International Bamboo and Rattan Organisation (INBAR)
Indian Institute of Soil and Water Conservation (ICAR– IISWC)

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RESEARCH METHODOLOGIES FOR FIELD MONITORING, ANALYSIS AND EVALUATION OF RESOURCE CONSERVATION ASPECTS OF BAMBOOS

International Bamboo and Rattan Organisation

INBAR, the International Bamboo and Rattan Organisation, is an intergovernmental organisation bringing together some 43 countries for the promotion of the ecosystem benefits and values of bamboo and rattan.

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FOREWORD

There are over 1600 species or varieties of bamboo growing in different agro-ecological zones of the world. Different species have different growth characteristics and ecological niches. Bamboo are known to rapidly re-green disturbed lands due to their adaptability and nutrient conservation abilities. It is commonly known that bamboo protects steep slopes, soils, waterways, prevents soil erosion, sequesters carbon and benefits the ecosystem in many other ways. However, understanding bamboo's role in ecological protection or resource conservation aspects is anecdotal for most bamboo species. Research on the role of different species of bamboo in the area of soil-water conservation has been a long-felt need in order to generate scientific data and to devise suitable intervention options.

This technical manual “Research Methodologies for Monitoring, Analysis and Evaluation of Resource Conservation Aspects of Bamboos” is aimed at providing the needed technical knowledge, measurement methodologies and skill set for researchers, conservationists, trainers and field-level technical staff from government agencies, non-governmental organisations (NGOs) and private entities to collect, analyse and interpret data on soil and water conservation aspects of bamboo. This is a practical information resource and teaching aid for technical institutions, bamboo propagation, planting entities and local extension workers in countries where bamboo is promoted to control land degradation and for soil and water conservation purposes.

The manual is produced under the International Bamboo and Rattan Organisation (INBAR) project “South-South Knowledge Transfer Strategies for Pro-Poor Livelihood Development and Environmental Management in Africa”, funded by the International Fund for Agricultural Development (IFAD) and the European Commission (EC).

The initial chapter of the manual provides a basic understanding of bamboo, with a focus on recording morphological and phenological features. Scientific layout of trials, along with pre- and post-planting operations such as site selection, preparation, fencing, planting, management practices and harvesting methods are discussed in the second chapter. It also includes collection of data needed to evidence the ecological and economic benefits of bamboo and prove the fact that bamboo plantations are an effective choice for climate change mitigation. Thus, the chapter describes methodologies for collecting data on growth parameters and biomass and carbon sequestration by bamboo.

Intensive cultivation alters soil properties and its interface with water. This is the subject of the third chapter, which provides an understanding of the hydrological cycle that is essential for the effective management of rainwater and soil water. The chapter explains hydrologic and sediment monitoring in terms of rainfall, runoff and sediment yield. It also covers laying and shaping of experimental runoff plots, design and installation of gauging devices, observation and data tabulation and maintenance of the monitoring system.

The fourth chapter details the collecting of soil samples and field methods for determining key soil properties and computing the soil quality index. Quantifying the physical, chemical and biological properties is important to determine soil health. Interaction of these quantitative aspects helps in determining soil quality, which provides a basic framework to evaluate the sustainability of land management systems.

Farming is, most often, the only source of income for rural populations and requires effective use of available resources for maximum production and profit. The last chapter focuses on the commercial aspects of plantations. It demonstrates how the judicious use of scarce farm resources can help achieve both food production and income generation on a sustainable basis – through the application of economic principles.

It is hoped that the manual will achieve its aim of increasing the number of more efficiently managed bamboo plantations that increase farm incomes and contribute to the overarching objective of sustainable agriculture and landscapes.

Dr Hans Friederich

Director General

PREFACE

The conservation of natural resources, particularly soil and water, has been steadily attracting attention across the world with the realisation of its vital importance in benefiting the resource poor and the environment. There is now greater use of bamboo plantations and bamboo biomass/ products as engineering materials in soil and water conservation. Bamboo plantations have emerged as a new paradigm in controlling landslides and stream bank erosion, stabilising land slopes, reclaiming ravine areas, rehabilitating degraded lands, etc. The scope and opportunity of bamboo in the field of bioengineering as living bamboo plantations and/ or as bamboo biomass is resulting in the greater use of bamboo to restore degraded landscapes in diverse landforms.

This manual on soil and water conservation with bamboo is intended to provide the needed information and methodologies in one place to bridge the knowledge and skill gap among practitioners, starting with the project partners and associated stakeholders working under INBAR's South-South Programme Phase-II. The manual includes information from working experiences, and tools and techniques useful in planning, implementing, monitoring and evaluating bamboo-based soil-water conservation plans and interventions. It is also supplemented with self-explanatory procedural steps, illustrations and flowcharts so that readers and field-level workers find it easy to follow.

The compilation of materials in this manual is largely drawn from previous efforts of the scientists of ICAR – Indian Institute of Soil & Water Conservation (ICAR – IISWC), Dehradun and the International Bamboo and Rattan Organisation (INBAR). The team of authors is indebted to Dr T. Mohapatra, Director General (DG), ICAR, India and Mr Hans Friederich, DG, INBAR, for their motivation and guidance to undertake the research project on assessment of growth, biomass, productivity, carbon sequestration and hydrological behaviour with a focus on soil and water conservation under INBAR's South-South Programme Phase-II. We gratefully acknowledge the contributions of Dr Selim Reza, Project Manager; Mr Bedilu Kifle, Project Coordinator (Ethiopia); Mr Donald Dickson Kibhuti, Project Coordinator (Tanzania); Mr Andriananjaka Rajaonarison, Project Coordinator (Madagascar); Mr S. Anand, INBAR, New Delhi (India) and Ms Baya Agarwal, INBAR, New Delhi (India) for their active logistical and coordination support. Our special thanks are due to Dr R.L. Banik and Dr Salil Tewari, Professor, G. B. Pant University of Agriculture and Technology, for inspiring and supporting us during the preparation of the manual. The support received from Mr S.T.S. Lepcha, MD, Uttarakhand Forest Development Corporation; Mr Vimal Dhiman, Manager – Natural Resource Management (NRM), Compensatory Afforestation Fund Management and Planning Authority (CAMPA) and Ms Gargi Pande, Consultant Designer, for her support in illustrations, are specially acknowledged. Thanks are also due to Uttarakhand State Forest Department for supporting and co-funding the project. We are grateful to all the officials and stakeholders who participated in the short-term training courses organised in Ethiopia, Tanzania and Madagascar during 2017 and who gave their valuable inputs and suggestions during the field validation of the manual. The technical assistance rendered by Er. R.K. Arya; Er. S.K. Sharma; Er. U.C. Tiwari; Er. C.S. Tiwari; Er. Amit Chauhan Mr H.S. Bhatia; Mr U.V.S. Chauhan; Mr Umesh Kumar; Mr M.P. Juyal and Mr Ravish Kumar are gratefully acknowledged.

Though a sincere attempt has been made to bring out a relevant and up-to-date manual for the benefit of the community of practitioners in the areas of soil-water conservation and bamboo plantations, the scope for further refinement and updating will always exist. We welcome any constructive suggestions for the further improvement of this publication.

Authors

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ACRONYMS AND ABBREVIATIONS

BCA	Benefit-cost analysis
BCR	Benefit-cost ratio
BD	Bulk density (BD)
CBA	Cost-benefit analysis
CHNS	Carbon Hydrogen Nitrogen Sulphur Analyser
CO_2	Carbon dioxide
cm	Centimetre
DBH	Diameter at breast height
FRB	Fine root biomass
FYM	Farmyard manure
G	Gram
GBH	Girth at breast height
GI	Galvanised iron
GPS	Global positioning system
H&S	Hydrologic and sediment
Ha	Hectare
HDPE	High-density polyethylene
IISWC	Indian Institute of Soil and Water Conservation
INBAR	International Bamboo and Rattan Organisation
IRR	Internal rate of return
Ln	Natural logarithm
Mm	Millimetre
MSD	Multi-slot divisor
NPV	Net present value
0_2	Oxygen
PBP	Payback period
PD	Particle density
PV	Present value
Q	Quintal
SQI	Soil quality index

CHAPTER I
BAMBOO: AN INTRODUCTION

1.1 Introduction

Bamboo, a group of tall arborescent grasses, have been intimately associated with mankind since time immemorial. They belong to family *Gramineae* but differ from other members of the grass family due to their tree-like habit, well-developed rhizome systems, woody and hollow culms, branching patterns, petiolate[1] leaves and specialised sheathing organs. Unlike trees, there is no central trunk or main axis in bamboo. The unique qualities of bamboo are that once planted, they may be harvested many times during their life cycle due to their perennial nature and annual production of new culms. These characteristics make bamboo a highly profitable crop.

There are over 1600 species of bamboo in the world. Working with bamboo at the field level requires proper understanding of its morphological characteristics. This chapter deals with a brief introduction on bamboo with focus on morphology and phenological behaviour. The morphological characteristics of different organs in various groups of bamboo are presented, such as clump habit and culm nature, branches, leaves and rhizomes including sheathing organs. A field exercise for recording observations on morphological/phonological characters is also included.

1.2 Morphology

Morphology refers to the outward appearance of the plant's components. The vegetative parts of the bamboo plant consist of clump, culms, roots, rhizome, culm sheaths, branches and leaves (Fig. 1.1). These are briefly discussed below.

Clump

A bamboo plant may be either clump forming or non-clump forming. A clump is a cluster or group of bamboo culms (Latin: *culmus* = stalk, stem, pole). In clump-forming bamboo (sympodial), the culms are derived from terminal buds. In non-clump forming bamboo (monopodial), culms develop from the lateral buds of the rhizomes and are therefore called running bamboo. Monopodial bamboo culms do not cluster into clumps but spread widely, with spaced-out single poles emerging from the land, giving the bamboo stand an impression of a forest of trees, like conifers. Some clump-forming bamboo have considerably long rhizome necks such that culms (poles) that emerge from the land are spaced out, looking much like running bamboo, and are sometimes referred to as amphipodial bamboo. Sympodial bamboo are commonly found in tropical countries, while non-clump forming bamboo are found in the temperate region.

1 Having a petiole, the stalk that attaches a leaf to the plant stem.

Culm

Every year, bamboo clumps produce culms of successively larger dimensions until this stabilises on maturity (five to seven years). Culms are typically like hollow cylinders that taper and narrow towards the top. They emerge from the ground as shoots and then grow fast and turn woody. Unlike trees, which grow both vertically and laterally, there is no lateral growth in bamboo because of lack of lateral meristem[2]. Bamboo shoots emerge at their final thickness with internodes already laid down on the shoots. These internodes grow out from each other in a telescopic fashion through the activity of apical[3] and intercalary[4] meristems. Most bamboo reach their maximum height within four months of their emergence. Thereafter, changes in strength properties take place through cell lignification[5] and intracellular lamellation[6] as the bamboo shoots gradually mature. Culms are usually hollow and their wall thicknesses vary in different species. They also vary according to growing conditions; bamboo are very adaptive plants. The culms may be arching or erect, scandent[7] or semi-scandent.

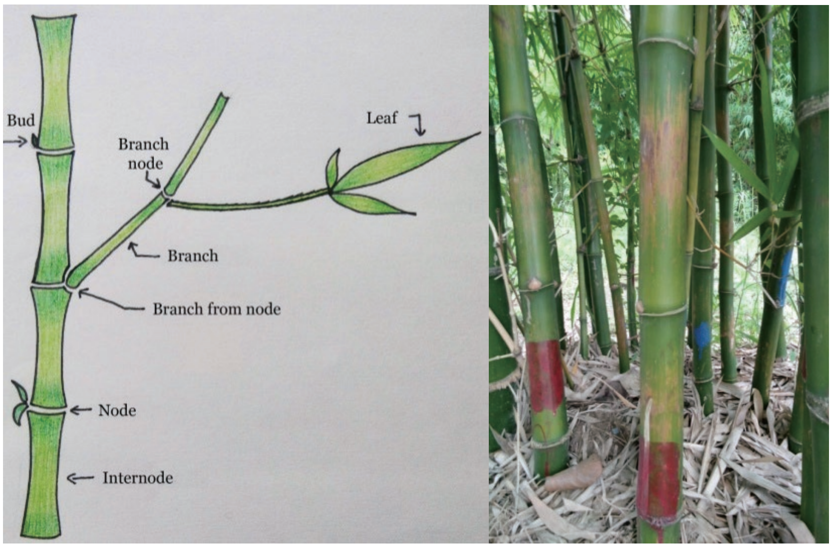


Fig. 1.1: Morphology of a bamboo culm

Shoot

The bamboo shoot is an emerging stem or culm (Fig. 1.2). It originates from buds on the underground rhizome. It is tightly encased in protective sheaths when it comes out of the ground. The sprouting of new culms/shoots occurs soon after the rains and bamboo attains its full growth into a culm/pole within three to four months, depending on the species.

2 Region of plant tissue, found chie y at the growing tips of roots and shoots and in the cambium, consisting of actively dividing A cells, forming new tissue.

3 The phenomenon whereby the main central stem of a plant is dominant over other side stems, thus situated at the tip of a root or plant.

4 Situated between zones of permanent tissue, thus a shoot growing at the base of a leaf.

5 A change in the character of a cell wall by which it becomes harder (supposed to be due to an incrustation of lignin).

6 Composed of or furnished with lamellae (a thin layer, membrane, or plate of tissue).

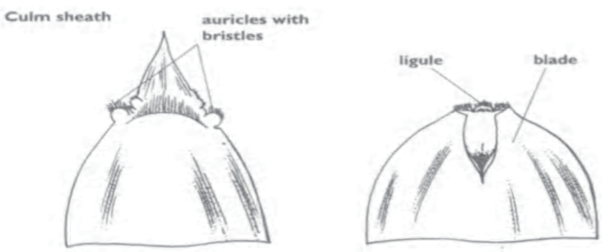
7 Characterised by a climbing mode of growth.

