without tree. Optimum density of around 200 tree ha^{-1} was also utilized in 'Maru Gauchar Yojana' of Rajasthan for developing pasture lands. The result indicated bio-economic benefits of optimum tree density of traditional practices of integrating trees in farming system in arid zones. In addition *P. cineraria* provides fruit of 350 –1040 g tree^{-1} used as vegetable.

Lessons learned

- Tree reduced yield of agricultural crops at both high (due to competition for resources) and low (increased solar radiation and soil water stress) tree density.
- But the yield of agricultural crop increased when density of P. cineraria was appropriate (i.e., optimum tree density), which varied with tree size/age because of competition for soil resources.
- Yield of annual crops was highest at optimum tree densities of 833 tree ha^{-1} (2 m x 3 m) at 2-3 years, 417 tree ha^{-1} (4 m x 6 m) at 4-6 years of age, 278 trees ha^{-1} (4 m x 9 m) at 6-7 and 7 years, 208 trees ha^{-1} (8 m x 6 m) at 11 year and < 208 trees ha^{-1} at 12 years of age or above.
- Legumes are more suitable than *Penisetum glaucum* (pearlmillet). Pearlmillet was found more competitive with tree than *V. radiata* (mungbean) as observed through reduced tree growth increment when pearlmillet was the intercrop.
- Agroforestry is more beneficial than sole agricultural crop in terms of carbon benefits also. *P. cineraria* is the best species for agroforestry although less competitive than *T. undulata* for agricultural production.

Table 11.5: Expected benefits associated *Prosopis cineraria* based Agroforestry for hot arid region of Gujarat and Rajasthan

Environmental	Economic	Social
Increased production per unit area	Increased landscape value	Diversion to education
Improved in soil status	Increased land value	Improvement in social status
Increased carbon stock both in soil and tree	Increased fuel wood supply	Reduced time in fuel wood collection and diversion of children to education
Tree integration reduce land degradation and conserve the natural resource improving biodiversity	Increased agricultural production and land value	Improved education and health
Increased production of fodder and fuel wood as *P. cineraria* provides utilizable biomass of 19.96 tones ha^{-1} including leaf fodder of 0.85 tones ha^{-1} per year at 12 year age (208 tree ha^{-1})	Increased income through fodder and fuel wood	Increased income facilitate social status and promote education

Steps to be taken/operational procedure

- The practice of *P. cineraria* based agroforestry is an age old practice is western Rajasthan and parts of Gujarat and Haryana. However, the present package of practice delves upon the optimum density that can be maintained without any significant loss to the agricultural production.
- Farmers who have standing trees in their agriculture land may maintain the number as prescribed herein.
- Maintaining optimum densities of 833 tree ha^{-1} (2 m x 3 m) at 2-3 years, 417 tree ha^{-1} (4 m x 6 m) at 4-6 years of age, 278 trees ha^{-1} (4 m x 9 m) at 6-7 years, 208 trees ha^{-1} (8 m x 6 m) at 11 year and < 208 trees ha^{-1} at 12 years of age or above.
- New agroforestry plot may be established by planting tree saplings.
- Protection of the area from wildlife, livestock and other anthropogenic disturbances by means of erecting fencing (ditch fencing, stone fencing, barbed wire fencing etc.) or by social fencing.
- Arrangement of saplings or raising nursery.
- Digging of pits (45 x 45 x 45 cm^3) for planting
- If termite infestation is there then apply phorate granules or any other termiticide in the pit and mix well with the soil to protect the seedlings from termite attack. Alternatively, drenching of pit soil with 0.3 % (active ingredient) Chlorpyriphos may be done.
- Planting of saplings at spacing of 2 m x 3 m and in pit size of 45 x 45 x 45 cm^3.
- Thereafter, thinning or reducing the stem density as mentioned above with advancing age.
- Watering at the time of plantation to establish good soil-root contact if required and life saving watering in the plantation establishment phase if required.
- Taking agriculture crops in the interspace between rows.
- Taking legumes and cereals alternatively in rotation may help maintain the fertility of the land.

REHABILITATION OF DEGRADED LAND THROUGH SEED SOWING TO INCREASE LAND PRODUCTIVITY AND COMBAT DESERTIFICATION

Description

In order to minimize the adverse effects of the environment and to increase the supply of fodder and fuel wood from the marginal/degraded lands, introduction of woody perennials is a common practice in dry areas. Many schemes like desert development wasteland development and externally added programmes are in way in order to combat desertification and to mitigate the adverse effect of this calamity. Millions of seedlings raised in nursery are planted under afforestation activities every year to increase green cover, improve fodder and fuel wood availability. The common species under plantations are *Acacia tortilis, A. senegal, A. nilotica, Zizyphus nummularia* and *Azadirachta indica* under rainfed conditions. *Dalbergia sissoo* and Eucalyptus camaldulensis are raised under irrigation in Indira Gandhi canal command area. Sowing of seeds of tree species particularly; *A. senegal, A. catechu, Jatropha, Z. mauritiana* etc along the rainwater harvesting structures or field bunds is common in dry areas, where the performances of regenerated seedlings are found equally good as the planted seedlings. This practice may be adopted in rehabilitation of degraded lands including sandy areas giving major emphasis on site preparation and selection of suitable drought hardy species. To prove this, an experiment was carried out at AFRI experimental farm during drought period of 2002 and found encouraging and implementable.

The experiment was laid to study the effect of site preparation and seed sowing of *Azadirachta indica* and *Colophospermum mopane* germination and seedling establishment of these tree species. The climate of the site is arid with mean annual rainfall of 420 mm and the mean annual pan evaporation is 2025 mm indicating high water deficit in the area. The soil is loamy sand with low soil organic matter and nutrients and is slightly alkaline in reaction. Topography of the land under experimentation is almost flat. The experimental site is located in the city of Jodhpur in western part of the state Rajasthan. In this, fruits of *A. indica* and *C. mopane* were collected from the experimental area. Site was deep ploughed to remove the existing vegetation and to enhance water conservation. Half kg of dry fruits was weighed and number of fruits counted in triplicate for both the species. Weighed fruits were broadcasted in July, 2001. The broadcast seeds were mixed through further ploughing to ensure seed burial in the soil. Average number of seeds in each plot were 1,530 and 955 for *A. indica* and *C. mopane*, respectively. Measurements of germinated seedlings were taken at different time interval. Some plants were also excavated to monitor root growth and its penetrability of the hard layer of calcium carbonate for better survival under harsh environment.

Germination percent for *A. indica* and *C. mopane* was 54 and 94 % with respective population 27500 and 30100 seedlings ha^{-1}. The survival reduced to 1.2 % and 9.7 %, respectively after one year, but still provided more than 300 plants per ha. Root of *C. mopane* seedlings was more than two fold lager as compared to *A. indica* plants. Shoot and root dry biomass of *C. mopane* were greater than 5-fold than the biomass of *A. indica* seedlings. Biomass allocation was high in root in both the species. Best field survival of *C. mopane* seedlings was due to their deep rooting behavior, which penetrated even hard layer of calcium carbonate to extract water/nutrient from the deeper soil layers and shoot during harsh conditions.

Fig 11.5. Regeneration of *C. mopane* under the canopy of same tree (left) and performance of 8 years old *C. mopane* plants grown through seed sowing (right).

Expected benefits associated with the package of practice

Broadcasted seed based seedlings/ regenerated seedlings proved better growth and performance than the planted one under harsh environmental conditions. Some of the best performers are *Acacia senegal, A. catechu, Jatropha curcas, Azadirachta indica* and *Colophospermum mopane,* though they vary in performance among themselves. The reduction in cost for raising nursery plantation, transportation etc. are the economic benefits.

Table 11.5: Expected benefits associated with rehabilitation of degraded land through seed sowing

Environmental	Economic	Social
Increased land productivity under improved soil nutrient status.	Increased landscape value and economic status.	Improved social status resulting in diversion towards education.
Reduced soil and water loss and combat desertification.	Decreased soil loss by wind erosion.	Improved air quality and human health.
Increased soil carbon stock and biomass.	Increased fuel wood supply.	Reduced time in fuel wood collection by the villagers.
Increased vegetation cover.	Increased landscape value and enhancement in productivity.	Increase in social status.

The seed sown seedlings show better root development and penetrating even hard layer, which enhance survival even during harsh environmental conditions. This species also suited to mild saline/ alkaline conditions and can be replicated in similar area. Forest department of Gujarat had procured the seeds of *C. mopane* from AFRI and utilized it in rehabilitating the degraded land of the Gujarat state.

Lessons learned

- *C. mopane* is able to establish and flourish in habitats characterized by arid or sodic soils.
- It is a preferred fuel wood and fodder species.
- *Azadirachta indica* is another multipurpose species and is well adapted to the dry areas.
- These species could be grown under direct seeding to rehabilitate the degraded lands of varying categories.
- Success of this practice emphasizes the importance of site preparation and conservation of soil and water resources. Low cost technology of seed broad casting is an effective solution to improve the vegetation status which is beneficial for the poor in the dry areas.
- This experiment demonstrating growth and performance of *C. mopane* is a viable strategy in the direction of rehabilitation of degraded land through broad casting.

- Based on the experiences elsewhere and this experiment, some more species are suggested for direct seed sowing:

  a. *Acacia jacquemonttii* and *Clerodendrum phlomides* in bare dune

  b. *Colophospermum mopane* in sandy plain including slight alkaline/ saline conditions A*cacia senegal* in gravelly area,

  c. *Acacia catechu, A. leucophloea* and *Acacia ferrugiana* in gravelly/rocky pediments with relatively greater rainfall.

Steps to be taken/operational procedure

- Selection of species based on soil type and rainfall regime as described in previous section.
- Collection of seeds of the selected species.
- Preparation of the site with deep ploughing and removal of unwanted weeds to enhance water conservation.
- Broadcasting / direct sowing of seeds during the onset of monsoon.
- One shallow ploughing to ensure seed burial and better seed –soil contact.

Though as per latest report, India's forest cover increased to 7,08,273 sq km, as against 7,01,495 sq km two years ago massive deforestation of natural forests is posing a serious threat towards achieving the target of 33 % forest cover. Reduction in growing stock because of degradation is also very significant and hence is an important factor deserving attention in any programme aimed at increasing green cover. Degraded lands present in various forms i.e. salt affected lands, waterlogged areas, shifting sand dunes in arid and semi arid regions, degraded hilly areas etc. provide ample opportunity to develop green cover and plantations as renewable source of fuel wood. Each of the problem sites/ area has been addressed with a brief description of the significance and details of the practice developed followed by benefits associated with the package of practice, lessons learned and operational procedure. Potential of increasing green cover through afforestation and restoration of different degraded lands narrated above in the form of package of practices will certainly be of great use for different stakeholders.