Fig. 1.2: Bamboo shoot

Culm sheath

Culm sheaths are modified leaves, arranged alternately on opposite sides of the growing culms, providing protective cover for the young shoots. The sheath is attached to the node. These are arranged in two ranks, alternately on either side or falling off when culms are mature, leaving scars. Apart from being the shoot's main protective body, the culm sheath consists of a blade, auricles[8] and ligule[9] (Fig. 1.3). The blade is the distinct portion at the top of the sheath which is smaller at the base of the culm and larger and leaf-like towards top.

Auricles are prominent ear-shaped structures present at the point of attachment of the blade to the sheath in some bamboo species. Ligule is the thin, short, upward-growth on the inside top of the sheath, which clasps the culm. The general appearance, colour, texture, shape, height, margin presence of hair, etc. are some of the key characteristics in culm sheaths which help in identification of bamboo (Fig. 1.4). For identification purposes, culm sheaths at about 150–200cm above the ground, or at the fifth node from young culms, should be used.



Source: NMBA (2004)

Fig. 1.3: A typical bamboo culm sheath

8 A structure resembling an ear or earlobe.

9 A narrow strap-shaped part of a plant, especially a membranous scale on the inner side of the leaf sheath at its junction with the blade in most grasses and sedges.

Bambusa balcooa

Bambusa nutans

Bambusa vulgaris

Dendrocalamus hamiltonii

Dendrocalamus giganteus

Dendrocalamus strictus

Fig. 1.4: Culm sheaths of different bamboo species

Branches

When a culm attains its maximum height growth and culm sheaths fall off, branches grow out from the nodes of the culm (Fig. 1.5). The pattern of branching is characteristic of each genus. In many monopodial bamboo, such as *Phyllostachys*, the branches start growing almost immediately after the protective sheaths fall off while in some other species, branches may not appear for an entire year. The typical branching behaviour is seen in the mid-culm regions with more branching towards the tip.

Depending on the species, the number of branches at each node varies. Normally, one main branch and two or more secondary branches emerge from each node (Banik 2000). The main branch is thick and long as compared to the secondary and tertiary branches. Initiation of branching on the culm nodes may be in the same year of culm emergence (syllepsis) as in *Bambusa bambos, Thyrsostachys oliveri*, or may be in the following year of culm emergence (prolepsis) as observed in *M. baccifera*. In many bamboo genera (*Bambusa, Dendrocalamus, Gigantochloa*) the primary branch emerges in the first year and remains strongly dominant (Banik 2000; 2016).

Fig. 1.5: Bamboo branches

Leaves

Bamboo leaves grow out from the top of the newly emerged culm when height growth ceases and proceeds downwards; quite the opposite of that observed for most plants. *"*Bamboo leaves are usually linear, lanceolate or oblong-lanceolate in shape; they have a short petiole; the side glabrous or softly hairy*"*. Bamboo leaves are very similar in general appearance, though variations are observed depending on the species and also within the position of bamboo culm. Venation is parallel and is of three orders, namely the midrib, secondary veins and tertiary veins. In certain genera, the adjacent veins are connected by transverse distinct veinlets (Banik 2016).

Nodes and internodes

Each culm segment begins and ends with a solid joint known as a node. Nodes are key growth points in rhizomes, culms and branches from where new vegetative axes develop and grow. Buds on the culms are also placed on nodes. The segment between two successive nodes is known as an internode. Internodes are initially covered by culm sheaths which fall off as the culm matures. The culm nodes show marked variation in appearance in different species and are important for identification of bamboo species. The culm sheath arises from the nodal region. It encloses a branch bud.

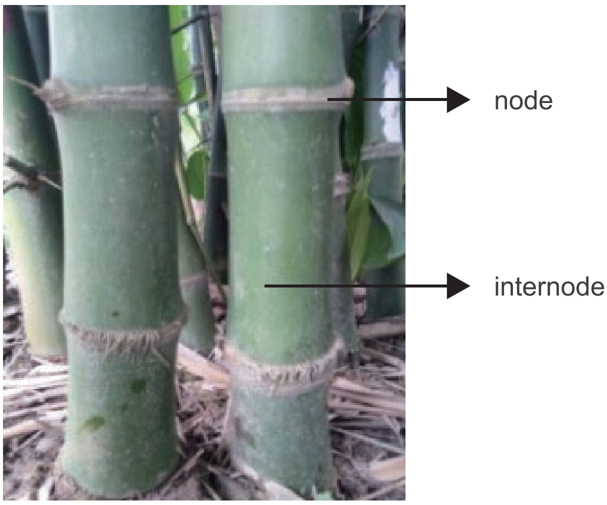


Fig. 1.6: Nodes and internodes in bamboo

Buds

Buds are meristematic organs located at nodal portions on culms, branches and rhizomes. The bud is usually located just above the nodal line (Fig. 1.7). Culm buds emerge on alternate sides of the culm just above the sheath scar at successive nodes. Primary buds of most bamboo species are solitary except genus *Chusquea* where the primary bud at each culm node (above ground) is flanked by two or many smaller buds (Banik 2016).

Fig. 1.7: Branch bud on culm node and rhizome buds

Rhizomes

The underground portion of the bamboo plant is the rhizome. The rhizome system constitutes the structural foundation of the plant. The individual axes of the rhizome system are referred to as rhizome segments. The rhizome consists of two parts, the proper rhizome and rhizome neck. As with culms/stems, the rhizome has nodes and buds; those of the neck commonly always lack buds and roots. The rhizome proper has roots or root primordia[10] and buds at all or most of the nodes. The rhizome contains food reserves and helps in the growth of the bamboo plant.

Basically, there are two types of rhizome systems in bamboo, viz. sympodial (pachymorph) and monopodial (leptomorph), depending on whether it is a clumping or running bamboo.

i) Sympodial: These are typically clump-forming bamboo. In these bamboo, new culms emerge close to each other because of small rhizome necks, thereby forming tight clumps. Most of the tropical and subtropical bamboo belong to this group, e.g. *Bambusa, Dendrocalamus, Thyrsostachys, Gigantochloa* (Fig. 1.8).

Fig. 1.8: Sympodial bamboo

ii) Monopodial: A monopodial form of bamboo can also be called non-clump forming or running bamboo; this growth is usually found in cooler climates and grows as “single, free- standing culms” (Fig. 1.9). In these bamboo, the underground rhizome runs straight in a particular direction. New culms emerge from the underground rhizome nodes at long, uniform distances, thereby giving the appearance of a single culm plantation. These long, expanding rhizomes can grow over 100 yards in order to establish a new plant sprout.

10 An organ, structure or tissue in the earliest stage of development.

Fig. 1.9: Monopodial/running bamboo

Roots

The profuse fibrous roots of bamboo form a dense network in the soil. The primary function of roots in bamboo is to anchor the culm to the ground. The root system prevents the culm from being vulnerable to damage from severe weather conditions, thereby allowing it to hold greater weight and enabling it to grow more leaves over wider distances. The roots do store nutrients; however, this is not their primary function. In appearance, the roots are typically symmetrical in size and shape. They form at the base of the culm from the rhizome nodes and generally go no deeper than 60cm below the surface. A single ring of roots arises at the nodal region of rhizome.

1.3 Flowering and seed behaviour

Unlike tree species, flowering and seed production in bamboo is commonly not annual. Most bamboo species flower after long periods; many only flower at intervals as long as 35 or 120 years. Two types of flowering, such as gregarious and sporadic, have been reported in bamboo (Fig. 1.10). In gregarious flowering, all the culms in a clump flower together over a period of time and then die, just like a field of wheat or rice. In sporadic flowering, a few culms in bamboo clumps flower, and die thereafter. The flowering interval in periodically flowering bamboo varies according to species.

Fig. 1.10: Flowering in *Dendrocalamus giganteus* and *Oxytenanthera abyssinica*

The size and shape of bamboo seeds/fruits vary according to the species (Fig. 1.11). Bamboo fruits can be classified as:

i) Caryopsis, in which the pericarp is membranaceous, thin, soft and adhering to the seed coat. The fruit has an apparent ventral suture which is nearly as long as the whole fruit. An orbiculate navel is located at the fruit base. Examples are *Bambusa, Chimnobambusa, Gigantochloa, Phyllostachys, Thyrsostachys*, etc.

ii) Glans, which have a hard, smooth, crustaceous pericarp, separated from the seed coat. The fruit has no ventral suture and navel. Examples are *Dendrocalamus, Schizostachyum*, etc.

iii) Bacca, which has a thick, fleshy pericarp separated from the seed coat. Examples are *Melocanna, Ochlandra,* etc.

Bacca – *Melocanabaccifera*

Caryopsis – *Bambusa bambos*

Fig. 1.11: Size and shape of bamboo seeds/fruits

1.4 Recording morphological/phenological observations in bamboo

Literally, phenology refers to “the science of appearance”. In the simplest terms, phenology is the study that measures the timing of life-cycle events in all living things. Life-cycle events or phenophases, include first leaf, budburst, first flower, last flower, first ripe fruit, seed dispersal and leaf colour change, among others. The timing of phenological events can be quite sensitive to environmental conditions. Phenology variables are indicated as some of the most sensitive data to climate conditions and therefore were proposed by the European Environmental Agency as climate difference and global change indicators. Recently, there has been a significantly increased interest in phenology primarily due to shifts in the timing of different phenological phases in plants within the context of climate change. Data from a single location can be valuable if recorded for a long run of years.

There is a need for documentation of phenological behaviour in bamboo that is fundamental to understanding the species-specific leaf and sheath dynamics and their ecological significance in plant adaptability being subject to the same climatic regimes. In agroforestry, phenological behaviour, particularly leaf emergence and leaf fall, is a very important aspect in making a choice of intercrops. Limited studies on bamboo phenology such as periodicity of culm emergence, bud break, new branching on the culm and leafing pattern are available in literature. There is an immediate need to strengthen this aspect of bamboo knowledge. The methodology for recording phenological observations is:

Procedure

- Select three clumps representing average diameter and height in the plantation.
- In each clump, randomly select four culms of different ages (current culm, one year, two years and more than two years old) and mark them with aluminium tags.
- Record your observations weekly for sheath appearance, changes in sheath colour, sheath fall, leaf appearance, leaf fall and culm colour (Fig. 1.12) and record the observations in the formats provided below (Table 1.1 and 1.2).
- For quantitative observations, select a few representative branches and count the number of leaves on the branches.
- Repeat the counting procedure after every 15 days and record leaf fall or emergence in the field book.
- When a phenophase is observed in 20 per cent of the tagged culms, consider the event to be initiated. And when a phenophase is observed in > 80 per cent of the tagged culms, consider the event to be at its peak.

Table 1.1: Phenological observations in different-aged culm

Culm age	Phenological features	Jan	Feb	Mar	Apr	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Current	Leaf														
	Sheath														
	Colour of sheath														
	Remarks														
1 yr	Leaf														
	Colour of sheath														
	Remarks														
2 yr	Leaf														
	Colour of sheath														
	Remarks														
3 yr	Leaf														
	Colour of sheath														
	Remarks														

+ appearance; ++ mature leaf; +++ -leaf fall and ++++ leafless

* sheath appearance; ** mature sheath; *** sheath fall **** peak sheath fall

Table 1.2: Culm colour in different age classes of culms in different bamboo species

Culm colour	Current year	1st year	2nd year	3rd year
Species A	*Light green with white, powdery substances*	*Dark green with small black spots*	*Brownish with white patches*	*Dark brown with large white patches*
Species B				
Species C				

Fig. 1.12: Age determination through visual observation

1.5 Conclusion

Morphological characteristics such as the presence or absence of culm sheath, culm texture and colour are found important to diagnose the species and age of a culm in the field. Observing these characteristics minutely over a long period of time can be very helpful in knowing the impact of climate change. The knowledge will also be important in scientific understanding and management of the bamboo. Field personnel involved in collecting the data therefore should be very careful in recording these observations.

CHAPTER II
RESEARCH PLOT ESTABLISHMENT, MAINTENANCE AND DATA RECORDING

2.1 Introduction

Before introducing any bamboo species for large-scale plantations outside their natural home, species trials need to be conducted to assess suitability. This chapter provides brief information on site selection, experimental layout, packages and practices for growing bamboo. Due to annual culm production, data collection in bamboo is complex and tedious as compared to trees. The chapter also provides procedure for recording data on age determination, growth and biomass parameters. Litter production and decomposition, which are two important aspects in nutrient cycling, have also been dealt in this chapter. Due to fast growth of bamboo, the vegetation and diversity in the bamboo understorey is considerably reduced. Methods for recording diversity measures and understorey biomass have also been dealt with in this chapter.

2.2 Laying out of the trial

Site selection

The trial site should represent the area where the species is likely to be planted. The site must be easily accessible in all seasons for better management and recording observations at regular intervals. Care should be taken that the selected site be near the meteorological observatory so that climate data is available for better interpretation of the results afterwards.

Site preparation

The site quality governs the survival and rate of growth of bamboo. Therefore, careful selection of an appropriate site is important for growing bamboo. Before taking up plantation work, the site needs to be prepared. The site is first cleared of shrubs, weeds and other grasses which could compete for the resources. By and large, bamboo can withstand partial shade. Thus, even if the selected plot has a few standing trees, it can be used for plantation purposes with thinning and canopy lifting.

Fencing

The site should be fenced prior to plantation work to avoid any damage from wild/stray animals. Barbed wire fencing, though relatively expensive, is very effective in controlling animals. While bio-fencing with *Bambusa bambos*, agave can be used as a live fence. However, bio-fencing takes some time for establishment and thus should be used in combination with barbed wire fencing.

Setting up a plot

The larger the total area sampled, the more accurate the estimate reflects the actual condition. The block layout depends on the shape of the plot, soil variability and practical field considerations. Choose the block shape to minimise the variability within the block. The geo-position of each plot should be recorded using a GPS. All site variations should be carefully evaluated when laying out the trial. If the site is uniform, square blocks can be laid out. If a dominant soil gradient in a particular direction is known (slope), a more rectangular block may be a better choice to minimise the variability. Blocks do not have to be contiguous or always of regular shape. If any silt monitoring station has to be installed, care should be taken to have uniform slopes in all the area.

For forest land, generally two rectangular plots (5m × 40m = 200m^2) are selected within a plot of at least 1ha, to avoid the boundary effects of the plot, unless specifically indicated in the sample design. Instead of sampling a large contiguous area, it is better to divide the sampling into several smaller areas within the field of study (randomly chosen or based on some a prior stratification). Plot location is randomised if there is marked discontinuity in the vegetation. In other words, be sure that the plots do not only fall in areas with the densest or least vegetation. For a plantation system with low population density in the range of 300–900 clumps/ha, set out in 500m^2 quadrats (20m × 25m).

Experiment design

For laying out a new experiment, design is a very important consideration. With use of replications and proper design, experimental error can be reduced. Layout of the experiment is dependent on the objective of the study. In case different bamboo species are to be evaluated, the experiment can be laid out in a randomised complete block design (RCBD). RCBD is one of the most widely used experimental designs in forestry research. The design is especially suited for field experiments where the number of treatments is not large. The distinguishing feature of RCBD is the presence of blocks of equal size, each of which contain all the treatments.

The purpose of blocking is to reduce experimental error by eliminating the contribution of known sources of variation among the experimental units. Here, experimental units are grouped into blocks so that variability within each block is minimised and variability among blocks is maximised. The randomisation process for a RCBD is applied separately and independently to each of the blocks. First, the blocks are randomly selected and then in each block, each treatment is selected randomly. A layout plan of a field experiment with seven different species S1, S2, S3 … S7 with three blocks (replications) has been illustrated below.

Replication III				Replication I				Replication II			
S3	S3	S3	S3	S5	S5	S5	S5	S7	S7	S7	S7
S3	S3	S3	S3	S5	S5	S5	S5	S7	S7	S7	S7
S3	S3	S3	S3	S5	S5	S5	S5	S7	S7	S7	S7
S3	S3	S3	S3	S5	S5	S5	S5	S7	S7	S7	S7
S2	S2	S2	S2	S7	S7	S7	S7	S4	S4	S4	S4
S2	S2	S2	S2	S7	S7	S7	S7	S4	S4	S4	S4
S2	S2	S2	S2	S7	S7	S7	S7	S4	S4	S4	S4
S2	S2	S2	S2	S7	S7	S7	S7	S4	S4	S4	S4
S1	S1	S1	S1	S3	S3	S3	S3	S6	S6	S6	S6
S1	S1	S1	S1	S3	S3	S3	S3	S6	S6	S6	S6
S1	S1	S1	S1	S3	S3	S3	S3	S6	S6	S6	S6
S1	S1	S1	S1	S3	S3	S3	S3	S6	S6	S6	S6
S4	S4	S4	S4	S2	S2	S2	S2	S1	S1	S1	S1
S4	S4	S4	S4	S2	S2	S2	S2	S1	S1	S1	S1
S4	S4	S4	S4	S2	S2	S2	S2	S1	S1	S1	S1
S4	S4	S4	S4	S2	S2	S2	S2	S1	S1	S1	S1
S7	S7	S7	S7	S6	S6	S6	S6	S3	S3	S3	S3
S7	S7	S7	S7	S6	S6	S6	S6	S3	S3	S3	S3
S7	S7	S7	S7	S6	S6	S6	S6	S3	S3	S3	S3
S7	S7	S7	S7	S6	S6	S6	S6	S3	S3	S3	S3
S5	S5	S5	S5	S4	S4	S4	S4	S2	S2	S2	S2
S5	S5	S5	S5	S4	S4	S4	S4	S2	S2	S2	S2
S5	S5	S5	S5	S4	S4	S4	S4	S2	S2	S2	S2
S5	S5	S5	S5	S4	S4	S4	S4	S2	S2	S2	S2
S6	S6	S6	S6	S1	S1	S1	S1	S5	S5	S5	S5
S6	S6	S6	S6	S1	S1	S1	S1	S5	S5	S5	S5
S6	S6	S6	S6	S1	S1	S1	S1	S5	S5	S5	S5
S6	S6	S6	S6	S1	S1	S1	S1	S5	S5	S5	S5

4 m

5 m

From each replication, data from the inner four clumps should be taken, skipping/avoiding the border plants.

2.3 Package and practices for bamboo cultivation

The success of any experimental plantation is dependent on pre- and post-planting care. The packages and practices for growing bamboo under different heads are as follows:

Planting material

Best quality planting materials should be selected for raising the bamboo plantation. Plants raised from cuttings from superior mother plants should be used. Planting materials from the seeds has the advantage of a known physiological age, allaying the uncertainties of gregarious flowering and should also be encouraged. However, care should be taken to collect the seeds from known superior mother plants.

Micro-propagated plants can also be used, if available, at reasonable cost. As it is difficult to identify the bamboo species during the nursery stage, due care should be taken to procure the right species. The planting material should always be procured from registered nurseries. Bare-root plants should never be used for planting, as these lead to huge mortality. If the plantation area is small, offsets can also be used from superior mother plants. It leads to early establishment.

Spacing

The choice of distance from line to line and plant to plant mainly depends upon the objective of the plantation. The spacing of 4m x 4m, 5m x 5m for block plantations is generally recommended for small and medium-sized bamboo. For large-sized bamboo, spacing of 7m x 7m should be followed. On hill slopes, planting should be done along the contour lines.

Preparation of pits

The dimension of the pits is also decided by the size of the planting material. Plants raised in polybags can be grown in pit sizes of 30cm x 30cm x 30cm or 45cm x 45cm x 45cm. However, when plants are to be raised from offsets, pit sizes of 60cm x 60cm x 40cm or pit sizes twice the size of the rhizomes are preferred. Pits should be dug one to two months before the rainy season so that soil gets enough time for weathering. This soil should be mixed with necessary quantities of fertilisers, FYM and insecticides/fungicides, if required.

Planting time

The best time for planting nursery-raised plants is during the pre-monsoon showers period so that establishment during the monsoon is successful and requires less watering. Planting should be done in early morning and/or evening. The seedlings/cuttings should be planted without disturbing the roots and rhizome of the plants. Soil around the plants should be tightly pressed. Dead plants should be replaced immediately within two months after planting.

Post-planting maintenance

Irrigation

For ensuring success of experimental plantations, lifesaving irrigation should be given as and when required. During the first year of planting, watering helps ensure higher survival rates, especially in areas where the dry period is longer than two months. Irrigation at 12–20 litre/plant should be given to each plant. In areas of low and uneven rainfall, natural soil and water conservation methods like mulching, ditches or crescent-shaped trenches should be promoted.

Fertiliser application

Both organic and chemical fertilisers are important to ensure higher and sustainable productivity of bamboo stands. The dose of fertilisers depends on the fertility status of soil, and therefore soil testing should be carried out before planting of bamboo. Required quantities of farmyard manure (FYM) and phosphoric and potash fertilisers are applied at the time of planting (Fig. 2.1), whereas nitrogen should be applied in split doses as per the requirement after establishment of the plants.

With the growth of the clumps, the dose of fertilisers is also increased. Organic fertiliser is best applied during the dry season, while chemical fertiliser may be used in the wet season. Care must be taken that fertilisers should not be placed close to the clump. Fertiliser application, if not given in the wet season, should be followed by light irrigation. Care should be taken that fertilisers are applied uniformly so as to avoid any experimental error. Fertiliser should be applied twice per year: the first time should be done when shoot buds differentiate from lateral buds of rhizomes, and the second time should be when shoots are in their highest production.

Fig. 2.1: Fertiliser application in the pit

Weeding

After planting, three to four weedings should be done in the first year, depending on the intensity and occurrence of weeds, for better survival of the plantation. In subsequent years, weeding can be reduced, i.e. three weedings in the second year, two weedings in the third and subsequent years (Fig. 2.2).

Fig. 2.2: Weeding, soil working and mulching during the early stages

Soil working and mulching

Soil around plants should be loosened every six months to increase rhizome growth and shoot production. It also checks weed growth. The requirement of silica for bamboo culms can also be met by the bamboo leaf mulch material. Heaping fresh, loose soil around and over the base of the clump (mounding) does not allow retention of water and should be done to accelerate drainage and create a favourable condition of O_2/CO_2 exchange for the underground rhizome system.

Mulching also helps in conserving soil moisture and enhances the health of culms. It should be encouraged with fallen tree leaves, grasses, crop residues, bamboo leaves, culm sheaths, etc. Then, mulch materials of 10cm thickness should be placed as a layer around the clump. It helps in checking weed growth and raising the temperature, which is favourable for new culm emergence.

Cleaning, pruning and thinning

Cleaning of the clump to facilitate the growth of new shoots should be done by removing the dead and dying culms from the clump (Fig. 2.3). Species like *B. nutans, B. bambos, B. balcooa* and *D. hamiltonii* have heavy branching at lower nodes. Pruning of these branches reduces culm congestion and helps in better growth of the clump. It is mainly done during the dormant season (December–January) to avoid injury to the growing parts. Thinning is essential once the clump is established and starts producing commercial shoots after four to five years. Thinning helps in removing damaged, weak or bent culms, avoids congestion and permits better growth of the remaining culms. All the culms up to three years of age should be thinned. Unwanted formed culms such as topless culms, horseshoed culms and dried-out culms should also be removed. Weak shoots should also be removed to ensure sufficient nutrients for the healthy ones. After thinning, the ground should be cleaned up.

Fig. 2.3: Cleaning and pruning bamboo

2.4 Data collection

Two types of data need to be collected. One-time information/data and periodical data should be collected in each experiment.

A. One-Time Observations

The following information should be collected at the beginning of the experiment:

a) Site description

- Name and address of Principal Investigator
- Site name, ID, state, country
- Latitude, longitude and elevation
- Climate (maximum and minimum temperature, precipitation)
- Previous vegetation (including existing land use) and method of clearing
- General relief: (flat, rolling, hilly or mountainous)
- Site relief: (flat, concave, convex or ridge)
- Slope gradient
- Length of slope
- Any other/remarks

b) Soil characterisation

- Top soil colour, texture, pH, drainage
- Soil family, moisture regime, temperature regime
- Soil depth, water table
- Parent material, bulk density (BD), stoniness, salinity
- Soil fertility

B. Periodical Observations

After the initiation of experiment/planting of bamboo, a lot of changes are observed over time in the growth and yield of bamboo. In addition, fast growth of bamboo brings changes in the micro-site conditions. Periodical observations, therefore, should be recorded about forage, survival, growth and biomass parameters. Data related to litterfall, understorey vegetation, temperature, light, soil moisture, soil physical, chemical and biological properties, etc. should also be recorded periodically to know the impact of bamboo plantations on soil health and microclimate. The methodologies for recording these observations, along with a worksheet for data collection, are discussed in this chapter.

2.5 Determining culm age in bamboo

Benefits

Due to annual production of new shoots, different-aged culms are observed in a bamboo clump. Age determination of these culms is important, as strength and properties of bamboo culms vary with the age. Culms below one year of age have very high moisture content and shrivel up after harvesting. Young bamboo culms have a high starch content and poor lignin[11] as a result of which these culms have poor strength and

11 A complex organic polymer deposited in the cell walls of many plants, making them rigid and woody.

mechanical properties. These culms are also vulnerable to borers and termites when harvested and used.

With increase in culm age, the starch content reduces and the lignin content is enhanced, which enhances the strength of the culm. For example, two- to three-year-old bamboo culms are preferred for pulping, craft and mat-making. During the fourth and fifth year, bamboo culms are strongest and suitable for structural applications and board-making. Culms over five years old become brittle and weak and are not desirable for structural/pulp use. A maturity marking system in bamboo helps in identifying the culms for appropriate use and enables them to be harvested at the appropriate time.

Bamboos lack the vascular cambium layer and thus lack secondary growth in diameter and do not possess annual rings as do trees. Under field conditions, it is not always easy to distinguish the age of a bamboo culm, since culms in a mature clump tend to have the same girth, length and nodal structure. Therefore, other methods have to be used to determine the age of bamboo. The culm age can be identified based on certain features of the culm sheath, development of branches and leaves, external colour of the culm, position of new culms, etc. For example, in sympodial bamboo, younger/current-year culms are usually on the outer side, while older culms are toward the inner side. Culm sheaths are usually absent on older culms. During initial stages of clump establishment, the diameter of older culms is less, compared to younger culms. The accuracy of such a distinction is, however, dependent on the skill and experience of the person and is not always reliable.

Age can also be determined by marking the culms (a) with different colour paints, (b) writing year and month of shoot emergence using colour/paint and (c) inscribing the year of shoot emergence. Alternately, other innovative approaches can be adopted too.

(a) Different colour paints: Five different colour paints are required, one for each year of a five-year cycle. Culms that are six years old should not be retained in the clump, as they become weak and brittle and can be expected to die within a year or so. After the culms attain full height during the first year, they are marked with paint. A scheme for identifying culm age is given in Table 2.1 and is suitable only for farm bamboo.

(b) Writing year and month of shoot emergence: Using single colour paint (black), write the year and month of shoot emergence. This method is widely adopted in China.

Table 2.1: Colour scheme for identifying the age of culms

Colour	Age (year)	Rotation-2
Red	Current (2017)	Current (2022)
Yellow	1 (2018)	1(2023)
Blue	2 (2019)	2 (2024)
White	3 (2020)	3 (2025)
Black	4 (2021)	4 (2026)

Depending on the requirements, culms of different age can be harvested. For example, if five- year mature culms are required, culms marked with black colour (Table 2.3) are harvested. Similarly, if four-year culms are required, culms marked with white paint are harvested. The colours are not standard and users can choose their own colour.

Marking is to be done after the culm attains its full height, that is, after it has stopped growing. The indication of the stoppage of further dimensional growth (length) is when branches begin to appear, normally first in the upper portion of the culm.

- Detach the culm sheath from the culm before beginning to paint.
- Mark the different-aged culms with the thick paint by making a three-inch band at breast height in the internodal portion of the culm, taking care that paint should not drip down the culm.
- Use different colours (as given in Table 2.1/Fig. 2.4) for marking different ages.

Fig. 2.4: Different colours and month/year markings used for identifying culm ages

Currently, in commercial farmer plantings, homesteads, farm boundaries and block farm plantings, the above painting method is not used since harvesting is done each year and there is no system of rotation. For sustainable management of bamboo culms and to ensure bamboo poles of the right age are supplied to industries, it is important to adopt age marking. Instead of paints, scratches on the culm skin or indelible writing can also be done.