CARBON SEQUESTRATION

Although, CO_2 constitutes a very small percentage (approx 0.04%) of the atmosphere (Vashum and Jayakumar, 2012), it plays a very important role in providing life support system to the earth. Plants, as primary producers, capture CO_2 from atmosphere, convert it into carbohydrates and release oxygen (O_2) into the atmosphere. This process is called photosynthesis and plants produce food through this process. Besides consuming CO_2 during photosynthesis, plants also release some CO_2 during respiration. The process of capturing or storing of carbon by plants is called carbon sequestration. When the plants die and decompose or their wood is burnt, the carbon stored in them is released back into the atmosphere. The need to remove this atmospheric carbon dioxide is inevitable for maintaining life on this planet. Atmospheric CO_2 concentration can be lowered either by reducing emissions or by taking this gas out of the atmosphere and storing in terrestrial, oceanic or freshwater aquatic ecosystems.

Sources and Sinks of CO_2

Source of CO_2 is defined as any activity or process that release CO_2 in the atmosphere and can be divided into two groups: natural and anthropogenic. Natural sources include the respiration of animals (60 Gt per annum) and the surface ocean (90 Gt per annum) (Schimel *et al.*, 1995). Carbon dioxide emissions from human activity arise from a number of different sources, mainly from the combustion of fossil fuels used in power generation, transportation, industrial processes and residential and commercial buildings. Reports suggests that 9.9bn tonnes of carbon in the form of $CO_2$was emitted from fossil fuels in 2015, 41 % came from coal, 34 % from oil, 19 % from gas, 5.6 % from cement production and 0.7 % from flaring. Averaged over the last decade, emissions from the fossil fuels and industries accounts to 91 % of human caused CO_2 emissions, with 9 % coming from land use change (Le Quere, 2016).

Sink is defined as a process or an activity that removes greenhouse gas from the atmosphere (FAO Soils Portal). The surface ocean also acts as a natural sink for atmospheric CO_2, with an annual removal flux of 92 Gt carbon. The other major natural sink is the primary productivity of land vegetation (photosynthesis), which sequesters 61.4 Gt carbon every year (Schimel et al., 1995).

TYPES OF CARBON SEQUESTRATION

Various biological, chemical and physical processes can sequester and store carbon. Few important sinks are listed below:

1. Biological Processes

Forestry - A huge amount of carbon is naturally stored in the forests by trees, other plants and forest soil. As part of photosynthesis, plants absorb carbon dioxide from the atmosphere, store this carbon as sugar, starch or cellulose and release oxygen back into the atmosphere. Over the life of an individual tree or other forest plant, the amount of carbon captured (sequestered) is equal to carbon released. As the plant grows, carbon is absorbed from the atmosphere and then released back into the atmosphere as the plant matures, dies and rots. Carbon sequestration potential varies in different species and at phase of its life.

Agroforestry - Agroforestry provides a unique opportunity to combine the twin objectives of climate change adaptation and mitigation. It has the ability to enhance the resilience of the system for coping with the adverse impacts of climate change. Agroforestry systems have the potential to provide significant mitigation options but they require proper management that influences the amount of carbon sequestered. The carbon sequestration potential of agroforestry systems is estimated between 12 and 228 mg per hectare, with a median value of 95 mg per hectare. An area between 585-1215 X 10^6 ha is suitable for agroforestry practices in the world, where 1.1-2.2 Pg carbon can be stored over the next 50 years.

Ocean iron and urea fertilization using natural or intentional introduction of iron and urea to the upper layers of ocean to stimulate the marine food chain. Fertilization supports the growth of marine phyto-planktons which help sequester more carbon dioxide from the atmosphere. A number of ocean laboratories and scientists are exploring these methods to revive declining populations of planktons and sequester billions of tonnes of carbon dioxide to reduce global warming and ocean acidification.

Ocean mixing requires geo-engineering approach, in which various layers of the ocean are mixed to enhance movement of nutrients and dissolve gases. Large vertical pipes are placed in the oceans to bring nutrient rich water from lower layers to the surface. It triggers algal blooms, which also store carbon when they die. This technique may result in a short term rise in CO_2 in the atmosphere.

2. Physical Processes

Biochar burial - Biochar is the charcoal produced by pyrolysis of biomass, which is landfilled and used as a soil improver to create terra preta. It is very dark, fertile anthropogenic soil, characterized by the presence of high quantities of organic matter such as plant residues, animal faeces, fish and animal bones and other nutrients like N, P, Ca, Zn, Mn, showing higher microorganism activities. By pyrolysing the biomass to biochar, carbon is sequestered in the soil and is unavailable for oxidation to CO_2 and consequential atmospheric release.

Biomass burial in soil and ocean- Burying biomass like trees lock carbon in the soil for longer period by removing it from the atmosphere. Rivers bring large quantities of dead material and nutrients including crop waste and trees into the ocean. This biomass is allowed to sink deep into ocean, thereby a large quantity of carbon is sequestered in the oceans.

3. Chemical Processes

Carbon in the form of CO_2 can be removed from the atmosphere by chemical processes and stored in stable margin forms. This process is known as carbon sequestration by mineral carbonation or mineral sequestration.

$CaO + CO_2 = CaCO_3$

$MgO + CO_2 = MgCO_3$

In nature, calcium and magnesium are found as silicates, hence reactions become like :

$Mg_2SiO_4 + 2CO_2 = 2MgCO_3 + SiO_2$ (Forsterite)

$Mg_3Si2O_5(OH)_4 + 3CO_2 = MgCO_3 + 2SiO_2 + 2H_2O$ (Serpentine)

CARBON CYCLE

The so-called carbon cycle, which involves the fixation of atmospheric CO_2 in plants through photosynthesis and return of part of that C to the atmosphere through plant, animal, and microbial respiration as CO_2 under aerobic and CH_4 under anaerobic conditions, is an important process related to C sequestration. Direct sequestration of C occurs in soil by inorganic chemical reactions that convert CO_2 into soil inorganic C compounds such as calcium and magnesium carbonates. Above ground C storage is the incorporation of C into plant matter either in the harvested product, or in the parts remaining on site in a living form. The amount of biomass, and subsequently C, that is stored depends to a great deal, apart from the nature of plant itself-on the properties of the soil on which it grows, with higher concentrations of organic matter, nutrients, and good soil structure leading to greater biomass production. Roughly two-thirds of the total C storage occurs belowground, the extent and rate of which are influenced by inherent soil properties and processes, including some that are not influenced by management practices. Decomposition of plant residues and other organic materials in the soil is a source of C and nutrients for new growth of microbial communities and plants. Much of this C is released back into the atmosphere as CO_2 during respiration, or is incorporated into living biomass. However, about one-third of soil organic matter (SOM) breaks down much more slowly and could still be present in the soil after 1 year. This SOM represents a significant C store and can remain in the soil for extended periods as a part of soil aggregates. The fraction of SOM that is so ''protected'' from further rapid decomposition is very important from the point of view of soil C sequestration.

12 TERRESTRIAL CARBON POOLS

There are five carbon pools which are considered during the assessment of carbon stock and annual sequestration in natural forests, plantations or agroforestry systems:

1. Above ground biomass
2. Below ground biomass
3. Dead wood
4. Litter
5. Soil organic carbon

Table 12.1. IPCC, 2006 guidelines providing methodologies for the estimation of the carbon stocks and stock changes in different carbon pools

Pool		Description
Biomass	Above ground biomass	All biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds, and foliage.
	Below ground biomass	All biomass of live roots. Fine roots of less than 2 mm diameter are often excluded because these often cannot be distinguished empirically from soil organic matter or litter
Dead organic matter	Dead wood	Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps, larger than or equal to 10 cm in diameter.
	Litter	Includes all non-living biomass with a size greater than the limit for soil organic matter (suggested 2 mm) and less than the minimum diameter chosen for dead wood (e.g. 10 cm), lying dead, in various states of decomposition above or within the mineral or organic soil. This includes the litter layer as usually defined in soil typologies. Live fine roots above the mineral or organic soil are included in litter, where they cannot be distinguished from it empirically.
Soil	Soil organic matter	Includes organic carbon in mineral soils upto 30 cm depth. Live and dead fine roots and DOM within the soil that are less than the minimum diameter limit (suggested 2 mm) for roots and DOM, are included with soil organic matter where they cannot be distinguished from it empirically.

QUANTIFICATION OF CARBON IN TREES

Quantifying carbon in the trees requires quantifying the entire biomass of a tree. The tree biomass estimation varies in their procedure, complexity and time demand depending on the specific aim of estimation operation. It is not only difficult to estimate biomass in trees because they are large and heavy, but also because cutting trees for the estimation is not always practical and permissible. A major challenge in modeling carbon sequestration in tropical plantations is estimating total above ground biomass (AGB), because a significant amount of the carbon in forest ecosystems is stored in the form of AGB. A certain amount of carbon is also stocked in the root systems of trees or below ground biomass (BGB).

Allometric equations for tree species are developed to estimate carbon in trees quantifying above ground biomass by non-destructive method, although such equations are developed as a result of cutting trees of varying age and girth (destructive method).

There are three general methods to generate the allometric equations for the estimation of biomass:

- Non-destructive method
- Sub-sampling method
- Complete harvesting method

The non-destructive method is used by means of sampling without destruction or felling the trees as applied by Vann et al. (1998); Verwijs and Telenius (1999) and Adhikari (2005). Sub-sampling method requires tree felling, weighing and drying of a small sample (Gier, 1999). This method is applied for large trees because direct weighing can only be done for small trees and for large trees partitioning is necessary so that the partitions can fit into the weighing scale. Complete harvesting method requires harvesting of randomly selected plots or individual trees within plots (Brown, 1997).

Destructive harvest method i.e. by felling and weighing a representative sample of trees is the most common and precise way to measure AGB. But this process is destructive and time consuming. Not only are the cut trees removed from the forest, but the felling and extraction process may seriously injure neighboring trees and undergrowth. Hence, non-destructive methods are used to measure AGB by developing allometric equations.

Above and Below Ground Biomass (AGBand BGB)

Allometric models are developed to measure AGB from variables including diameter, height, age and wood density. Such models have the potential to protect plantations from unnecessary destruction and save time on the field. Species specific models should be developed to increase the precision of AGB estimates because of significant differences in architecture and wood density in the trees (Ketterings et al., 2001). But it is very impractical to develop species-specific models keeping in view the high level of biodiversity in natural forests; hence, most models developed so far have not been species-specific (Chave et al., 2005). For plantation studies, species-specific allometric equations can be developed because of limited number of species and systematic pattern of plantation.

Many equations have been developed for estimating AGB in natural tropical forests. Scientists have reported that diameter at breast height (DBH), height and specific wood density are the most important predictors of biomass (Chave et al., 2005). Strong correlations exist between AGB and both tree diameter and tree height. Out of these variables, DBH is the most easily measurable, consistently reported and highly correlated with biomass. Height has been incorporated in many models (Nelson et al., 1999), but it is very difficult to measure height in closed canopy forests. The difficulties of measuring height may be reduced in more widely spaced plantations. The use of specific wood density in regression models has also been somewhat controversial. Nelsen et al. (1999) observed that specific wood density has not been very useful for predicting biomass in single species regressions.

The below ground biomass (BGB) of experimental trees is calculated using 0.25 times above ground biomass as per norm of Intergovernmental Panel on Climate Change (IPCC, 1996). The carbon content is considered 0.5x time total dry biomass of trees.

Polynomial/ linear regression equations are developed between AGB and other parameters including Girth at Breast Height (GBH), Height and Basal girth. Although, the equations are developed against GBH, Height and Basal area, AGB is generally quantified using regression equations against GBH only, because GBH is easy to measure and highly correlated parameter.

For example, following allometric equation can be used to quantify above ground biomass in Tectona grandis:

$y = 3.174x - 21.27$

where, y = AGB (kg)

x = GBH (cm)

$y = 10.20x - 27.37$

where, y = AGB (kg)

x = Height (m)

$y = 5.943x - 20.42$

where, y = AGB (kg)

x = Age (years)

To minimize the number of trees to be cut for developing allometric equations and considering raising plantations of diverse species, the equations are developed for mixed species.

For example, following allometric equation can be used for plantation of mixed tree species to quantify above ground biomass:

$y = 0.007x2 + 1.898x - 32.69$

where, y = AGB (kg)

x = GBH (cm)

By putting the values of x in the regression equations, the values of AGB (y) can be calculated.

QUANTIFICATION OF CARBON IN SHRUBS AND HERBS

Herbaceous biomass is the biomass obtained from plants that have a non-woody stem and which die back at the end of the growing season. Carbon in shrubs and herbs is quantified by destructive method after rainy season in the month of August when herbaceous biomass is found maximum. For the assessment of ground flora biomass (shrubs and herbs), 3 quadrats of 1m x 1m size are laid out within each tree quadrat. The herbs and shrubs collected are brought to laboratory and dried until constant weight is obtained. The carbon content is considered 0.5 times total dry biomass of the collected herbs and shrubs.

QUANTIFICATION OF CARBON IN DEADWOOD AND LITTER

Litter and deadwood is collected in 0.5m x 0.5m size quadrats laid out in the tree quadrats. 3 quadrats for litter in each tree quadrat are laid out and dug for about 10 cm deep to collect litter throughout the year. All the litter and deadwood collected in the entire year is air dried to constant weight readings. The carbon content is considered 0.5 times total dry biomass observed.

Plant Carbon Analysis

The samples of wood, other parts of trees, shrub, herbs and litter can be analyzed for carbon content by employing CHNS analyzer (Elementar Vario Micro Q 2013), otherwise it can be estimated by indirect methods. Generally, the carbon fraction values used by countries vary from 0.45 to 0.53 but, overwhelmingly, countries used the default value of 0.50 to estimate carbon in plants and plant parts. The average weighted by forest area is 0.49 (Marklund and Schoene, 2006).

SOIL ORGANIC CARBON (SOC)

(Walkley and Black's (1993) Rapid Titration Method)

SOC is the long-term storage of carbon in ocean, soil, vegetation (especially forests) and geologic formations. Although, oceans store most of the earth carbon, soils contain approximately 75 % of the carbon pool on land, three times more than the amount stored in living plants and animals. Therefore, soils play a major role in maintaining a balanced global carbon cycle.

A great variety of organisms live in the soil. Most of the soil organisms depend on the addition of carbon compounds in plant materials like roots, leaves and stems and the faeces of animals. By decomposing these materials CO_2 and mineral nutrients are produced, which plants take up through their leaves and roots respectively, some of the carbon remaining in the soil in organic matter.

The organic materials added to the soil are the products of photosynthesis by higher plants. Some of the carbon in compounds that are photosynthesized is returned to the atmosphere as CO_2 by plant respiration. The rest is known as net primary production (NPP); some of this is stored in perennial tissues such as wood, some may be eaten by herbivores and a large part is shed as litter (Wild, 1993).

Soil organic matter plays a very important and spectacular role in the maintenance and improvement of soil properties. Organic matter constitutes between 1 and 6 percent of the top soil weight of most upland soils. Top soils with less than 1 percent organic matter are mostly limited to desert areas. At the other extreme, the organic matter contents of soils in low wet areas may be as high as 90 percent or more. Soils with more than 12-18 percent organic carbon (approximately 20 – 30 percent organic matter) are called organic soils.

Organic carbon is an integrative property of soil and it is generally assumed that higher the level of organic carbon, higher the soil fertility. The decomposition of organic carbon and production of organic acid have in general effect on site pH. The organic carbon also influences the availability of nitrogen and phosphorus to the plants. Since the ground cover generally consists of grasses, herbs, ferns etc., hence the higher value of all nutrients occurs in the surface soil and then it gradually decreases to lower horizons.

To collect the soil samples, fresh rectangular pits of size 30 cm wide, 0-5 cm deep (surface) and 15-30 cm deep (subsurface) were dug after clearing the top layer. Soil samples from 0-30 cm of the surface were collected because this zone is intended to cover the actively changing soil carbon pool. Soil from three sides of the pit was scraped with the help of khurpee from 0 to 15 cm and 15-30 cm deep. Uniform thickness of soil layer was scraped from top to bottom. Soil was kept in a polythene bag and tightly closed with thread. A label showing the sampling details was put inside the polythene bag before closing the bag. Proper entry was made in the field note book. Soil organic carbon in the collected samples was quantified by Walkley – Black Method.

In this method the soil is digested with chromic and sulphuric acids, making use of the heat of dilution of the sulphuric acid. The excess of chromic acid, not reduced by the organic matter of the soil is then determined by titration with standard ferrous sulphate. Nitrates interfere only if present in amounts in excess of one-twentieth of the carbon content. Carbonates, even when they constitute 50 per cent of the soil, do not affect the results. Manganese dioxide may also exceed the carbon content by three or four times without introducing serious error. Interference due to significant amounts of chlorides can be overcome by the addition of an excess of silver sulphate to the sulphuric acid as described below or a suitable correction can be applied if the amount of chlorine is known. Elementary carbon, such as charcoal or coal, is practically unattacked in this method so this source of error is eliminated.

Reagents:

N Potassium Dichromate- Dissolve 49.04 g of reagent grade K_2Cr2O_7 in water and dilute to 1 litre.

Sulphuric acid- Not less than 96 per cent.

Phosphoric acid-. 85 per cent.

Diphenylamine- Dissolve 0.5 g diphenylamine in a mixture of 100 ml conc. sulphuric acid and 20 ml water.

N Ferrous Sulphate- Dissolve 278.0 g of reagent grade $FeSO_4$.7 H_2Oin water, add 15 ml of conc. sulphuric acid and dilute to 1 litre. Standardize by titrating against 10.5 ml of N potassium dichromate, as described in the method given below. The ferrous sulphate solution is quite stable if kept under an atmosphere of hydrogen in the reservoir bottle of an automatic burette.

Method

For this determination the soil sample should be ground to pass a 0.5 mm screen. Transfer a weighed quantity of soil, not exceeding 10 g and containing about 10-25 mg of organic carbon to a 500 ml Erlenmeyer flask. Add 10 ml of N potassium dichromate followed by 20 ml of conc. sulphuric acid. Where large numbers of analyses have to be carried out the dichromate is most conveniently added from a burette with an automatic zero and the sulphuric acid from an automatic pipette. Shake by hand for one minute and leave the flask to stand on a sheet of asbestos for about 30 minutes. Then add about 200 ml of water, 10 ml of phosphoric acid and 1 ml of diphenylamine indicator solution. Titrate by adding ferrous sulphate from the automatic burette until the solution is purple blue. Continue to add the ferrous sulphate in small lots of about 0.5 ml, until the color flashes to green. This occurs with little or no warming. Then add 0.5 ml of N potassium dichromate to restore an excess of dichromate and complete the titration by adding ferrous sulphate drop by drop until the last trace of blue color disappears. If more than 8 ml of the 10 ml of potassium dichromate originally taken have been reduced during the digestion, repeat the determination using a smaller quantity of soil.

The end point can easily be recognized to within one drop of ferrous sulphate. The color is not always purple on adding the indicator at the beginning of the titration, but the purple or blue color always appears just before the end point. The original blue color frequently does not reappear on the addition of 0.5 ml excess of potassium dichromate but it soon redevelops after the addition of the first drop or two of ferrous sulphate.

The color change is more difficult to follow in the presence of larger amounts of soil and for this reason not more than 10 g of soil should ever be used for a determination. Large amounts of calcium sulphate (precipitated from calcareous soils) or silver chloride (if silver sulphate is used to prevent chlorine interference in saline soils) tend to alter the shades of the colors produced. The color change at the end point, however, is still quite sharp and easily recognized.

Where chlorides are present in amounts not in excess of the molecular equivalent of carbon, 1.25 g of silver sulphate should be dissolved in each 100 ml of concentrated sulphuric acid. Twenty ml of this acid then contain sufficient silver to precipitate the whole of the chlorides as silver chloride and so prevent their oxidation by the chromic acid.

Calculation of the Results

One ml of N potassium dichromate is equivalent to 3 mg of carbon. The amount of carbon oxidized, expressed as a percentage of the soil, and is therefore given by the expression:

$$\frac{V1 - V2}{W} \times 0.003 \times 100$$

Where V1 = volume of N potassium dichromate (10.5 ml)

V2 = volume of N ferrous sulphate, in ml

W = weight of soil taken.

If the soil contained chlorides and the silver sulphate modification was not used, make a correction by deducting one twelfth of the percentage of chlorine present from the value calculated above.

Walkley finds that the percentage recovery by this method varies from 60 percent for some subsoils to 90 or more per cent for peat soils, taking values obtained by dry combustion as the standard of comparison. For the majority of agricultural surface soils the mean recovery lies between 75 and 80 per cent. As the recovery factor varies with soil type it is considered undesirable to use a general factor unless it has been correlated with the dry combustion values for the soils under examination. It is preferable to report the results obtained without the use of a recovery factor as "single value" determinations and designate them "Organic Carbon, Walkley and Black values".