2.6 Survival

Monitoring of plant mortality and growth rates ought to be considered an essential in any plantation programme. The information can be used to influence the choice of species for future programmes, thus limiting losses and providing savings with regards to cost, time and effort. For measuring survival, permanent plots are fixed at the site. Within each plot, planted species are identified and also recorded as to whether they are alive or dead. Clump survival should be measured every three months until the 12-culm stage is reached. Survival is calculated as the ratio of number of survived clumps to the total number of clumps planted.

2.7 Growth parameters

The biomass and carbon mass in bamboo depend mostly on the diameter and the height of the culm, and thus their measurements are very important. The main objective of this exercise is to measure diameter, height and other growth parameters in bamboo which are used to estimate the biomass and determine suitability of bamboo for different end uses.

2.7.1 Culm diameter

There are two options available for measurement of culm diameter: caliper and measurement tapes.

Place of measurement

Culm diameter should be measured at 1.37m above ground level. This height is the universally adopted standard height for measuring the girth and diameters of standing trees in India, Burma, America, South Africa and other British colonies. This height also standardises diameter measurement, giving a uniform point of measurement. However, if there is a node at 1.37m, the observer should slightly shift above or below the node to measure the diameter of the culm.

Diameter measurement with caliper

Caliper are generally used for measuring the diameter of a standing bamboo culm. The caliper consist of a horizontal graduated rule and two vertical arms, one of which is fixed at a '0' reading while the second arm moves along the rule parallel to the fixed arm (Fig. 2.5). In the case of caliper, two readings are needed, as the bamboo poles are not always perfectly round.

Fig. 2.5: Caliper for measuring diameter in bamboo

Procedure

- Mark breast height point (1.37m) on the culm.
- Hold the caliper in both hands.
- Separate the two arms of the caliper enough to hold the culm between them.
- Bring the graduated scale in touch with the culm.
- Shift the moveable arm inwards in the tilted position so that the culm touches the fixed arm and moveable arm.

- Bring the moveable arm slowly into a perpendicular position to the graduated scale (Fig. 2.6).
- Read the diameter reading from the graduated scale.
- Record the reading in Table 2.2.
- Repeat the same procedure by moving the caliper at a right angle to the previous reading.
- Average the two diameters reading to get the final reading.
- In the case of large-sized bamboo, use aluminium caliper of a larger size.
- On sloping land, take diameter readings from the uphill side at 1.37m above ground level.
- In case of leaning culms, record readings along the upper side of a lean at 1.37m height above ground level.

Precautions

- The caliper must be placed on the bamboo with movable arms well-opened and must not be forced on the culm, thereby causing stress or damage to the arms.
- The reading must be taken before the caliper is removed from the bamboo.
- The reading should not be taken near the node position.

Fig. 2.6: Measuring diameter with the help of caliper

Girth measurement with tape

Alternately, tape made of cloth, reinforced cloth, or plastic or steel is used to measure the girth/circumference of the culm. Girth is also measured at breast height (1.37m) and is known as girth at breast height (GBH). Sometimes, diameter tape (D-tape) is used for measuring the diameter directly. A diameter tape has either metric or imperial measurements reduced by the value of pi.

Relation between diameter and girth

DBH (Diameter at Breast Height) = 2r, where r is the radius of the stem

Girth = $2\pi r$

Thus, GBH = DBH * π

Procedure

- Mark breast height point (1.37m) on the culm.
- Encircle the culm with the help of tape at a right angle to the axis of the culm.
- Read the girth reading from the tape (Fig. 2.7).
- Convert the girth reading to the diameter by using the relation d=G/3.14.
- Record the reading in Table 2.2.

Fig. 2.7: Measuring girth and diameter with the help of tape

Precautions

- The tape should not be old and therefore stretched, or possibly with the end broken off.
- It must be flat against the culm and not twisted.
- It must lie in a plane perpendicular to the axis of the culm.

Table 2.2: Field measurement to measure the DBH and GBH of standing bamboo

Culm No.	Calliper			Ordinary tape	
	DBH			GBH	DBH= GBH/3.14
	Reading 1	Reading 2	Average		
1					
2					
3					
4					
5					
6					
7					

2.7.2 Clump height

The main objective of height estimation in bamboo is to calculate the volume and biomass, assess the site condition and describe the growth performance. Height of bamboo culms is a stable parameter and is not affected by age as the young bamboo culms are formed by the elongation of their internodes and reach their full height within a period of only a few months, after which there is no change in height.

Clump height is the vertical distance between the base to the tip of the clump and is difficult to measure accurately. Clump height is measured from ground level to the tip of the highest culm. The height of a bamboo clump can be measured directly or indirectly. Direct methods involve measuring the height with a graduated rod or height stick or directly by climbing with tape and a graduated pole. When culms are small, height can be measured accurately with a graduated pole. However, direct methods are not cost-effective and practical for large-sized clumps. In case of large-sized clumps, height can be measured indirectly by instrumental or non-instrumental methods. Both the methods are cost-effective and are used widely. Heights of bamboo culms can also be measured by a destructive method where a few bamboo culms are felled and their length is then taken with the help of tape.

Indirect/non-destructive methods for measuring the heights of bamboo poles such as (a) stick method and (b) Ravi altimeter are described below:

a) Stick method: In the absence of any equipment for measuring clump height, the stick method can be used. The method is very simple and requires an arm's-length stick and tape for measuring clump height. This method is based on the principle of similarity of triangles.

Procedure

- Hold a 1.5m stick vertically at arm's-length in one hand in such a way that the portion of the stick above the hand is equal in length to the distance of the stick from the eye.
- Without changing the position of the hand with reference to the eye, move slowly forward or backward till the line of sight to the tip of the bamboo clump passes through the tip of the stick and then to the base of the bamboo clump, through the point where the stick is held by hand (Fig. 2.8).

Fig. 2.8: Measuring clump height with stick method

- The height of the bamboo is then equal to the distance of the observer's eye from the base of the bamboo clump as follows:

Let AB be the bamboo clump and ab a stick of about 1.5m long, held at b vertically so that the distance from the observer's eye E to b is equal to ab; then, in this Fig. 2.9:

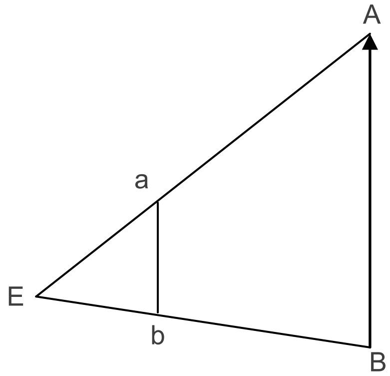


Fig. 2.9: Height calculation using stick method

$$\frac{AB}{ab} = \frac{EB}{Eb} \text{ Therefore } AB = \frac{EB \times ab}{Eb}$$

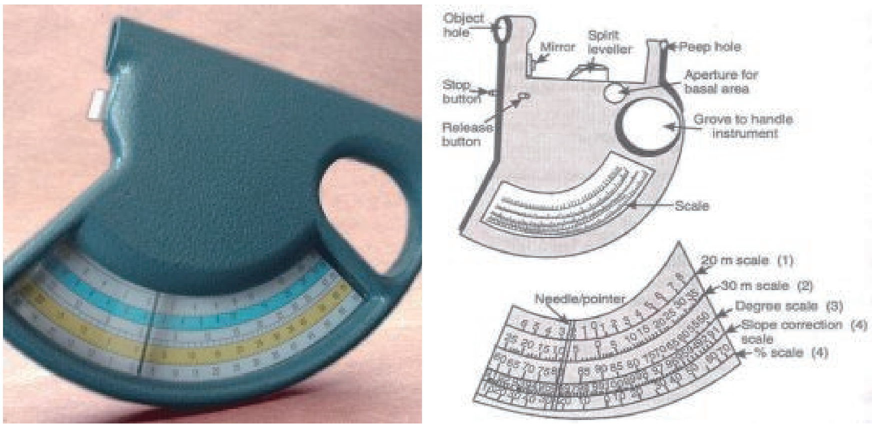
Since ab = Eb, therefore AB (bamboo clump height) = EB (distance from bamboo clump)

Limitations

- The method is not suitable in dense plantations, where it is difficult to locate the tip and base

b) Using Ravi altimeter: A Ravi altimeter is a tool which is used for measuring the height of the clump directly. The method is simple, cost-effective and requires less time for measuring the clump height.

Equipment description: The Ravi altimeter is made of aluminium, with moving parts enclosed to withstand shock or damage. It is meant to measure the height of objects, angles of elevation (in degrees) and the correction for heights in sloping or hilly regions. It is compact, portable, lightweight and weighs around 200gm. It is provided with two different scales of 20m and 30m. In addition, it has a per cent scale, a degree scale, and a scale for correcting sloping distance. All these scales are visible simultaneously. On the observer side, it has a groove to handle the instrument while taking the observation. A peephole and an object hole are provided. A stop button is present at the far end as well as a release button on the front of the instrument. It also has an aperture to measure basal area and a leveller for measuring crop height (Fig. 2.10).



Source: Panwar and Bhardwaj, 2005

Fig. 2.10: Ravi Altimeter

Procedure

On levelled ground

- Release the pointer by pressing the release button on the side.
- Select the horizontal distance (20m or 30m) for making the observation with the instrument.
- See through peephole and aim at culm top through the object hole (Fig. 2.11).
- When the culm top is in the line of vision, gently press the stop button and note the reading (Scale 1 or 2, according to the distance from the clump).
- Get the total height of the culm by adding the eye-height of the observer to the pointer reading.
- If measurements are made at a distance other than 20m or 30m, then the scale 5 (outermost) is read.
- In this case, note the horizontal distance from the culm with the help of tape.
- Multiply the reading with the horizontal distance from the culm to get the height of the culm above the eye-height of the observer.
- Get the total height of the culm by adding the eye-height of the observer to the pointer reading.
- Record the reading in Table 2.3.

Fig. 2.11: Measuring clump height with Ravi altimeter

On sloping ground

On sloping ground, the baseline distance measured along the ground is not the horizontal distance between the culm and the observer. Hence, correction is necessary.

- Mark the culm at the observer's eye level.
- From a distance, observe through the peephole and object hole and press the stop button.
- Read scale 4, which is the slope correction scale. If the pointer reading is 100 per cent, then the ground is horizontal and there is no need for any correction.
- If the pointer reading is anything other than 100 per cent, then correction is necessary.
- Multiply the sloping distance between the observer and the culm with the reading from scale 4. The product is the correct baseline distance.
- View the top and base of the culm and note the readings of scale 4.
- Add the two readings if they are on the opposite side of zero, and subtract if they are on the same side of zero.
- Multiply the reading with a corrected baseline (step 5) to get the correct total height of the culm.
- Record the reading in Table 2.3.

Example: If the reading on scale 4 was 90 per cent, then to get the corrected horizontal distance between observer and culm, we multiply sloping distance, say 23m with 90 per cent, i.e.:

$$\text{Corrected horizontal distance} = \frac{23 \times 90}{100} = 20.7\,\text{m}$$

Now we observe the reading from the tip of the culm as well as the base of the culm on scale 5, the per cent scale. Say the tip of the culm makes a 60 per cent slope toward right side of zero and the base makes a 14 per cent slope on the left side of zero. Add these two readings, i.e. 14 + 60 = 74 per cent. This total per cent value (74 per cent) is multiplied with the corrected horizontal distance (20.7m) to get the total height of the culm, i.e.:

$$\text{Total height} = \frac{20.7 \times 74}{100} = 15.31\,\text{m}$$

Advantages

- The instrument is small, light and easy to use.

Disadvantages

- It needs to measure the distance first, which sometimes may be difficult in sloping areas.
- Shaking of the hand makes the sighting of the top and bottom of the culm a little difficult and time-consuming.
- Cannot be used by an unskilled person.

Table 2.3: Field measurement to measure growth parameters in bamboo

Plot No.	Clump No.	Species	Clump age (years)	No. of culms	Clump girth (m)	Clump height of 3 dominant culms (m)		

2.7.3 Internode length

The internode is part of the culm between two successive nodes. The internode length refers to the characteristics of each species and affects its utilisation values. At nodes, the parallel cell structures of the internodes become diverted, whereby bamboo species with long internodes are preferred for furniture, splitting and weaving. The length of culm internodes increases gradually from the base towards the middle portion of the culm and decreases upwards. Clump height, along with the length of internodes of bamboo culms, varies with species.

Procedure

- Mark three clumps in the plantation with paint/tag.
- From each clump, select different-aged culms and mark them with tag/paint.
- Fell the selected culms with the help of a saw at ground level.
- Take the length of the bamboo culm with the help of tape (Fig. 2.12).
- Mark the internode number, starting from the base to the top for different-aged culms.
- Measure the internode length with the help of the scale and record it in Table 2.4.
- Repeat the procedure for different-aged culms.

Table 2.4: Number of internodes and internode lengths in different bamboo species

Species......................... Clump age...................... Culm age............................

S. No.	Internode number	Internode length (cm)	Diameter (cm)
1	1		
2	2		
3	3		
4	4		
	5		
	6 ...		

Fig. 2.12: Measuring length of the internode

2.7.4 Wall thickness

Culm wall thickness is one of the most important parameter for determining its strength and identify its suitability for different end uses. The true value of culm volume depends on the wall thickness that is directly correlated to shrinkage as well as other properties. Culm thickness varies with species, clump and culm age, site condition, etc. For example, *Dendrocalamus strictus*, known as male bamboo, growing in dry areas, possesses a higher culm thickness and produces even more solid culms. The diameter of the culm tapers from bottom to top and the reduction in diameter is accompanied by a reduced wall thickness. Ratio between wall thickness and culm diameter might be an important consideration when classifying bamboo as thick- and thin-walled species.

Procedure

- Mark three clumps in the plantation with paint/tag.
- From each clump, select different-aged culms and mark them with tag/paint.
- Cut the culm into three equal parts.
- Measure the culm diameter and wall thickness of the culm with the help of a caliper at three cut ends (Fig. 2.13).
- Record your observation in Table 2.5 and repeat the procedure for different-aged culms.

Table 2.5: Ratio of wall thickness/diameter in different bamboo species.

Species......................... Clump age...................... Culm age............................

S.No	Base			Middle			Top		
	Diameter (cm)	Wall thickness (cm)	Ratio	Diameter (cm)	Wall thickness (cm)	Ratio	Diameter (cm)	Wall thickness (cm)	Ratio

Fig. 2.13: Measuring culm diameter and thickness

2.7.5 Culm emergence and mortality

Knowledge of culm emergence periodicity is important in managing the bamboo clump. Shoot emergence and vigour are dependent on the amount of stored food material in the rhizomes. However, climatic factors like soil temperature, rainfall and relative humidity have been found to be important determinants of culm emergence in bamboo. All emerging culms do not develop into full-grown culms. Clumps with congested sympodial rhizome systems produce most of the culms within a short distance, and therefore competition for survival among the developing culms become intense. Mortality of young culms is therefore more in congested sympodial bamboo as compared to monopodial bamboo.

Procedure

- Mark three bamboo clumps in the plantation with paint/tag.
- Observe the clumps daily/weekly for new shoot emergence (Fig. 2.14). Be very careful during monsoons as the majority of new shoot emergences are recorded during monsoon season.
- Record soil temperature and soil moisture at 0–15cm and 15–30cm soil depth at weekly intervals.
- Record air temperature, relative humidity and rainfall data regularly.
- Record the data in Table 2.6.
- Calculate mortality (%) from the data.
- Develop correlations between different parameters.

Fig. 2.14: New culm emergence in bamboo

Table 2.6: New shoot emergence in bamboo

Species......................... Clump age...................... Clump girth (cm)....................

Month	No. of new culm emerged	Live culm	Dead culm	Soil temperature (ºC)		Soil moisture (%)		Relative humidity (%)	Air temperature (ºC)	Rainfall (mm)
				0–15 cm	15–30	0–15 cm	15–30 cm			
Jan										
Feb										
Mar										
Apr										
May										
Jun										
Jul										
Aug										
Sep										
Oct										
Nov										
Dec										

2.7.6 Culm elongation

Bamboo is a quick-growing plant and its height stabilises over a comparatively short span of time. After appearing from the ground, bamboo culms elongate very slowly for one to two weeks and then gradually gain speed until they attain the optimum size and thereafter the rate of elongation quickly slows down. The rate of elongation is also dependent on the food material stored in the rhizome. The culm's diameter is determined by the size and vigour of the bud present in the mother rhizome from where it originated. Culm diameter does not increase throughout its life. Therefore, a longitudinal study is preferred for measuring height rather than considering different random samples at different times.

Procedure

- Mark three bamboo clumps in the plantation with paint/tag.
- From each clump, mark four different newly emerged culms, heights of approx. 5–10 cm. Do this carefully, as newly emerged clumps are very susceptible to damage (Fig. 2.15).
- Measure the length of newly emerged culms daily (up to 30 days) on alternate days with the help of tape in earlier growth stages and (up to three months/till height stabilises) with marked poles during later stages.
- Calculate the elongation rate by dividing the length with number of days.
- Measure the culm height growth rate between any two-time epochs (say t_1 and t_2/ measured as y_2-y_1/ t_2 - $t_{1,}$ where y_1 and y_2 are heights at time t_1 and t_2.)
- Record the observation in Table 2.7.

Fig. 2.15: Culm elongation in bamboo

Table 2.7: Culm elongation rate

Species	Day/date	Culm No.	Total length (cm)	Elongation (cm/day)
	1			
	2			
	3			
	4			
	5.....			

2.8 Moisture content

Following the detailed discussion on age identification of bamboo by examining various aspects such as phenological observations, clump and culm growth, which help explain growth pattern in bamboo, the next step is to determine the moisture content in different components (culm, branch, leaf, sheath, roots) of bamboo.

Similar to wood, the physical properties of bamboo are related to moisture content, wood density, shrinkage, etc. Variation of both moisture content and wood density of bamboo is due to species, age of culm, position in the culm, site condition, season, etc. which are the primary factors affecting the weight, strength and other properties of bamboo products. Knowledge of moisture content also helps us in determining biomass in bamboo, which is discussed later on. The moisture content (MC) is determined by the weight of water in wood and is expressed as a percentage of the oven-dry weight of wood. The requirement and procedure for moisture determination is:

Requirement: Drying equipment. An oven for drying moisture samples at a uniform temperature not exceeding 115°C and balance sensitive to 0.1 per cent of the minimum weight of the sample to be weighed, with a capacity equal to the maximum wet weight of the samples to be weighed.

Procedure

- Select a representative quantity of the plants sample from different plant components, viz. culm/ branch/ leaf/rhizome/root etc.
- Weigh moisture sample immediately and record as “wet weight of sample”.
- Dry the wet sample until a constant weight is attained at a temperature not exceeding 70°C in the oven.
- Allow the sample to cool.
- Weigh the cooled sample again and record as the “dry weight of sample”. Repeat the heating-cooling-weighing process until sequential similar weight recordings of the sample are obtained.
- Calculate the moisture content of the sample component (culm/branch/leaf/rhizome/root, etc.) using the formula:

$$Mcd = \frac{Lwf - Lwd}{Lwd}$$

where Mcd= moisture content as a percentage of oven-dry weight

Lwf = fresh weight of the plant sample

Lwd = oven-dry weight of the plant sample

- Use the following formula to convert the fresh weight of leaf biomass into dry weight:

$$Ldw = \frac{Lwf}{1 + Mcd}$$

where, Mcd = Moisture content of leaf on dry weight basis

Table 2.8: Moisture calculation in different plant components in bamboo

Component	Fresh weight of the component	Fresh weight of the sample	Oven-dry weight of the sample	Moisture content of the sample	Dry weight of the component
Culm					
Branches					
Leaf					
Rhizome					
Roots					

2.9 Biomass estimation

2.9.1 Above-ground biomass

Quantification of biomass and carbon stored has recently become important all over the world and is presently an important component in the implementation of the emerging carbon credit market mechanism. A common framework and good practice guide for carbon reporting through biomass equation has also been recognised by the United Nations. Biomass can be estimated by destructive and non-destructive methods.

In the case of the destructive method, all the growing parts of the plant components are sampled for determination of dry matter. This method gives more accurate measures of the biomass estimation but is time-consuming and expensive due to the large dimensions and amounts of biomass that have to be processed.

In the case of the non-destructive method, biomass can be estimated using regression/allometric equations that establish quantitative relations between some key characteristic dimensions of the culm which are usually fairly easy to measure (such as culm diameter and height) to total culm biomass. This method yields a non-destructive and indirect measurement of biomass components and is often the preferred approach since it is less time-consuming and less expensive than direct measurements. Besides, this avoids destruction of the vegetation. These biomass equations are important tools for understanding the changes related to productivity, energy, stocks and fluxes of nutrients. Together with laboratory analysis (carbon content measurement), allometric models can be converted to C stock at the plot level and are then scalable to the C stock per unit area (hectare).

Requirement: Caliper, measuring tape, weighing machine, plastic bags, brown paper bags

Procedure

- Establish three plots of 25m x 25m size so that all plots have 9–15 clumps.
- Mark three clumps in each plot with paint.
- Count number of culms in each clump annually
- Categorise bamboo culms into different ages, i.e. current, 1-, 2- and 3-year based on colour of paint on the culm or another marking. In case culms have not been marked, age should be

determined on the basis of culm sheath, the development of branches and leaves and the external colour of the culm.

- Measure the DBH and record the data in Table 2.9.
- Group the culms into different diameter size classes (for example 5–9; 9–11; 11–13; 13–15cm) representing the whole diameter range in the plantation.
- Harvest three culms from each age/diameter class with the help of a saw, cutting them as close to ground level as possible (Fig. 2.16).

Fig. 2.16: Harvesting bamboo culm with saw

- Measure the length of the culm with the help of the tape (Fig. 2.17).

Fig. 2.17: Measuring length of bamboo pole

- Separate the felled culm into different components viz., main culm, branch, twigs, leaves and rhizome.
- Weigh the separate components immediately after felling and record the observation in Table 2.9.

- Take representative samples from the top, middle and bottom portions of the culm and other components for determining moisture content, as described in the previous exercise, or oven-dry to fresh-weight ratio.
- Obtain oven-dry weight for individual components as described in the previous exercise and record data in Table 2.9.
- Use the 75 per cent dataset to fit the biomass equation and 25 per cent for validating the biomass equation (see below).

Table 2.9: Field observation to estimate bamboo biomass

Site name: ………..... Location (GPS): .... E, ... S

Species……..................... Clump height (m)………....... Clump girth (cm)………….

Clump age........................ Date……………..

Oven to fresh weight ratios: Stem………., branch…………, foliage…………

Culm No.	Culm age	Culm diameter (cm)	Culm length (m)	Fresh weight (kg)					Oven dry (kg) = Fresh weight (kg) x ratio				
				Culm	Branch	Foliage	Rhizome	Root	Culm	Branch	Foliage	Rhizome	root
1	1												
2	2												
3	3												
…..													
Total													

2.9.2 Model fitting and validation

Different equations are used to estimate growth, biomass production and carbon capture potential using diameter as an explanatory or dependent variable. Among these equations, the allometric model is widely used to estimate different biomass components. The equation is $Y = aX^b$, where a and b are the parameters of the allometric equation.

The allometric model is non-linear, hence the estimation of parameters is not straightforward. There are several methods available to estimate the parameters of the allometric model. One such method is making the equation linear by taking the natural logarithm on both sides and then estimating the parameters by using the 'least squares' method of linear regression model. The method is as follows:

The equation is of the form

$$Y = aX^b \qquad (1)$$

By taking the natural log of both sides of our equation we get:

$$\ln(Y) = \ln(a) + b\ln(X) \qquad (2)$$

$$Y' = a' + b'X' \quad (3)$$

Where,

$Y' = \ln(Y)$

$a' = \ln(a)$

$b' = b$

$X' = \ln(X)$

Equation (3) is just like Y = a + bX. So the log-transformed power function ($Y = aX^b$) becomes a straight line (Y = a + bX). This is a real advantage – not only is it easier to visualise the data, but it is much easier to work with linear vs. non-linear functions when doing statistical analyses.

The parameters a' and b' can be obtained using a linear regression parameter estimation procedure. Once the parameters a' and b' are obtained, we need to calculate a and b to get the actual parameters of the equation (1) as

$$a = e^{a'} \quad (4)$$

$$b = b' \quad (5)$$

Once the model is fitted, the model is validated using some datasets to see whether the fitted model is good or not. In general, 75 per cent observations are used for model fitting and 25 per cent are used for model validation. Several validation methods are available in literature. One such method is validated by observing whether there is any significant difference between observed and predicted observation or not. This can be done by using a paired test between observed and predicted observations or through visualising using 1:1 line.

For fitting the allometric model, data from Table 2.9 is used:

			Biomass									
Culm no.	DBH (cm)	In (DBH)	Culm	In (culm)	Branch	In (Branch)	Leaf	In (Leaf)	Rhizome	In (Rhizome)	Root	In (root)
1												
2												
3												
….												

Where ln = natural logarithm

Example: The following data was recorded on culm biomass in *Dendrocalamus strictus*

Diameter (cm)	Biomass (kg/culm)		Diameter (cm)	Biomass (kg/culm)		Diameter (cm)	Biomass (kg/culm)
1.52	0.16		3.47	2.35		6.35	11.74
1.61	0.15		3.49	1.99		6.52	10.88
1.75	0.38		3.49	2.01		7.06	13.04
1.81	0.65		3.56	2.53		7.18	15.73
1.82	0.45		3.57	2.83		8.12	17.91
1.86	0.10		3.61	2.00		1.30	0.06
2.17	0.45		3.75	2.20		1.76	0.14
2.21	0.26		4.04	3.35		1.88	0.26
2.23	0.69		4.13	4.23		2.55	1.23
2.57	0.70		4.39	5.20		2.70	0.96
2.64	0.95		4.51	2.13		2.86	1.34
2.66	1.03		4.54	3.28		3.26	1.48
2.71	0.59		4.62	6.13		3.47	2.25
2.73	1.01		4.71	5.28		3.57	2.26
2.80	1.11		4.75	4.16		3.89	3.00
2.91	1.66		4.90	5.46		4.44	4.75
2.93	0.98		4.94	4.05		4.70	4.70
2.94	1.83		5.22	3.95		4.91	4.20
3.33	1.84		5.43	9.09		5.81	9.80
3.40	1.26		6.26	11.23		7.62	13.10

Use the 45 readings of the above dataset for model fitting and leave the remaining 15 for validation.