CARBON STOCK ASSESSMENT IN DIFFERENT POOLS AT ROURKELA STEEL PLANT, ODISHA: A CASE STUDY

During 1958-59 to 2013-14 about 42.12 lakhs tree plantations have been raised with 2.5 m x 2.5 m spacing covering an area of about 2504 acres at Rourkela Steel Plant (RSP). Vegetation survey of trees, shrubs and herbs in all the plantations was conducted by “Quadrat Method”. A total of 68 quadrats of 10 m x 10 m size (0.01 ha) for trees were laid out in the plantations raised in the premises of steel plant as well as in the steel township and in the nearby natural forest. The quadrats were laid out in such a manner that most of the tree species of different age groups are covered so that the selected quadrats could represent all the plantations raised at RSP. Assessment of tree plantations along road side or surrounding boundary wall was done using line or belt-transect method. The size of line transect was 1m x 100 m (0.01 ha) and belt transect was 10 m x 50 m (0.05 ha). The size of quadrat laid out in nearby natural forest was 31.62 m x 31.62 m (0.1 ha).

All the trees in the selected quadrats were tagged by Aluminium foil and given a unique identification number then marked at 1.37 m from the surface of the ground. Growth characteristics of the trees were measured. The height of trees was measured with Clinometer and DBH with Gaytor Eye Vernier Calliper.

In the quadrats laid out in plantations, a total of 30 tree species were recorded with maximum number of individuals of *Tectona grandis* – Teak (284), followed by *Alstonia scholaris*-Saptaparni (135) and *Cassia siamea* – Kassod (91). In the natural forest, a total 12 tree species with 12 different genus and 11 families were recorded. As a whole, a total of 39 tree species with 959 individuals having DBH greater than 10 cm were selected in plantations and natural forest (Table 12.2).

To quantify carbon in trees, allometric equations for *Tectona grandis, Azadirachta indica*, *Phyllanthus emblica, Pongamia pinnata* and *Butea monosperma* were developed to estimate above ground biomass, thereby carbon, by non-destructive method. Although such equations were developed by cutting trees of different girth classes (destructive method). Equations for other tree species *viz. Delonix regia, Dalbergia sissoo, Albizialebbek, Casiasiamea, Terminalia arjuna, Eucalyptus hybrid, Syzygium cumini* and *Alstonia scholaris* were used developed for another study conducted in similar climatic and edaphic conditions.

9 trees of each species of different girth classes (ranging from very young to full mature trees) were selected and cut. Geo-coordinates, location, GBH, basal diameter, diameter at uppermost corner and height of each tree were measured before having been cut for estimation of above ground biomass. The cut trees were separated to different components viz. main bole, twigs, leaves etc. Above ground biomass (AGB) was quantified on fresh as well as dry weight basis. Sub-sampling method was applied for the estimation of moisture in different parts. Slips and sub-samples of all the cut trees were freshly weighed and brought to the laboratory, where these samples were oven dried till the readings became constant.The below ground biomass (BGB) of experimental trees was calculated using 0.25x times above ground biomass as per norm of Intergovernmental Panel on Climate Change (IPCC, 1996). The carbon content was considered 0.5x time total dry biomass of trees.

Polynomial order two regression equations from zero intercept were developed between carbon of the trees and other parameters including Girth at Breast Height (GBH), Height and Basal diameter with exception in *Eucalyptus hybrid* where by linear equation was used. Although, the equations were developed against GBH, Height and Basal area, but in this study carbon in trees was quantified using regression equations against GBH only because GBH is easy to measure and highly correlated parameter.

Tectona grandis(Teak)

y = 0.0248x2 - 0.1887x ……………………………….. (i)

Azadirachta indica (Neem)

y = 0.0097x2 - 0.1267x ……………………………….. (ii)

Phyllanthus emblica(Aonla)

y = 0.0041x2 -0.035x ……………………………. (iii)

Pongamia pinnata (Karanj)

y = 0.0146x2 -0.12x ……………………………. (iv)

Butea monosperma(Palas)

y = 0.0034x2 -0.0085x ……………………………. (v)

where,

y = Total carbon in trees (kg)

x = GBH (cm)

FIRST YEAR ASSESSMENT

In the selected quadrats, maximum carbon was found in *Tectona grandis* trees (10.99 t) followed by *Alstonia scholaris* (4.89 t) and *Cassia siamea* (4.54 t). The total carbon content in 959 trees belonging to 34 species was calculated to be 39 tonnes. The area occupied by the selected 68 quadrats under study was 0.79 ha. Average number of trees/ ha was calculated to be 1013 having 63.31 % survival rate.

No. of saplings planted at RSP during 1958-59 to 2013-14	42,12,125
Total area under plantation	1013 ha
Spacing between saplings	2.5 m x 2.5 m
At the time of plantation, No. of saplings/ha	1600
At the time of assessment, No. of trees/ha	1013
Survival of trees at the time of assessment	63.31%
No. of survived trees at the time of assessment	26,66,696
Average GBH of trees	52.08 cm
Carbon in 1 tree (with 52.08 cm GBH)	54.81kg
Carbon in total survived trees at RSP (Carbon stock)	1,46,159.25 tonnes
Say,	1,46,159 tonnes
Carbon stock per hectare	144.28 t/ha

Hence, first year assessment of carbon stock in total survived trees at RSP in the form of above and below ground biomass was calculated to be 1,46,159 tonnes or 144.28 t/ha.

SECOND YEAR ASSESSMENT

In the next consecutive year, average number of trees/ha was calculated to be 969 having 60.56% survival rate.

At the time of assessment, No. of trees/ha	969
Survival of trees at the time of second assessment	60.56%

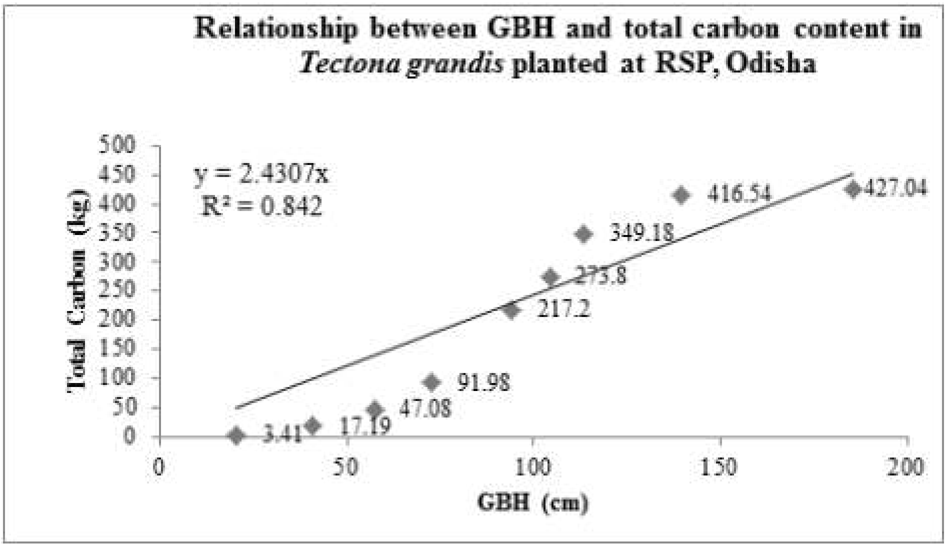
No. of survived trees at the time of assessment	25,50,863
Average GBH of trees	55.09 cm
Carbon in 1 tree (with 55.09 cm GBH)	59.24kg
Carbon in total survived trees at RSP (Carbon stock)	1,51,100.72 tonnes
Say,	1,51,101 tonnes
Carbon stock per hectare	149.16 t/ha

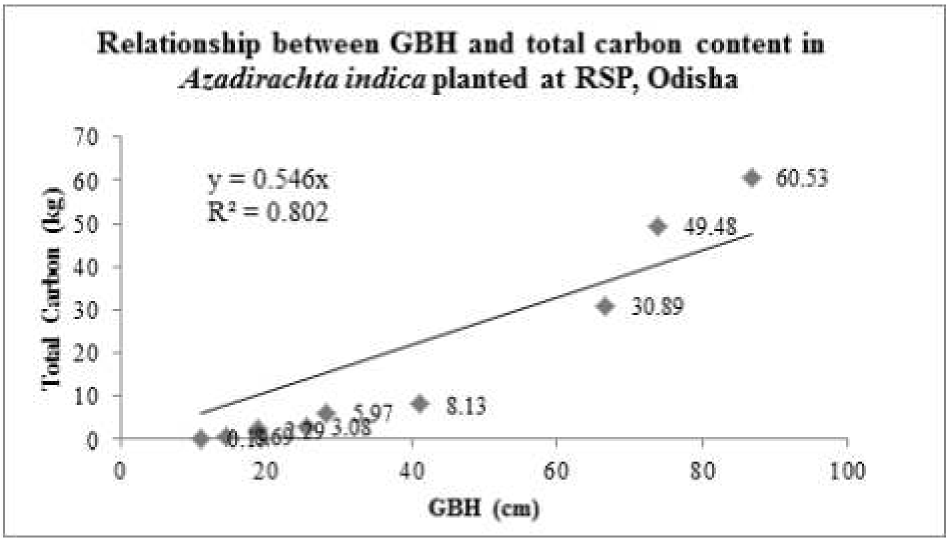
The carbon stock in trees in the first year assessment was found to be 1,46,159 tonnes at the rate of 144.28 t/ha with 63.31 % survival rate of the trees at RSP. In the second year, the carbon stock in trees was calculated to be 1,51,101 tonnes at the rate of 149.16 t/ha with 60.56 % survival rate of the trees. Annual carbon sequestration in the trees of RSP was calculated by deducting carbon stock of first year assessment from the second year assessment, which was calculated to be 4942 tonnes. The mortality rate of the trees during the assessment year was found to be 2.75 % per year. In the selected quadrats, maximum carbon was found in *Tectona grandis*, followed by *Alstonia scholaris* and *Cassia siamea* trees.