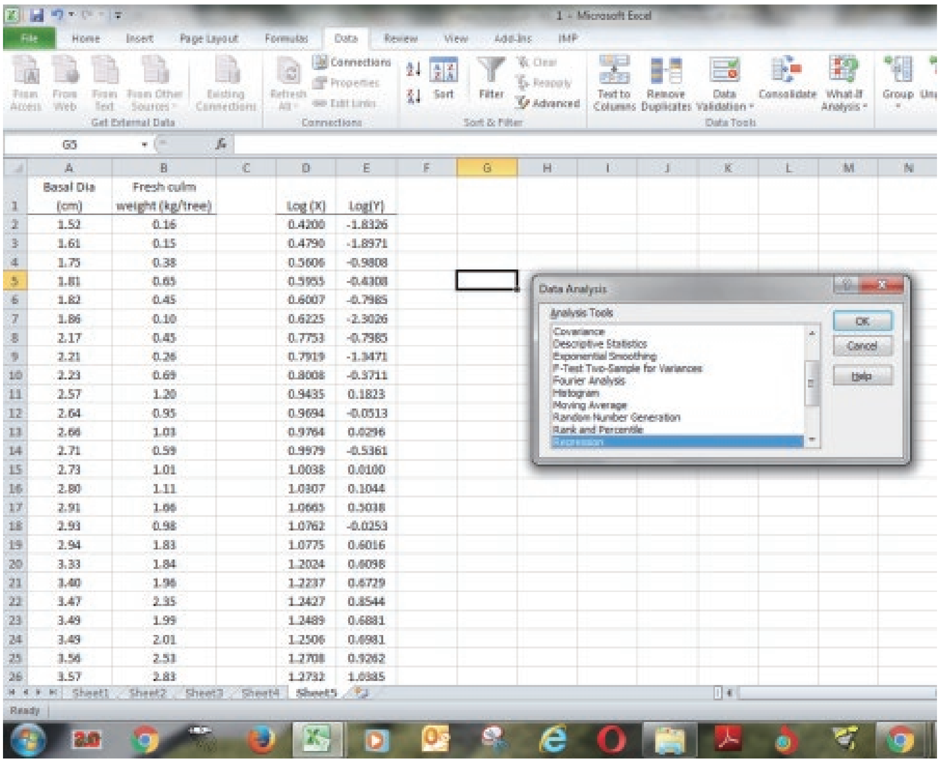
First take the natural logarithm on both sides

Y' = ln(Y) where Y = biomass of culm/branch/leaf/rhizome/root

X' = ln(X) where X = diameter

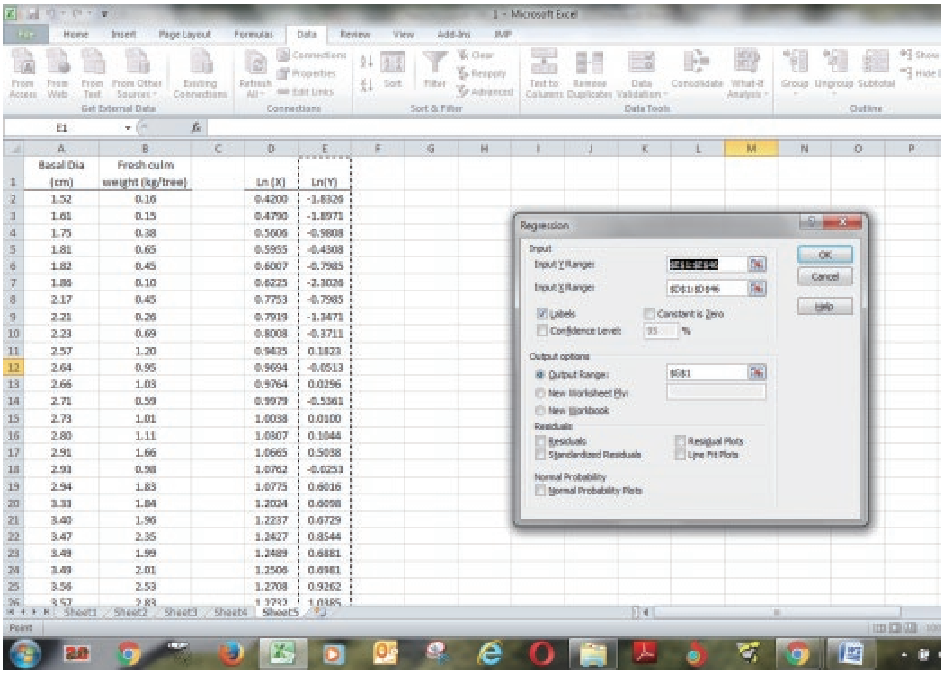
Now perform regression analysis:

Data > Data Analysis > Regression



Input the dependent and independent variables.

Select values of Ln (Y) column in Input Y range and select Ln (X) values in Input X range. Click on label box to label the dependent and independent variables in the output tables. Click ok.



The output of the regression equation obtained is as follows:

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.965509
R Square	0.932208
Adjusted R Square	0.930632
Standard Error	0.337937
Observations	45

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	67.52706	67.52706	591.2967	9.28E-27
Residual	43	4.910671	0.114202		
Total	44	72.43773			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%
Intercept	-2.20138	0.156735	-18.5905	3.56E-22	-3.22987	-2.5977	-3.22987
Ln (X)	2.351613	0.118915	24.31659	9.28E-27	2.651797	3.131428	2.651797

So, a' = -2.20138; b' = 2.351613

Parameters a and b are obtained by using the equation. We get:

a = exp(a') = exp(-2.20138) =0.11065

b = b '= 2.351613

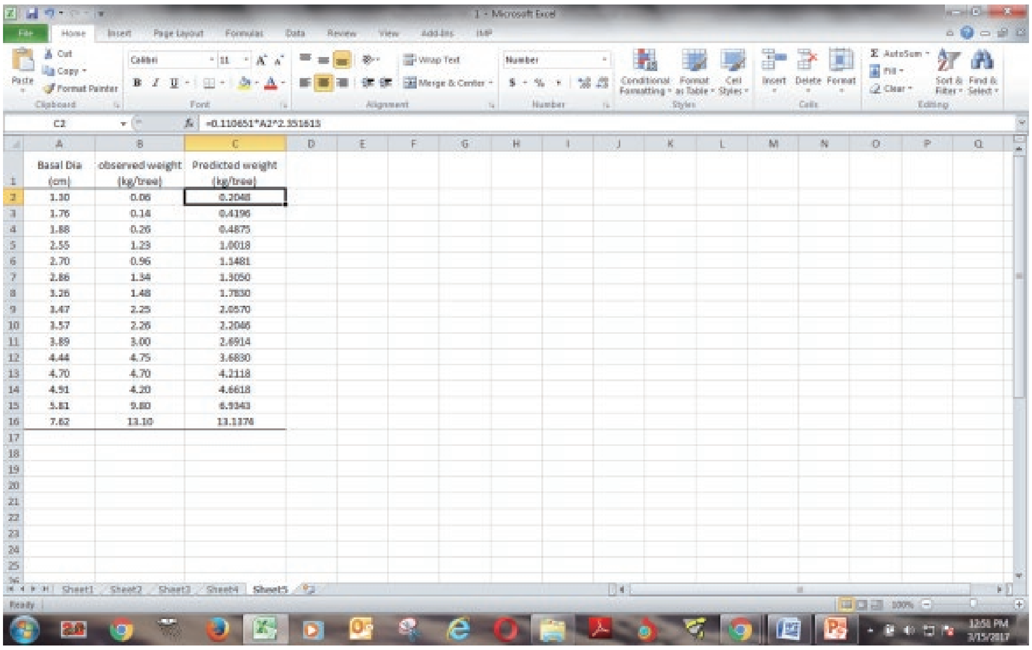
So the fitted allometric equation to obtain biomass using basal diameter as an explanatory variable is

$$Y = 0.11065\ X^{2.351613}$$

Model Validation

The remaining 15 data points are used to validate the fitted model. The predicted biomass is obtained using the fitted equation:

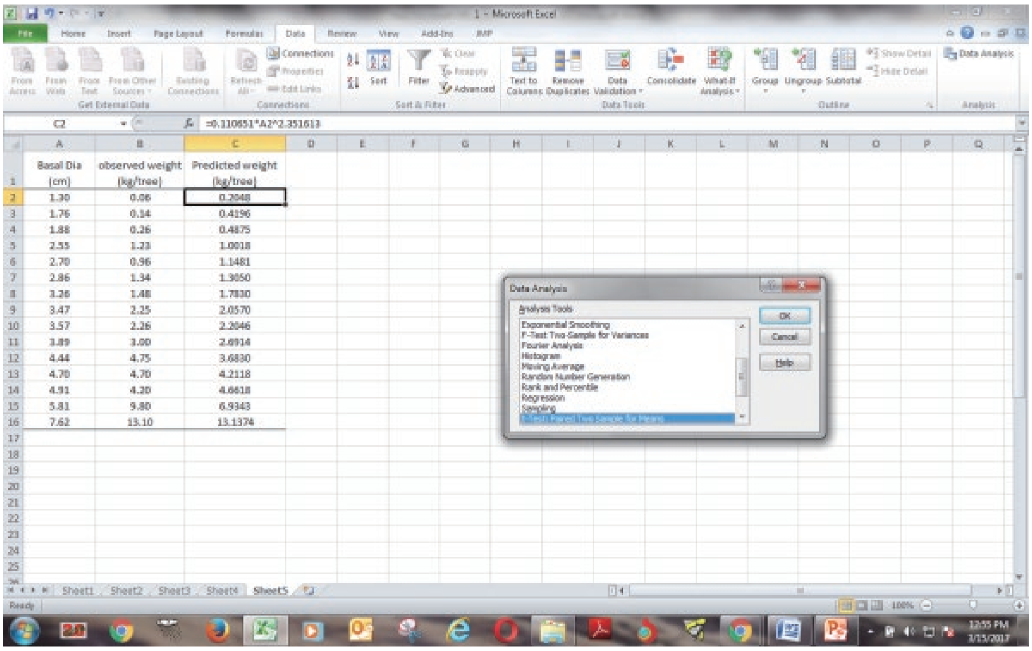
$$Y = 0.11065\ X^{2.351613}$$



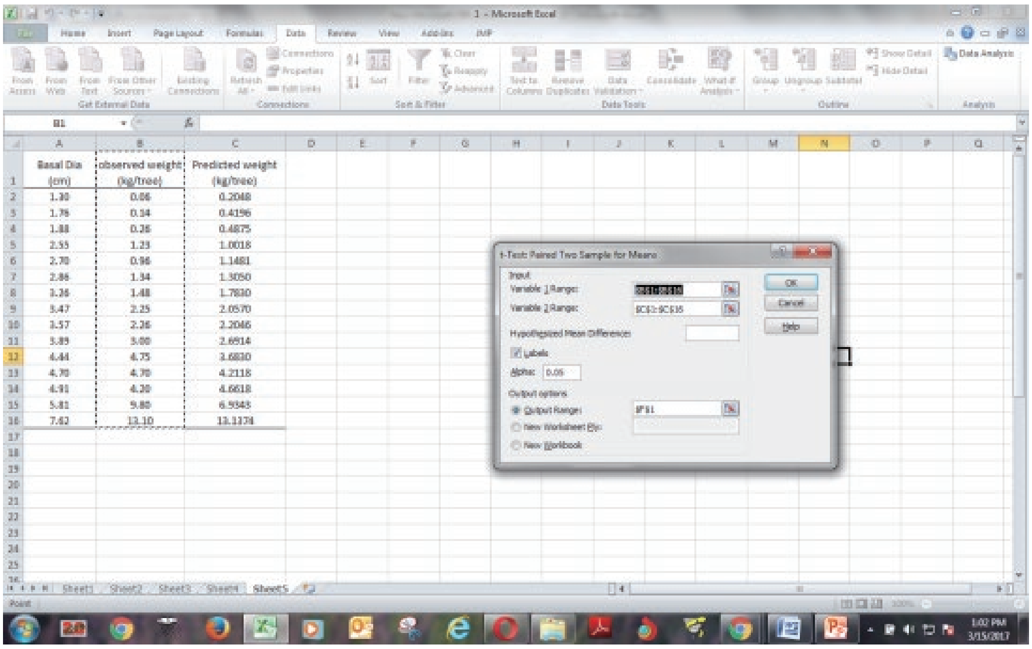
To know whether there is any significant difference between observed and predicted data, a paired t-Test needs to be performed, as the observations are coming from the same dataset.

To perform a paired t-Test, the following steps are followed:

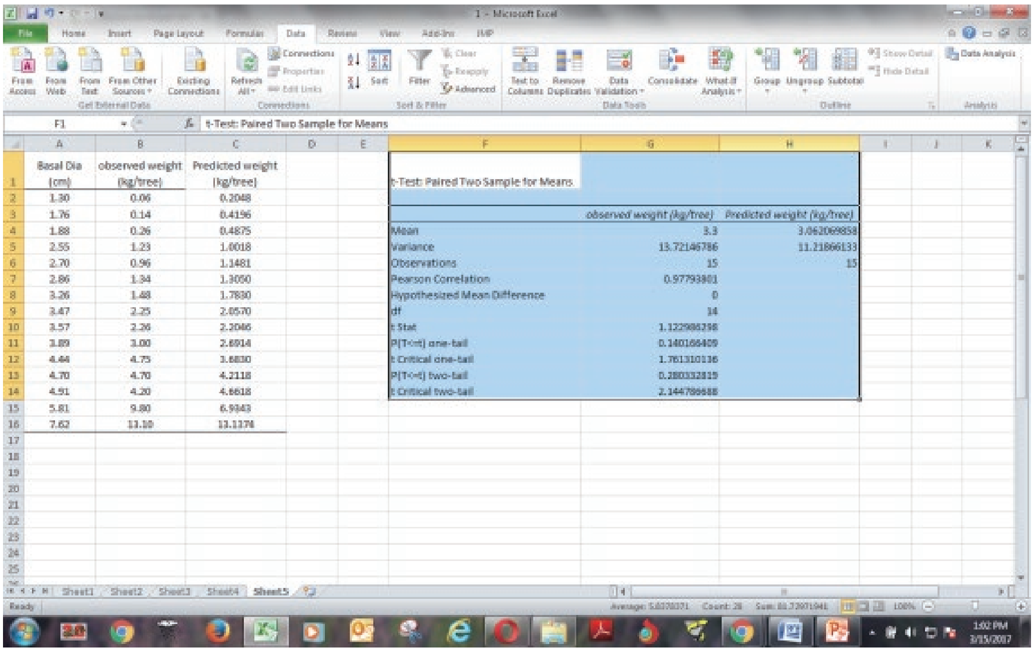
Data > Data Analysis > t-Test: Paired Two Samples for Means



Now input the two variables:



Click on OK and the following output window will appear:



Calculated t-statistic is 1.122 with corresponding p value = 0.280. As the p value is more than 0.05, the test statistic is non-significant, i.e. there is no significant difference between observed and predicted biomass. This can also be visualised through Fig. 2.18 (1:1 graph between observed and predicted biomass) where almost all the points are falling on or near the 1:1 line.