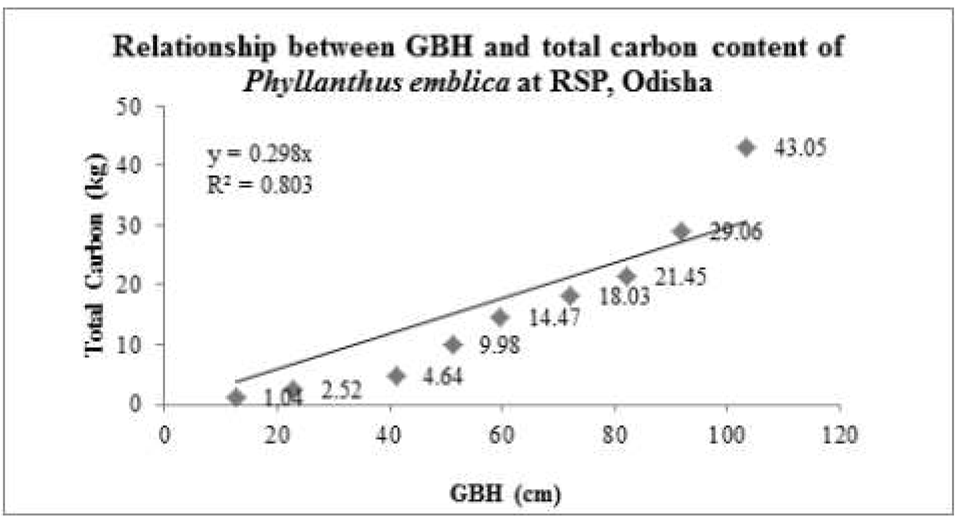
Table 12.2. Carbon content in trees of different species found in the quadrats laid out at RSP

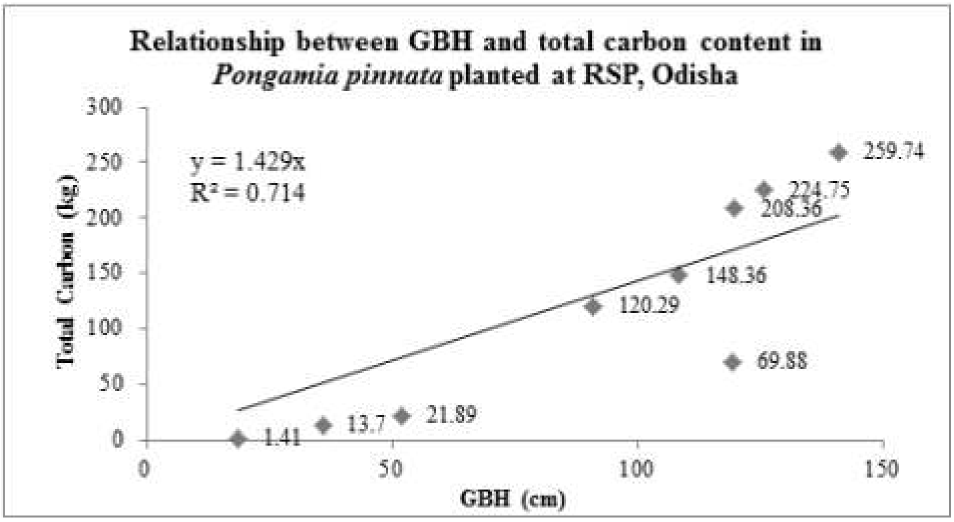
			First year assessment				Second year assessment			
S. No.	Tree species	Frequency	No. of trees	Average GBH (cm)	Carbon /tree (kg)	Total Carbon (t)	No. of trees	Average GBH (cm)	Carbon /tree (kg)	Total Carbon (t)
1	*Acacia leucophloea*	0.015	4	149.25	115.15	0.46	4	150.25	116.03	0.46
2	*Albizia lebbeck*	0.059	25	54.81	45.15	1.13	21	58.09	50.71	1.07
3	*Albizia procera*	0.014	3	42.49	29.35	0.09	1	63.11	44.58	0.04
4	*Alstonia scholaris*	0.161	135	49.47	36.23	4.89	133	52.13	38.59	5.13
5	*Anogeissus latifolia*	0.01	1	30.14	20.54	0.02	1	32.34	22.09	0.02
6	*Azadirachta indica*	0.22	55	40.72	10.92	0.60	51	41.71	11.59	0.59
7	*Bauhinia racemosa*	0.01	1	64.37	45.53	0.05	1	66.88	47.43	0.05
8	*Bombax ceiba*	0.01	4	150.8	116.52	0.47	4	154.10	119.45	0.48
9	*Bridelia retusa*	0.01	1	97.03	71.03	0.07	1	97.65	71.53	0.07
10	*Butea monosperma*	0.044	11	46.3	6.89	0.08	11	47.44	7.25	0.08
11	*Cassia fistula*	0.044	4	32.66	22.32	0.09	4	34.54	23.65	0.09
12	*Cassia graveolens*	0.01	1	29.2	19.88	0.02	1	29.83	20.32	0.02
13	*Cassia siamea*	0.161	91	60.51	49.89	4.54	89	63.56	55.89	4.97
14	*Cordia dichotoma*	0.01	4	59.42	41.81	0.17	4	60.68	42.75	0.17
15	*Dalbergia sissoo*	0.161	35	62.38	46.46	1.63	34	64.24	48.36	1.64
16	*Delonix regia*	0.029	53	51.07	28.16	1.49	53	53.22	31.78	1.68
17	*Eucalyptus* hybrid	0.029	17	50.81	75.36	1.28	15	58.32	86.50	1.30
18	*Ficus racemosa*	0.01	13	108.98	80.76	1.05	13	111.92	83.19	1.08
19	*Gmelina arborea*	0.029	3	64.06	45.29	0.14	3	65.21	46.16	0.14
20	*Grewiati liifolia*	0.01	3	47.41	32.93	0.10	3	51.29	35.77	0.11
21	*Holarrhena antidysenterica*	0.029	2	26.38	17.90	0.04	2	28.42	19.33	0.04
22	*Lagerstroemia speciosa*	0.059	6	33.07	22.61	0.14	5	38.12	26.21	0.13

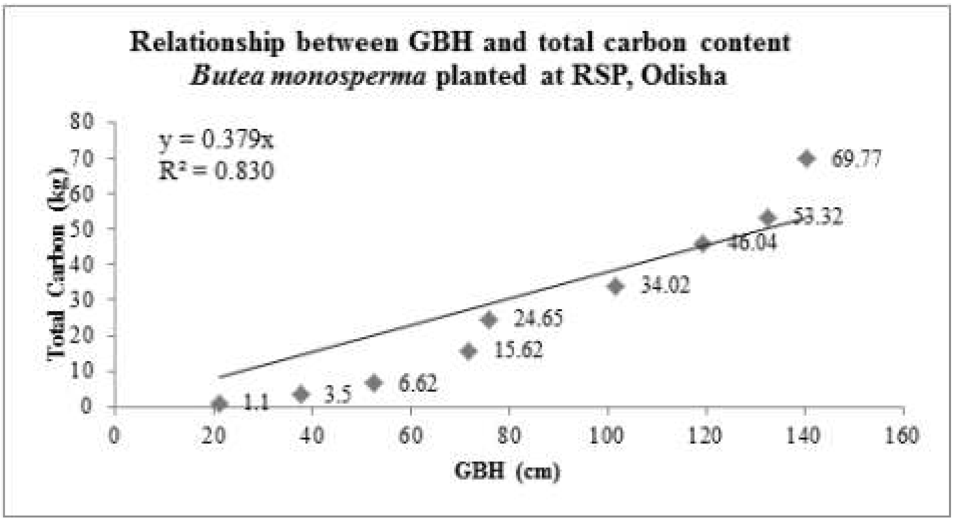
23	*Lannea coromandelica*	0.01	2	100.17	73.56	0.15	2	101.42	74.58	0.15
24	*Mallotus philippensis*	0.01	5	86.29	62.46	0.31	5	89.49	65.00	0.32
25	*Morinda coreia*	0.01	1	53.38	37.31	0.04	1	54.95	38.47	0.04
26	*Peltophorum pterocarpum*	0.044	51	35.66	22.29	1.14	51	34.88	23.89	1.22
27	*Phyllanthus emblica*	0.029	9	47.48	7.58	0.07	7	55.26	10.59	0.07
28	*Pongamia pinnata*	0.073	23	49.56	41.81	0.96	23	52.93	34.55	0.79
29	*Pterospermum acerifolium*	0.01	2	132.97	100.95	0.20	2	136.12	103.66	0.21
30	*Putranjiva roxburghii*	0.044	27	114.9	85.66	2.31	27	117.28	87.65	2.37
31	*Simarouba glauca*	0.088	30	33.12	22.64	0.68	30	35.14	24.08	0.72
32	*Syzygium cumini*	0.044	22	52.38	80.10	1.76	22	55.09	85.44	1.88
33	*Tabebuia rosea*	0.01	1	21.35	14.41	0.01	1	21.98	14.84	0.01
34	*Tectonag randis*	0.308	284	43.48	38.68	10.99	278	46.85	45.59	12.67
35	*Terminalia arjuna*	0.029	7	81.51	80.21	0.56	7	83.39	84.80	0.59
36	*Terminalia bellerica*	0.102	18	73.72	52.66	0.95	18	77.96	55.94	1.01
37	*Terminalia tomentosa*	0.01	2	88.71	64.38	0.13	2	90.43	65.74	0.13
38	*Wrightia tinctoria*	0.01	2	27.45	18.65	0.04	2	28.89	19.66	0.04
39	*Ziziphus oenoplia*	0.01	1	35.48	24.32	0.02	1	36.42	24.99	0.02
		Total	**959***			**38.84**	**933***			**41.64**
		Average		**52.08**				**55.09**		

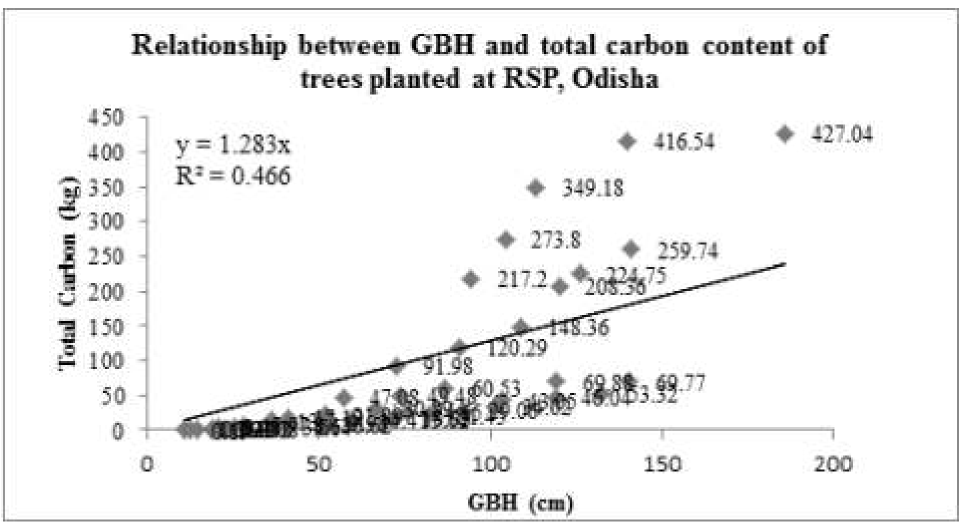

Relationship between GBH and total carbon content in
Tectona grandis planted at RSP, Odisha
y = 2.4307x
R² = 0.842
Total Carbon (kg)
GBH (cm)
3.41
17.19
47.08
91.98
217.2
273.8
349.18
416.54
427.04


Relationship between GBH and total carbon content in
Azadirachta indica planted at RSP, Odisha
y = 0.546x
R² = 0.802
Total Carbon (kg)
GBH (cm)
3.08
5.97
8.13
30.89
49.48
60.53


Relationship between GBH and total carbon content of
Phyllanthus emblica at RSP, Odisha
y = 0.298x
R² = 0.803
Total Carbon (kg)
GBH (cm)
1.04
2.52
4.64
9.98
14.47
18.03
21.45
29.06
43.05


Relationship between GBH and total carbon content in Pongamia pinnata planted at RSP, Odisha
y = 1.429x
R² = 0.714
Total Carbon (kg)
GBH (cm)
0
50
100
150
200
250
300
0
50
100
150
259.74
224.75
208.36
148.36
120.29
69.88
21.89
13.7
1.41


Relationship between GBH and total carbon content Butea monosperma planted at RSP, Odisha
y = 0.379x
R² = 0.830
Total Carbon (kg)
GBH (cm)
0
10
20
30
40
50
60
70
80
0
20
40
60
80
100
120
140
160
69.77
53.32
46.04
34.02
24.65
15.62
6.62
3.5
1.1


Relationship between GBH and total carbon content of trees planted at RSP, Odisha
y = 1.283x
R² = 0.466
Total Carbon (kg)
GBH (cm)
0
50
100
150
200
250
300
350
400
450
0
50
100
150
200
427.04
416.54
349.18
273.8
259.74
217.2
224.75
208.36
148.36
120.29
91.98
60.53
69.88
69.77

CARBON IN SHRUBS AND HERBS AT RSP

Herbaceous biomass is the biomass obtained from plants that have a non-woody stem and which die back at the end of the growing season. Carbon in shrubs and herbs was quantified by destructive method after rainy season in the month of August when herbaceous biomass is found maximum. For the assessment of ground flora biomass (shrubs and herbs), 3 quadrats of 1 m x 1 m size were laid out within each tree quadrat. Out of 68 quadrats (0.81 ha) shrubs and herbs were found in 47 quadrats (0.60 ha) only, covering 74.07 % of the total area covered under the selected quadrats. Average herbaceous biomass was found to be 31.42 g/m^2. By extrapolating the data on per hectare basis, it was calculated to be 0.31 t/ha. Since, in the selected quadrats, ground flora covers 74.07 % area, hence the herbaceous biomass was finally found to be 0.23 t/ha.Hence, it can be concluded from the present study that in the plantation area and natural forest at RSP, carbon in the form of shrubs and herbs was recorded as 0.12 t/ha.

CARBON IN DEADWOOD AND LITTER AT RSP

Litter and deadwood were collected in 0.5 m x 0.5 m size quadrats laid out in the tree quadrats at RSP. 3 quadrats for litter in each tree quadrat were laid out and dug for about 10 cm deep to collect litter throughout the year. Out of 68 quadrats (0.81 ha) litter was found in 61 quadrats (0.74 ha) only, covering 91.36 % of the total area covered under the selected quadrats. Average litter was found to be 72.53 g/quadrat or 290.13 g/m^2. By extrapolating the data on per hectare basis, it was calculated to be 2.90 t/ha. Since, in the selected quadrats, ground flora covers 91.36 % area, hence the herbaceous biomass was finally found to be 2.65 t/ha. Hence, it can be concluded from the present study that in the plantation area and natural forest at RSP, carbon in the form of deadwood and litter was recorded as 1.33 t/ha.

13 ESTIMATION OF FOREST CARBON USING GROWING STOCK (VOLUME)

- Collect data on growing stock of the forest in cubic meter.
- Multiply the growing stock with Biomass Expansion Factor (BEF) to include twigs, branches and other parts, except bole, to get the data on Above Ground Biomass (AGB) (Volume).
- Estimate Below Ground Biomass (BGB) or calculate following IPCC Guidelines to get the ratio between AGB and BGB.
- Multiply AGB with the ratio between AGB and BGB to get the data on BGB.
- Sum the values of AGB and BGB to get the values of Total Biomass (Volume).
- Multiply the Total Biomass (Volume) by wood density to get the value of Total Biomass (Weight).
- Calculate the ratio between 'Other forest floor biomasses (like herbs and shrubs) except tree to tree biomass.
- Multiply this ratio by Total Biomass (Weight) to get the value of 'Other forest floor biomass'.
- Sum the values of Total Biomass (Weight) with other forest floor biomass to get the total forest biomass (Trees + Herbs + Shrubs).
- Estimate the moisture content and get the values of Dry Weight of Biomass.
- Estimate carbon content in biomass through CHN analyzer or calculate following IPCC Guidelines to get the values of forest biomass.

Table 13.1. Calculation of forest carbon of India using growing stock

Item with symbolic description	Factor	1995	2005
Growing Stock of Country in Mm^3 - GS		5842.320	6218.282
Mean Biomass Expansion Factor - EF	1.575		
Ratio (Below to Above Ground Biomass) - RBA	0.266		
Above Ground Biomass (Volume) - AGB = GS X EF		9201.654	9793.794
Below Ground Biomass (Volume) - BGB = AGB X RBA		2447.640	2605.149
Total Biomass (Volume) – TB = AGB + BGB		11649.294	12398.943
Mean Density - MD	0.7116		
Biomass in Mt = Growing Stock (Mm^3) x Mean Density (MD)		8289.638	8823.088
Ratio (Other Forest Floor Biomass except tree to Tree Biomass)	0.015		
Total Forest Biomass in Mt (Trees + Shrubs + Herbs) - TFB		8413.982	8955.434
Dry Weight in Mt (80 % of TFB) - DW		6731.186	7164.348
Carbon in Mt (40 % of DW)		2692.474	2865.739

Ref. : India's forests and tree cover, Kishwan *et al.* (2009)

Factors for various items were derived from mainly Kaul, *et.al.*, 2009; Roy and Ravan, 1996 and Singh and Singh, 1985.

14 CARBON SEQUESTRATION IN BAMBOOS

Bamboos are tall arborescent grasses, belonging to the family Poaceae, subfamily Bambusoideae, tribe Bambuseae and are popularly known for their industrial uses. These are the fastest growing woody plants in the world with a unique rhizome-dependent system, highly dependent on local soil and climate conditions. Due to their biological characteristics and growth habits, bamboos are not only an ideal economic investment, but also have enormous potential for sequestering carbon from the atmosphere. In the era of global climate change, aspects such as carbon sequestration and biomass production potential of bamboos have been receiving increasing attention.

Bamboo Phylogeny Group has compiled 1,439 described species in 115 genera (Bamboo Phylogeny Group, 2012). Globally, India has the second highest number of species (140 species) after China, and within the country North-East states have more than 100 bamboo species (Nirala *et al.*, 2016, Nathani 2008; Nimachow et al., 2010). There are more than 1500 different documented uses of bamboo (INBAR, 1997; Shrestha, 1999). More recently in 2016, International Network on Bamboo and Rattan (INBAR) has recorded more than 10000 uses of bamboo.

In the Indian scenario, based on the property testing and assessment of inherent characteristics matching with end uses, the National Mission on Bamboo Applications (NMBA) has selected 18 commercially important species, *viz; Bambusa bambos, B. nutans, B. pallida, B. polymorpha, B. tulda, B. vulgaris, B. balcooa, Dendrocalamus brandisii, D. giganteus, D. hamiltonii, D. stocksii, D. strictus, D. asper, Guadua angustifolia, Melocanna baccifera, Ochlandra travancorica, Schizostachym dullooa* and *Phyllostachys bambusoides* of which 10 species have been reported to be edible while the rest have potential in the construction and industrial application sector. INBAR has selected five species which are most suited for the development of bamboo shoot industry in India (*Bambusa balcooa, Dendrocalamus giganteus, D. hamiltonii, D. strictus* and *Melocanna baccifera*).

Bamboos have the added advantage of sequestering higher carbon dioxide from the atmosphere and can play major role in Afforestation/Reforestation CDM, however, until recently under the UNFCC, bamboos were not accepted as trees and hence did not actively form part of discussion as a mitigating agent for climate change. Bamboos have extensive underground rhizome and root systems which can live even up to 100 years. Even if the bamboo stems are harvested, the underground carbon is not lost into the atmosphere, as the plant continues to live. When the harvested bamboo is turned into durable products, the ecosystem can actually store more carbon when it is being used productively, than if it is left to grow wild. Life cycle analysis of industrial bamboo products had indicated that if best practice technology is employed bamboo products can be labelled as carbon neutral (Lugt et al., 2012).INBAR in their recent research have shown that managed bamboo actually is an extremely efficient carbon sink, performing better than traditional trees like Chinese fir and Eucalyptus when grown under similar environmental conditions.

Growth of the new shoots in bamboo clumps occurs as a result of transfer of the energy accumulated in culms through photosynthesis in the previous year. As such, the growth of a bamboo culm is not driven by its own carbon sequestration, but by sequestration in previous seasons in other parts of the bamboo system, and as such growth of new shoots is not an indicator of sequestration rate. On the other hand, as the bamboo system requires more inputs in the shooting season of young culms (when new shoots grow), high growth in bamboo shoots can be equated with a high rate of carbon sequestration (Zhou et al., 2009).

Biomass accumulation and carbon storage in bamboos vary significantly from species to species and location to location (Table 14.1).

Table 14.1. Carbon storage in bamboos

S. No.	Bamboo species	Location	Biomass (mg ha^{-1})	Biomass C storage (mg ha^{-1})	Reference
1	*Bambusa blumeana*	Philippines	143	72	Uchimura, 1978
2	*Gigantochloa levis*	Philippines	147	73	Suzuki, 1989
3	*Phyllostachys bambusoides*	Japan	136	68	Isagi et al., 1993
4	*Yushania alpina*	Ethiopia	110	55	Embaye et al., 2005
5	*Phyllostachys makinoi*	Taiwan	105	50	Yen et al., 2010
6	*Phyllostachys heterocycla*	Taiwan	89	41	Yen and Lee, 2011
7	*Bambusa oldhamii*	Mexico	104	51.5	Castaneda Mendoza et al., 2005

Source: Nath *et al.*,2015

Studies have compared carbon sequestration by different bamboo types *viz.* sympodial and monopodial and inferred that sympodial bamboos have greater carbon stocks and higher carbon sequestration rates than monopodial counterparts. For example, *D. giganteurs* stores upto 47.823 m ha-1 carbon stock Teng et al. (2016).

A study was conducted by IWST on biomass and net primary productivity of six industrially important bamboo species in semi-arid and humid regions of Peninsular India (Table 14.2). The study showed that total above ground biomass was found maximum in *B. balcooa* in tropical humid conditions (Koppa) (206.64 mg ha^{-1}) and in semiarid conditions (Hosakote) (98.94 mg ha^{-1}). The minimum total above ground biomass was found in *G. angustifolia* (14.11 mg ha^{-1}) in semiarid conditions (Hosakote) and in *D. stocksii* (33.79 mg ha^{-1}) in tropical humid conditions (Koppa). Table 14.3 depicts net primary productivity in two locations Koppa and Hosakote for the six bamboo species. Productivity was observed maximum for *D. asper* (28.8 mg/ha/yr)in Koppa and *D. stocksii* (21.08 mg/ha/yr) in Hosakote.