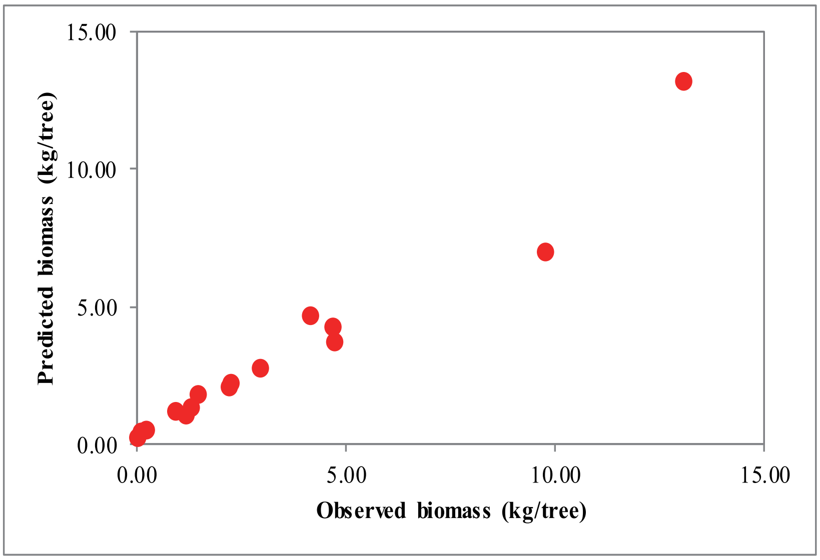


Fig. 2.18: Observed vs. predicted biomass

So it can be concluded that the allometric model fitted for estimating biomass has been validated well and can be used to predict bamboo fresh-weight biomass.

2.9.3 Below-ground biomass

Roots play an important role in the functioning of various ecosystems. Besides uptake and storage of water and nutrients, roots help in stabilising the slopes and imparting resistance against wind, water and gravitational forces. The analysis of root distribution in the field provides a basis for the study of root interactions with the soil and between associated plant species. Excavation of representative sections of a plot is much more labour intensive and is required when coarse roots need to be quantified.

i) Excavation method for coarse root distribution and biomass

Requirement: Spade, shovel, screwdriver, forceps, sharp-pointed needles of different sizes, paintbrushes (Fig. 2.19).

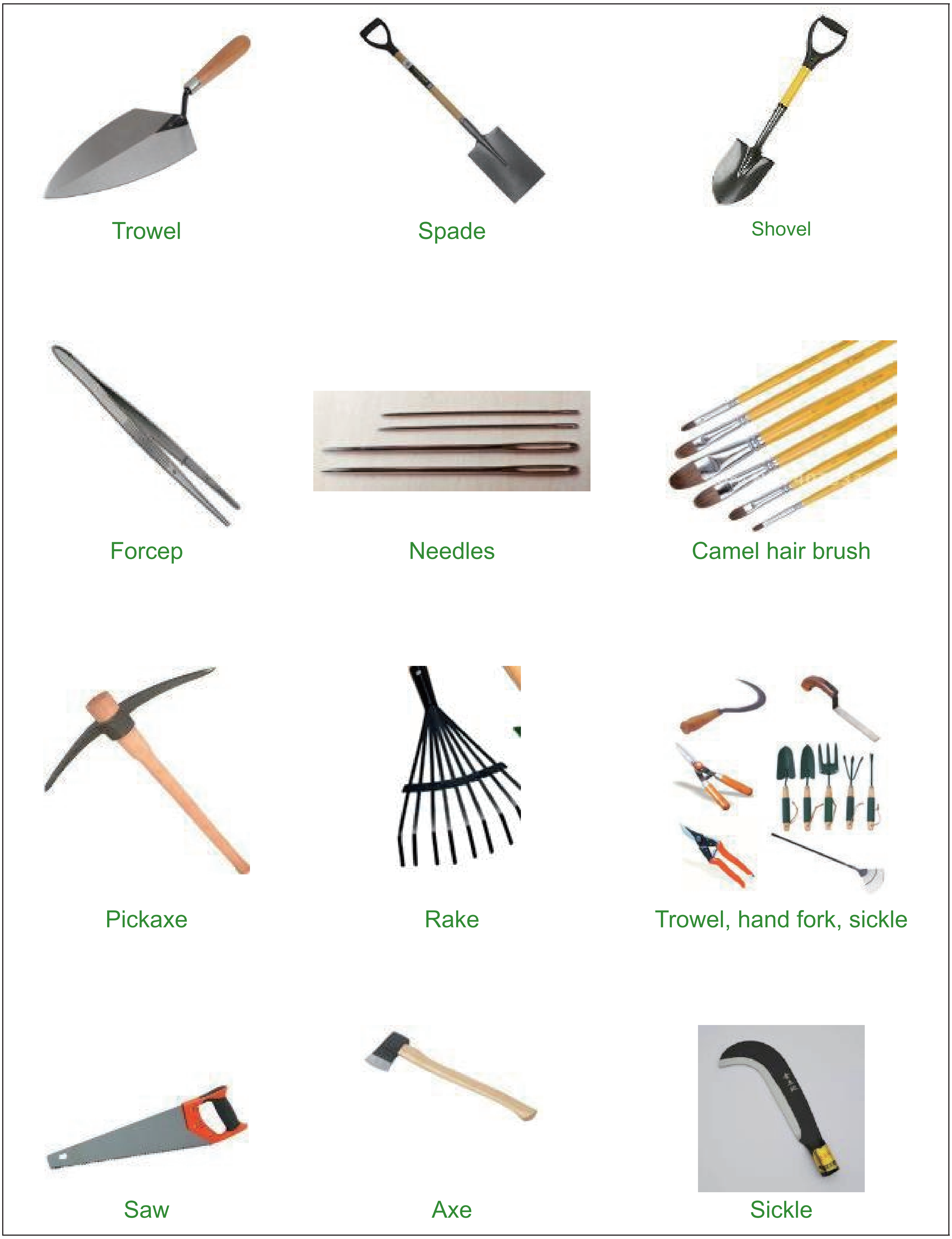


Fig. 2.19: Common tools required for root studies

Procedure

- Mark three uniform healthy clumps randomly surrounded by others of their kind, representing average diameter and height of the plantation. Leave two border rows on both sides.
- Record the diameter, height, crown height and crown spread of each selected clump before harvesting.
- Remove the top portion of the clump by cutting the culms 0.5m above ground level using a saw.
- Secure the remaining portion of the clump firmly with strings to maintain its original position.
- Remove the surface soil very carefully, beginning from the clump so that the full horizontal extent of the root is determined up to the root tip. At this point, dig a trench at least 1m wide with nearly vertical walls
- Start carefully exposing the root system by removing the soil from the plant side of the trench, starting with surface soil and gradually working downwards and into the face of the exposed profile.
- With the help of small tools or water pressure, remove soil particle by particle in a direction parallel to the roots to avoid root destruction.
- As much as possible, rearrange the entire root system into its original position after excavation (Fig. 2.20).
- Keep on measuring and drawing the root system simultaneously with excavation on graph/drawing sheet by reducing the scale.
- Record fresh biomass in rhizomes and coarse roots.
- Take representative samples of each root category and dry them in an oven at 60–70°C for moisture determination.
- Calculate the dry weight of rhizomes and coarse roots.

Fig. 2.20: Root system exposed by excavation method

ii) Profile wall method for coarse root distribution

The profile wall method includes scraping off thin layers of soil from smoothed profile walls to obtain quantitative root data. On plots with plants growing in rows, the trench is generally dug transversally to the rows so that variation in whole profile can be inspected in a better manner. The length, width and depth of the trench depend on the size of the clump. In general, the trench should be dug in a manner so that the rhizome system does not interfere with the trench. On levelled land, trenches should be dug on four sides with the clump as a geometrical centre at a distance of 1–5m (depending on spacing of the plantation) from the clump down to the maximum rooting depth. On sloping land, trenches should be excavated at a distance of 1–5m from the clump in the downslope and upslope direction to the maximum rooting depth. The number of trenches depend on sampling intensity, availability of labour and required degree of accuracy. In any case, at least two trenches should be dug in both directions of the clump. This method is suitable for clumps planted in square or rectangular patterns.

Requirement: Spade, shovel, screwdriver, profile knife, forceps, sharp-pointed needles of different sizes, paintbrushes and an iron frame with a grid arrangement (Fig. 2.21).

Procedure

- Select three average-sized representative clumps from the plantation.
- Mark the position of the profile wall and dig a trench of 1.2m x 0.6m x 1m by hand or trench-digging machine transversally to the bamboo rows in such a manner that the entire bamboo clump is covered. The length of the trench can be increased depending on the spacing and size of the clump.
- With the help of a specially designed blade (profile knife), smooth the trench by removing 1–2cm soil from the soil surface to the bottom of the trench to obtain the final working face of the profile
- Cut the roots which protrude from the working face of the profile wall.
- Make the ditch (10–20cm deep) at the bottom of the trench directly under the end of the working face of the profile for collecting the soil removed from the profile wall during the additional exposure procedure.

Mapping and counting the roots

- After exposing the roots, roots are counted by placing a square grid net against the profile wall. The size of grid depends on the size of the wall and number of exposed roots. In general, for trees, a 10cm x 10cm grid size is mostly used.

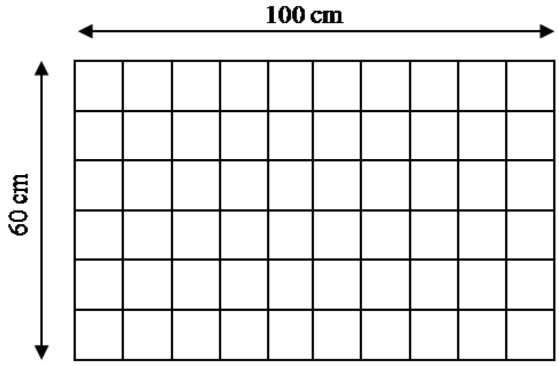


Fig. 2.21: Grid systems for studying roots

- Take the 100cm x 60cm or 50cm x 60cm iron/wooden frame of a complete system of square grids net of 10cm x 10cm size (Fig. 2.21).
- Place the frame against profile wall.
- Map the roots in their natural position on cross-section paper (millimetre paper) with a scale of 1:10 or 1:5 by marking dots where each dot corresponds to one root on a profile wall. Root count can also be done directly rather than by mapping.
- In case roots have different diameters, they can be distinguished according to their thickness, i.e. bigger-sized dots for larger diameter roots.
- Count the number of dots in each grid for quantifying the number of roots.
- If the root distribution is to be expressed only by number, the counting procedure should be used.

iii) Logarithmic spiral trench method for coarse root distribution

This method is suitable for scattered bamboo clumps or clumps which are planted on the boundaries of the farm. This method should not be used for block plantations planted in square/rectangular patterns at close spacing. In this system, a logarithmic spiral trench (Huguet 1973) is made, which enables a large proportion of the root system to be examined with minimal damage to the clumps (Tomlinson et al., 1998). The dimensions of each trench are determined using the following formulae (modification of Tomlinson et al., 1998):

$x = 0.75\,(d)$ (1)

$y = [\ln(r/d)]/(\pi/2)$ (2)

$z = xe^{y\theta}$ (3)

where

d = clump diameter in m

r = the average of the crown radius at four cardinal points in m.

x = the distance of the starting point of the spiral from the clump in m.

y = the natural logarithm of the ratio of crown radius to diameter of clump divided by $\pi/2$

z = the distance of any point on the spiral from the clump base in m.

θ = The starting point for the internal face of each trench (A) is obtained by calculating x from the north-facing point of the clump base. The origin (O), with the spiral bending clockwise in the opposite direction, thus sampling a 135° sector of the root system.

θ is assigned 0°, 22.5° (π /8); 45° (π /4); 67.5° (3 π /8); 90° (π /2); 112.5° (5 π /8) and 135° (3 π /4) to obtain the seven coordinates of the inside trench: OA, OB, OC, OD, OE, OF and OG as shown in Fig. Exterior side of the trench was fixed by stretching the coordinates for the internal side by 60cm to give OA'; OB'; OC'; OD'; OE'; OF' and OG'.

- Mark the contours of both internal and external spirals on the ground using a plastic rope (Fig. 2.22).

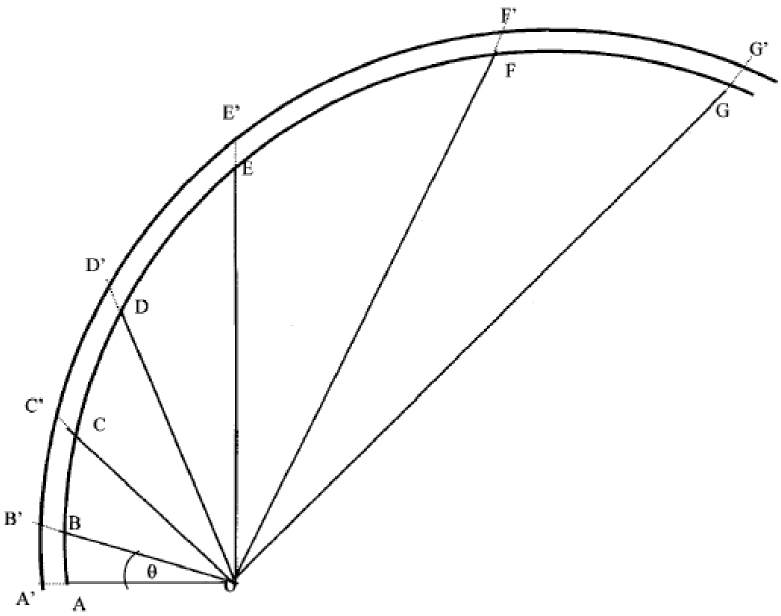


Fig. 2.22: Logarithmic spiral trench for root distribution

- Dig the trench to a depth of 60cm and to a breadth of 60cm, taking care that the sides remained intact (Fig. 2.23).
- Count bamboo roots on the internal and external trench walls by placing a 50cm x 50cm quadrant having 10cm x 10cm mesh size (Fig. 2.23).

Fig. 2.23: Logarithmic spiral trench and grid arrangement for root study

- Classify roots into < 2 and 2–5 mm and > 5 mm diameter classes and convert them to root intensity, i.e. number m^{-2}.

iv) Fine root studies

Roots less than 2mm are regarded as fine roots. They play an important role in water and nutrient adsorption and represent the dynamic portions of below-ground biomass and nutrient pools. Soil coring is the simplest method used to estimate fine root production and mortality. Although the sequential soil core method may lead to some underestimation in fine root production, it is one of the most widely used methods. It is also used for obtaining spatial variation (depth-wise and horizontal) and temporal variations. It also gives biomass production and turnover rate by repeated samplings, but necromass estimation is less accurate, and thus chances of error increases.