Table 14.2: Total above ground standing biomass (mg ha^{-1}) of six bamboo species in Koppa and Hosakote

Species	Productivity (mg $ha^{-1}yr^{-1}$)	
	Koppa	Hosakote
Bambusa balcooa	23.80	11.31
Bambusa bambos	22.60	12.22
Dendrocalamus asper	28.80	10.08
Dendrocalamus stocksii	10.42	21.08
Dendrocalamus strictus	14.70	8.96
Guadua angustifolia	22.40	2.04

Yongfu et al., (2011) studied the dynamic changes in height, biomass, and carbon accumulation in young Phyllostachys pubescens and found that the accumulation of biomass and carbon in young bamboos depended mainly on ground diameter and the length of time after the bamboo shoots sprouted.

METHODOLOGY FOR CARBON ANALYSIS IN BAMBOOS

Carbon analysis in bamboos involves various stages from sample collection to its analysis.

Sample Collection

Randomly selected culms of different sizes and age groups should be harvested. Care should be taken that harvesting is representative of different age groups and sizes. Once harvested, culm samples are further segregated to twigs and leaves, side branches and the main culm component. Fresh weight of these samples is taken in the field. Next, sub-samples of each component are over dried to a constant weight and dry matter is calculated.

Table 14.3: Productivity of six bamboo species in tropical humid zone (Koppa) and semiarid zone (Hosakote) in Karnataka

Bamboo Species	Total Biomass (mg/ha^{-1})	
	Tropical Humid condition (Location: Koppa, Chikmaglur, Karnataka)	Semi arid condition (Location: Hosakote, near Bangalore, Karnataka)
B. balcooa	206.64	98.94
B. bambos	55.02	71.15
D. asper	148.66	45.87
D. stocksii	33.79	59.97
D. strictus	99.89	91.50
G. angustifolia	73.828	14.12

Age : 7 years; density of planting : 400 /ha (5x5 m); pit size : one m^3

Biomass Determination

Biomass of each component is determined by their dry to fresh weight ratio. Addition of these individual biomass components will give the above ground standing biomass.

Carbon Content Determination

The collected subsamples should be powdered and analyzed for carbon content by standard procedures. Typically, ash content is determined by igniting 1g powdered furnace at 550°C for 6 hours in a muffle furnace or in a CHN analyzer.

Another method of estimating carbon sequestration is carbon in phytoliths. Phytoliths are silica particles present in the epidermis of a plant. Bamboo plants are rich in phytolith occluded carbon, which in turns plays an important role in carbon sequestration and climate change mitigation. This was explored by Parr et al., (2010) in their study wherein the group of researchers worked on phytoliths. In their study they researched that bamboos are major phytolith generating plants thereby storing large quantities of carbon within itself and surrounding soil in the form of phytolith carbon. The study showed the potential of this phytolith component in leaf litter of ten economically important bamboo species ranged upto 0.7 tonnes $ha^{-1}yr^{-1}$.

Challenges of C Sequestration in Bamboo Species:

Many studies have compared carbon sequestration potential of bamboos with that of other forest tree species. One of the problems associated with that is with respect to unmanaged bamboos. In unmanaged bamboo clumps, carbon sequestration due to production of new culms will be almost the same as that of carbon release due to decay and death of old culms (INBAR, 2009). To avoid this, harvesting bamboo to make bamboo products makes logical sense. This will ensure carbon is locked and secured and thereby inhibiting its release back to the environment.

Bamboos have high rates of carbon sequestration in the first few growing years, making it a strong candidate for mitigating climate change. With its recent inclusion by CDM as a prospective fast-growing species, there is a little doubt that bamboo can be a good alternative for carbon sequestration and hence needs to be explored to maximize its potential for the same.

B. cacharensis made up to 46 per cent of total stand biomass followed by *B. vulgaris* (28 per cent) and *B. balcooa* (26 per cent). Carbon storage in the above ground biomass was 61.05 t ha^{-1}.Allocation of C was more in Culm components (53.05 t ha^{-1}) than in branch (5.81 t ha -1) and leaf (2.19 t ha^{-1}). Carbon storage in the litter floor mass was 2.40 t ha^{-1}, of which leaf litter made up the highest amount (1.37 t ha^{-1}) followed by sheath (0.86 t ha^{-1}) and branch (0.17 t ha^{-1}). Carbon stock in the soil up to 30 cm depth was 57.3 t ha^{-1}. Gross C stock in the plantation was estimated to be 120.75 t ha^{-1}.

The presence of 48 per cent carbon in bamboo biomass with the average annual yield of 100 t ha^{-1} makes it possible to sequester carbon dioxide of over 200 t ha^{-1} $year^{-1}$ which is currently the most superior plant. Gasification of bamboo biomass generates 10 to 15 per cent carbon as biochar apart from generation of electricity, which makes this process “Carbon negative” (Barathi, 2010).

DEVELOPMENT OF ALLOMETRIC EQUATIONS IN BAMBOOS

Linear regression models have been developed to estimate the above ground biomass of five bamboo species *viz. Dendrocalamus strictus, B. vulgaris, B. multiplex, B. bambos* and *Phyllostachys nigrain* Uttarakhand (India), which differ in size and growth pattern (Agarwal and Purwar, 2010). The developed modelsindicated that above ground biomass depends on the height of the pole and girth to height ratio at 1.0 m and 1.5 m. Biomass produced was 30 per cent more on fresh weight basis than dry weight in all the species. Percentage of organic carbon in the soil also increased due to planting of various species, which was 20.4 to 74.5 per cent higher over control. Nath et al., (2008) reported that the above ground carbon sequestration potential of a bamboo stand consisting of *Bambusa balcooa, B. cacharensis* and *B. vulgaris* was in the tune of 21.36 mg ha^{-1}. They observed that the harvesting of mature culms was balanced by the carbon gains from the new culms.

Kumar *et al.* (2005) developed allometric equations relating clump biomass and culm number with clump diameter of 20 year old hedge rows of *Bambusa bambos*. The fitted equations gave high R2 value and gave reasonably good predictions of culm number per clump and standing stock of clump biomass. The regression equations linking measurements of diameter at 15 cm of the base (D15), vertical height of the culm (L), green and dry weight of the culm, branches and foliage of Bambusa tulda were developed by Oli (2005)at Eastern Terai, Nepal. A regression model W = a + b × (D2 L) was developed on the basis of oven dry and green weight. Using this model, biomass tables of *Bambusa tulda* grown at Belbari, Morang district of Eastern Nepal; *Bambusa nutans* subspecies cupulata grown at Belbari, Morang district of Eastern Terai and Dendrocalamus hookeri grown at Jhanjhatpur, Kailali district of far-western Terai were prepared.

The average culm production of *B. balcooa, B. bambos, O. travancorica* and *T. oliveriat* the age of seven years was 7,799, 7,000, 29,945 and 3,725 culms ha^{-1} respectively (Jijeesh, 2014). The biomass production of bamboo clumps increased with age. The average biomass accumulation in six years old *B. balcooa, B. bambos, O. travancorica* and *T. olivericlumps* was to the tune of116.079, 31.660, 12.145 and 99.067 kg and that of seven year old clumps was 159.935, 51.334, 17.731 and 111.286 kg, respectively. Among the clump components like culm, branch, leaf, rhizome and root, culms contributed major share of biomass accumulated in a clump. Carbon content in the clump components varied significantly irrespective of species with an average value of 40.53 per cent.

Above ground biomass components recorded a higher carbon concentration than belowground in all the bamboo species. Carbon sequestration of *B. balcooa* at the age of six and seven years was to the tune of 22.34 ± 6.87 and 30.66 ± 10.01 mg ha^{-1} and that of *B. bambos* was 7.19 ± 0.53 and 10.33 ± 2.58 mg ha^{-1}respectively. Moreover, carbon sequestration of *O. travancorica* at the age of six and seven years was 2.690 ± 0.14 and 3.02 ± 0.23 mg ha^{-1} and that of *T. oliveri* was 18.66 ± 2.19 and 21.14 ± 6.15 mg ha^{-1}, respectively. Soil carbon content and density declined with increasing depth. Total carbon density of soil under *B. balcooa, B. bambos, O. travancorica* and *T. oliveri* at the age of seven was 56.95 ± 4.34, 62.86 ± 6.26, 46.28 ± 4.31 and54.02 ± 3.17 mg ha^{-1}, respectively.

Biomass production in 9 years old *Dendrocalamus strictus* bamboo species planted under varying spacings (4x4, 6x6, 8x8, 10x10 and 12x12 m; Densities: 625, 277, 156, 100 and 69 clumps/ha) in Keralaindicated that the clump wood constituted the largest (60-70 %) share to the total biomass in all the spacings. The leaf biomass in the widest spacing increased by 325 per cent compared to closest spacing. The densest (625 clump/ha) stand though recorded maximum biomass, the eventual clump-wise biomass was the highest in least dense stand (69 clumps/ha). The C in clump wood decreased by 55 % in the closest spacing compared to the widest spacing. The majority of C was accumulated in clump wood (5.45 to 22 mg/ha). When spacing increased to 12x12 m, C storage in above ground biomass increased by 3.61 times compared to the densest stand (4x4 m)(Kittur, 2014).

15 CARBON SEQUESTRATION IN AGROFORESTRY SYSTEMS

Agroforestry has been recognized by IPCC as having high potential for sequestering carbon as part of climate change mitigation strategies. In India, agroforestry systems are promising land use systems to increase and conserve above ground and soil carbon stock to mitigate climate change. The potential of agroforestry systems as carbon sink varies depending upon the species composition, age of trees, geographical location, local climatic factors and management regimes. Agroforestry systems have the potential to sequester large amount of above and below ground carbon in addition to Soil Organic Carbon (SOC) enhancement, as compared to treeless farming systems.

Agroforestry systems have attracted special attention in view of their perceived advantage of large volumes of aboveground biomass (AGB) and deep root systems of trees. The site-specific nature of agroforestry systems and the lack of uniformity in methods and procedures used to sample, analyze, determine or estimate and present the data on carbon sequestration in these systems make it difficult to compare the results from different locations. The multitude of agroforestry systems and practices that are reported in the carbon sequestration studies can be grouped under following categories:

Intercropping (alley Cropping and Other Forms of Tree Intercropping)

Alley cropping and various other forms of tree intercropping can be identified with reduced tillage, effective residue management and species diversity. Efficient nutrient cycling and use of deep rooting/N2 fixing species are particularly significant in tropical alley cropping, where fast -growing trees and shrubs, especially N2-fixing ones, are grown as hedgerows in crop fields and are pruned periodically during the cropping season for the biomass to be returned to the soil as a source of nutrients or used as animal fodder. In moderately sloping lands (<10% slope), alley cropping is also an effective soil-erosion control strategy in both the temperate regions (where the trees are not pruned, but are harvested at the end of the tree-rotation cycle) and the tropics. Root turn over and decomposition is another process that contributes to carbon sequestration in these systems.

Another agroforestry technology that has been promoted, especially in nutrient depleted soils, is improved fallow, in which leguminous trees and shrubs are grown in association with crops. Such practices are reported to sequester substantial amounts of carbon in plants and soil in the short term, and enhance the stabilization of water stable aggregates, which in turn decreases the risk of erosion in subsequent crop periods. Apart from the N-rich materials directly returned by coppicing, trees also return sizeable quantities of organic C through root detritus, root exudates, and mycorrhizal hyphae. The year-round buildup of SOC on the soil surface due to litterfall and/or coppicing increases the carbon stock at that layer while belowground long- term carbon storage potential is improved via the rooting systems.

Multistrata Systems

Intensive, multispecies, tree-based farming systems such as homegardens and shaded perennial stands are common agroforestry practices, especially in the humid and sub-humid lowlands of the tropics. Homegardens have a long tradition of providing food and nutritional security as well as environmental sustainability in smallholder production systems, often in thickly populated regions of lowland humid tropics in South- and Southeast Asia, and to a small extent in other tropical and subtropical regions. Growing tree crops such as coffee (*Coffea* sp.) and cacao (*Theobroma cacao* L.) under the shade of overstory tree species, known as shaded-perennial systems, is another traditional example of high-intensity crop combination that has some unique ecological features and commercial value.

As in most agroforestry systems, accurate estimates of area under multistrata systems are not available and may not exceed 100 million ha globally. However, over the decades, even centuries, the area under these systems has not declined either. Thus, although the prospects of enhancing the role of these multistrata systems in future scenarios by extending the area under the systems do not appear to be very promising, their area is likely to remain unchanged and therefore these systems will continue to be quite important in maintaining the status-quo of carbon sequestration and climate change mitigation.

Protective Agroforestry Systems

These systems encompass the use of trees and shrubs for exploiting their ecosystem-protection benefits by planting them as windbreaks, riparian buffers, soil conservation hedges and similar other arrangements. Field windbreaks are used to protect a variety of wind-sensitive row, forage, tree and vine crops, to control wind erosion, and to provide other benefits such as improved bee pollination of crops and wildlife habitat. Livestock windbreaks help reduce animal stress and mortality, feed and water consumption, and odor, while timber belts are managed windbreaks designed to increase the value of the forestry component; and, shelterbelts are planted along sea coast to reduce the impact of sea encroachment and protect crops from salt-water damage. Riparian and upland buffers are strips of permanent vegetation, consisting of trees, shrubs, and grasses that are planted and managed together. Riparian buffers are placed between agricultural land (usually crop land or pastureland) and water bodies (rivers, streams, creeks, lakes, wetlands) to reduce runoff and non-point source pollution, stabilize streambanks, improve aquatic and terrestrial habitats, and provide harvestable products.

The trees and shrubs planted in these protective tree barriers contribute to climate change mitigation directly through their carbon sequestration and indirectly and more importantly through the protection they offer by reducing soil erosion by wind and water. Depending on the planting patterns adopted the number of trees/shrubs per unit area and the extent of carbon sequestration vary considerably.

Silvopasture

Silvopasture that combines trees, forages, and shrubs/trees with livestock operations is another type of agroforestry practice that is popular in both the tropics and the temperate regions. Broadly, there are two major forms of silvopasture: grazing- and tree-fodder systems. In grazing systems, cattle are allowed to graze on pasture under widely spaced or scattered trees, whereas in the tree-fodder systems, the animals are stall-fed with fodder from trees or shrubs grown in blocks on farms. The carbon sequestration in any agroforestry system depends largely on the amount and quality of biomass input provided by tree and non-tree components of the system, and on properties of the soils, such as soil structure and their aggregates. In the establishment of silvopastoral systems, some functional consequences are inevitable when trees are allowed to grow in grass-dominated land such as an open pasture. It also needs to be noted here that in intensive ruminant production systems, energy- containing compounds produced as biomass in primary plant production are converted to desired animal products such as meat and milk and into waste products.

The extent of carbon sequestration and climatechange mitigation in silvopastoral systems will vary, depending on the nature and level of management of the systems, with rather low levels in the extensive system to relatively high levels in the intensively managed systems.

Table 15.1. Approximate global area under different agroforestry system sub-groups and the carbon sequestration potential

AFS sub-group	Distribution (major regions) Including potential	millionha (including potential)	Estimated C stock range (kg ha^{-1} yr^{-1})		Potential CSP in new area (kg ha^{-1} yr^{-1})	
			Above ground	Below ground	Above ground	Below ground
Alley cropping and other tree intercropping systems	Humid and sub humid tropics	650	Up to 15	Very low to 150	2 - 5	25 - 75
	Temperate (N. America, Europe)	50	Up to 10	Up to 200	2 - 6	50 -150
Multistrata Systems (Shaded, perennials, homegardens)	Mostly tropical humid and sub humid lands, predominantly lowlands, but up to 2000 m altitude	100	2 to 18	Up to 300	2 - 10	100 -200
Protective systems (Windbreak, riparian buffer, shelterbelts, etc.)	Arid and semiarid lands of the world, primarily sub-Saharan Africa, China and N. and S. America	300	2 to 10	Up to100	1 - 8	20 - 60
Silvopasture	Grazing systems: mostly semiarid and sub humid lands in Africa, India, and the Americas	450	2 to 15	Up to250	3 - 10	80 - 120
Woodlots (firewood, fodder, land reclamation, etc.)	Firewood and fodder-tree lots are mostly in tropics; Land reclamation plantings in	50	1 to 12	Up to140	1- 5	40 - 70

Tree woodlots and specialty crops

These terms are used to denote agroforestry practices that are undertaken for special situations and needs. Examples include growing tree woodlots as fodder banks (for production of cut-and-carry tree-fodder), boundary planting of trees for production of firewood, small timber poles and fence posts; tree planting for reclamation of degraded lands such as saline soils and mined land; establishing tree woodlots for biomass and bioenergy production etc. These activities contribute less in terms of carbon sequestration unless large-scale tree woodlotsare established although are important for economic, social, and cultural benefits of people.

CARBON SEQUESTRATION IN AGROFORESTRY SYSTEMS – A CASE STUDY

15 years old Tectonagrandis (teak) plantation with spacing of 2 m x 2 m was used for establishment of agroforestry systems in a simple randomized complete block design at Tropical Forest Research Institute, Jabalpur, M.P. (India). The teak plantation area was divided into three blocks each of 6 m x12 m. The individual block was further divided into six plots each of 2 m x 6 m in which five agricultural crops, *viz.*, *Triticum aestivum* (wheat), *Cicer arietinum* (gram), *Withania somnifera* (ashwagandha), *Avena fatua* (wild oat) and *Hordeum vulgare* (barley) and one control without the crop were randomly established. Thus, a total of 6 m x 6 m area was allocated to each crop and the control comprising 16 teak trees.

GBH of teak trees in all five agroforestry systems was measured by a measurement tape during two consecutive years. AGB values of the same teak trees was computed, employing $y = 3.174x – 21.27$ ($p < 0.01$) linear regression equation developed from standard GBH value of reference trees. The below ground biomass (BGB) of experimental teak tree was calculated using 0.25 times AGB as per guidelines of Intergovernmental Panel on Climate Change. The carbon content was considered 0.5 times total dry biomass (AGB + BGB) of tree.

Maximum increase (60.47 %) in annual carbon stock was found in *T. grandis–H. vulgare* agroforestry system, followed by *T. grandis – T. aestivum* (56.92 %), *T. grandis – A.fatua* (54.94 %), *T. grandis – C. arietinum* (37.15 %), while minimum increase was observed in *T. grandis – W. somnifera* (11.86 %) in comparison to monoculture *T. grandis* plantations (without agricultural crop).

Five agricultural crops did not significantly influence carbon stock in teak trees. The situation can be explained, if one considers the distribution of root systems of teak and agricultural crops being distributed in different soil strata, offering no competition for mineral nutrients and water. In fact, the agricultural crops spread their root system up to 30-45 cm and tree roots go beyond 150-200 cm deep in soil. However, significant decrease in economic yield of all five crops was recorded, maximum 88 % loss in gram and minimum 64 % loss in ashwagandha. The observation supports the argument as both crops belonging to dicot produce tap root system, which goes deep and faces competition from tree root system. Besides teak trees may have also decreased intensity of irradiation available to agricultural crops because cereal crops with very shallow root system also showed decrease in their economic yield. That is why a deciduous tree is incorporated in agroforestry system for shedding leaves in winter to provide maximum irradiation to cereal crops for their optimal photosynthetic efficiency.

Table 15.2. Effect of agricultural crops on growth and carbon stock intestinegrandis trees in various agroforestry systems during 1st and 2nd years

Agroforestry system	Characteristics of tree carbon component											
	GBH (cm)		Above ground biomass (kg)		Below ground biomass* (kg)		Total biomass (kg)		Total C/tree (kg)		Total C/ha with 2x2 m spacing (t)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Teak – Wheat	39.5	40.3	104	107	26	26.7	130	133	65.1	66.7	163	167
Teak – Gram	41	41.7	109	111	27.2	27.8	136	139	68	69.4	170	174
Teak – Ashwagandha	40.8	41.4	108	110	27.1	27.5	135	138	67.6	68.8	169	172
Teak – Wild Oat	39.7	40.4	105	107	26.1	26.8	131	134	65.4	66.9	163	167
Teak – Barley	39.2	40	103	106	25.8	26.4	129	132	64.4	66	161	165
Teak (without crop)	39.8	40.3	105	107	26.3	26.7	131	133	65.7	66.7	164	167
$LSD_{0.05}$	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

* As per IPCC norms

Carbon stock in *Tectonagrandis* plantations and agroforestry systems was quantified during two consequent years and difference in carbon stock showed the annual carbon sequestration rate of *Tectonagrandis*. Annual carbon stock increased in this tree species when cultivated with short term agricultural crops, which could be due to ample supply of water and nutrients made available to agricultural crops and also due to regular soil working and increase in organic matter in the soil due to continuous addition of agricultural residues. In conclusion, the present study provides GBH based regression equation for precise computation of carbon stock in teak and demonstrates no impact of agricultural crops on carbon sequestration in the tree.

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