Requirement: Core samplers, set of sieves of different sizes and hammer

Procedure

- Take a core sampler (between 6–9cm diameter and 15cm depth) made up of a sharp- edged steel tube auger and locate the sampling point below the clumps.
- Fix the time of sampling. It can be monthly or on a seasonal basis. For better estimates, cores should be taken in the first week of every month.
- Take soil samples with cores from 0–15, 15–30cm soil depths at three distances, equal to 0.5, 1.0 and 1.5 times the mean canopy radius or at any suitable distance (Fig. 2.24).
- Transport the samples to the laboratory immediately.
- Separate the roots from the soil by soaking the soil core in water and gently washing them over sieves with mesh sizes ranging from 5mm—0.5mm.
- Record the roots with diameters of less than 2mm and wash them with clean water to remove any clay particle or detritus adhering to the roots.
- If possible, try to separate live and dead roots on the basis of pliability, degree of cohesion between

cortex[12] and periderm[13], elasticity and colour; live roots usually are light-coloured and elastic, while dead roots usually are dark-coloured and brittle in contrast to the smooth and light-coloured live roots.

- Oven dry the roots at 60°C for 48 hours.
- Classify the fine roots into coarse (> 2mm); large-fine (0.5–2mm) and small-fine (< 0.5mm) categories.
- Sum up the fine roots collected from different depths and express them in g m^{-2}.
- Record observations in Table 2.10.
- Estimate root production as a total amount of root mass for topsoil (0–30cm) by minimum-maximum method. The 'minimum-maximum method' calculates the difference between minimum and maximum of FRB during the measuring period and equates it with production. The rate of fine root production is expressed as g m^{-2} y^{-1}.
- Record observations in Table 2.11.
- Calculate fine root turnover (y^{-1}) rate by dividing annual fine root production with maximum fine root standing biomass.

Fig. 2.24: Taking soil samples with core for estimating fine root biomass

12 Outer layer of tissue immediately below the epidermis of a stem or root.

13 The corky outer layer of a plant stem formed in secondary thickening or as a response to injury or infection.

Table: 2.10: Seasonal variation in FRB (g m^{-2}) at different positions and soil depths

Months	Below canopy		Outside canopy	
	0–15 cm	15–30 cm	0–15 cm	15–30 cm
Jan				
Feb				
March				
April…				

Table: 2.11: Seasonal FRB, mean FRB, annual fine root production and annual turnover rate in 0–30cm soil depth

Species	Seasonal FRB (g m^{-2})		Mean FRB (g m^{-2})	Production (g $m^{-2}yr^{-1}$)	Turnover rate (yr^{-1})
	Maximum	Minimum			
A					
B					
C					
D					
E					

2.10 Carbon sequestration

Global climate change, considered to be one of the most serious threats to the environment, has been at the centre of scientific and political debate in recent years. Vegetation in terrestrial ecosystems has been recognised as an effective and low-cost method of offsetting carbon emissions and mitigating climate change. Bamboo have been recognised as a most effective land use system because of their abilities to lock carbon for the long-term, in addition to other secondary environmental benefits they provide. Carbon sequestration depends upon the biological productivity, which in turn depends upon interaction between species, climate, topography and management practices.

Bamboo sequester and store large amounts of carbon in their above-ground (trunks, branches, leaves) and below-ground (roots) biomass. Measuring the C sequestration in bamboo starts with estimation of biomass in different components (culm, branch, leaf, rhizome roots). Above-ground biomass can be measured destructively for annual crops or grasses or for the understorey. Bamboo biomass can be measured non-destructively using allometric biomass regression equations as discussed in the previous section. Once the biomass is estimated, different components are measured for carbon content using a CHNS analyser or by the ashing method in a muffle furnace.

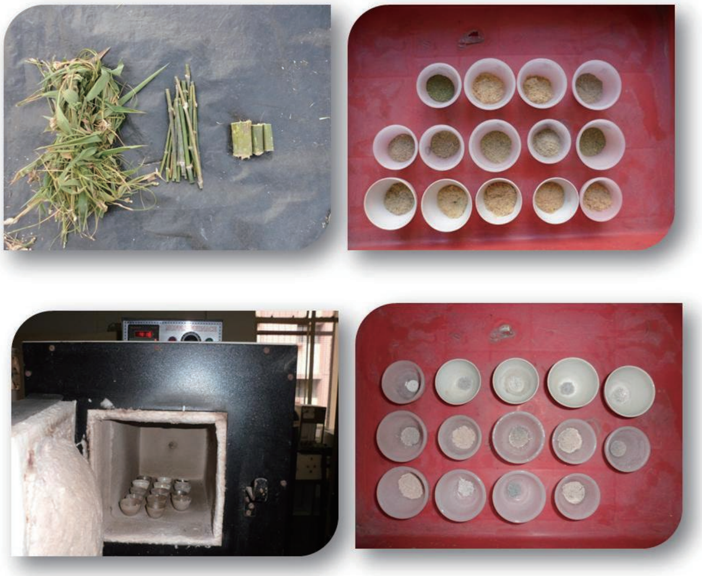


Fig. 2.25: Estimating carbon content by ashing method in muffle furnace

The carbon content of samples in different components is then multiplied with the respective biomass to get the carbon stocks. Alternatively, carbon stocks are estimated by multiplying the carbon content conversion factor (use a default value of 0.46) by the biomass. CO_2 sequestered is calculated by multiplying biomass carbon stock with a default value of 3.67.

2.11 Understorey vegetation

Due to its fast growth, bamboo affects the understorey vegetation significantly in a short period of time. By constantly monitoring the vegetation under bamboo, the changes can be quantified.

2.11.1 Diversity index

The simplest way to quantify the understorey vegetation is by calculating the biodiversity index, which is a particular way of measuring biodiversity. There are different ways and different biodiversity indices that are used by scientists to measure diversity. Some of the indices for calculating biodiversity are discussed in this section.

Requirement: Measuring tape, cord, Vernier caliper, wooden pegs/nails, knife

Number of quadrats

The number of quadrats to be laid depends upon the accuracy with which a survey is to be done. This invariably depends upon the intensity of survey and resources available. However, it should be kept in mind that the more the intensity, the more the accuracy and the more resources will be required and vice-versa. In general, intensity is restricted to 10–15 per cent. However, the optimal number of quadrats can also be determined by laying 30 to 50 quadrats of the requisite size. The species occurring in each quadrat are noted. The data is plotted on graph paper with the number of quadrats on the X-axis and species on the Y-axis.

The point at which the curve flattens gives the minimum number of quadrats required for adequate sampling of the area under consideration. Once the number and size of quadrats is fixed, they are randomly distributed in the forest.

Procedure

- Mark a quadrat of 1m x 1m for measuring grasses/herbs; 5m x 5m for shrubs in the study area.
- Lay out an appropriate number of quadrats in the study area.
- Count no. of species occurring in each quadrat.
- Record the average number of species and individuals in the studied quadrat in Table 2.12.

Table 2.12: Number of species and individuals observed in each quadrat

			Number of species occurring in the quadrat				
Bamboo species	Quadrat No.	Understorey Species	Year 1	Year 2	year 3	Year 4	Year 5
1	1	A					
		B					
		C					
		D					
		E					
	2	A					
		B					
		C					
		D					
		E					
	3						

- Calculate Simpson index using the formula

$$D = \frac{\sum n_i(n_i - 1)}{N(N-1)}$$

where D = Simpson's index (D), n_i = the total number of each individual species and N = the total number of all species

The value of D ranges from 0 to 1. With this index, 0 represents infinite diversity and 1, no diversity. That is, the bigger the value of D, the lower the diversity.

A few examples for calculating different biodiversity indices:

Example: In a *Dendrocalamus strictus* plantation, the following understorey species were recorded at different periods of time. Calculate different diversity measures in the forest.

	Average number of individuals of different species occurring in the quadrat				
Species	**Year1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
A	20	12	10	8	6
B	14	10	8	6	4
C	11	7	4	3	1
D	8	5	2	0	0
E	11	6	4	3	0
Species richness	5	5	5	4	3

Calculation for Simpson index

	Year 1			Year 2		
Species	n_i	$n_i - 1$	$n_i(n_i - 1)$	n_i	$n_i - 1$	$n_i(n_i - 1)$
A	20	19	380	12	11	132
B	14	13	182	10	9	90
C	11	10	110	7	6	42
D	8	7	56	5	4	20
E	11	10	110	6	5	30
Total	N = 64		$\sum n_i(n_i - 1) = 838$	43		$\sum n_i(n_i - 1) = 392$

Simpson index for year 1 =

$$D = \frac{838}{64 \times 63} = 0.207 \text{ (high diversity)}$$

Simpson index for year 2 =

$$D = \frac{392}{43 \times 42} = 0.251 \text{ (low diversity)}$$

Similarly calculate the Simpson index for different years and observe the variations in the diversity.

Calculating Shannon-Wiener index (H)

Shannon index (H) is calculated by the formula= - $\sum P_i \log n P_I$

$$\text{where } P_i = \frac{\text{Number of individuals of one species}}{\text{Total number of all individuals}}$$

Species	No. of individuals	P_I	$\ln(P_I)$	$P_{iI}\ln(P_I)$	$(P_I)^2$
A	20	0.313	-1.163	-0.363	0.098
B	14	0.219	-1.520	-0.332	0.048
C	11	0.172	-1.761	-0.303	0.030
D	8	0.125	-2.079	-0.260	0.016
E	11	0.172	-1.761	-0.303	0.030
	64			-1.561	0.220

Thus, first forest $P_i lnP_I$ from table 10 is – 1.43. Thus, H = -∑ - 1.9 = 1.43.

$$\text{Species richness} = \frac{(S-1)}{\text{Log N}}$$

Where S= total number of species

N = total number of individual of all species

For the first forest, the numbers of species is 8 and individuals are 68. So

$$\text{Species richness} = \frac{(5-1)}{\text{Log } 64} = 2.21$$

$$\text{Evenness index} = \frac{1.561}{\text{Ln } 5} = 0.9699$$

Where H = Shannon-Wiener diversity index

S = total number of species

Thus, for first year H is 1.561 and the number of species is 5, so

$$\text{Eveness index} = \frac{1.561}{\text{Log } 5} = 1.728$$

Index of dominance = $\sum (n_i/N)^2$ or $\sum (P_I)^2$ where n_I = number of individuals of a species

N=Total number of individuals of all species

In this example, the index of dominance is 0.22.

Similarly calculate different indices for different times (Year 2, 3, 4 and 5) and observe the variations in the diversity.

Interpretation: Higher values of Shannon-Wiener diversity index and Margalef species richness index indicate higher species diversity. Evenness index shows that whether there is a same pattern of distribution of species or it varies. The higher the value of evenness, the more uniform distribution of individuals of all species is reflected. In the index of dominance, a higher value reflects that one species is dominating more than other species.

2.11.2 Understorey biomass

The studies on estimating biomass of understorey vegetation should be undertaken during the period when the biomass production is at its peak.

Requirement: Clipping shears to clip understorey vegetation, paper bags, aluminium tags/labels, small herbarium press for species that cannot be identified in the field

Procedure

- Select the core plot from which the study is to be undertaken.
- Divide the core plots into different quadrats, preferably of 5m x 5m size for identification and estimation of cover of understorey plant species.
- Place frame of 0.5m x 0.5m within the subplot in a place where understory vegetation is relatively abundant and where vegetation composition is representative for the whole subplot.
- Cut all above-ground parts of the vegetation passing through this small frame at ground level using a pair of shears/sickle.
- Omit plant parts (of plants rooted inside the frame) which grow outside of the frame. Likewise, plant parts (of plants rooted outside the frame area) which grow into the frame are included.
- Take fresh weight (g/0.25m^2) of the different species observed in the subplot.
- Chop all samples and mix them well before taking subsamples. Weigh about 100g as a subsample and place it in a paper bag for moisture determination in the lab.
- Record all data into Table 2.11.
- Calculate dry weight and express in q/ha.

Table 2.13: Observations to be recorded for studying understorey biomass

Species	Fresh weight (kg)		Sample fresh weight (g)		Sample dry weight (g)		Moisture (%)		Dry weight (kg)	
	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem
Species 1										
Species 2										
Species 3										
Species 4										

2.12 Litterfall and decomposition rate

2.12.1 Litterfall

Litter includes dead plant material, such as leaves, bark, needles and twigs that have fallen to the ground. This detritus or dead organic material and its constituent nutrients are added to the top layer of soil, commonly known as the litter layer or O horizon ('O' for 'organic'). Items larger than 2cm in diameter are referred to as coarse litter, while anything smaller is referred to as fine litter or litter. Litter production is a major process in transferring organic matter and nutrients from above-ground plant parts to the soil. Dry matter and nutrient return to soil through litterfall is the major component of nutrient cycling. The most extreme variability of litterfall is seen as a function of seasonality which can be determined by the collection and classification of plant litterfall throughout the year in litter traps. The main objectives of litterfall sampling and analysis are to quantify litterfall production and chemical composition over time in order to assess the variation in litterfall quantities and hence its role in nutrient cycling. For collecting litterfall, litter traps are installed randomly below the plantations and are monitored for a given period of time.

Requirement: Nylon litter bags, weighing balance, oven

Procedure

- Make litter traps of 0.5m x 0.5m x 0.15m with an iron mesh/nylon net at the bottom (Fig. 2.16).
- Place eight litter traps randomly beneath the canopy of the clump in all the four directions.
- Collect the fallen litter in the trap at 15-day intervals.
- Classify the litter into different components (leaf, sheath, branch or culm) and fractions (coarse and fine).
- Average the values of the litter collected from different litter traps and record them in Table 2.12.
- Express the values in kg m^{-2} yr^{-1} by using the formula:
  Litterfall (kg m^{-2} $month^{-1}$) = total litter mass for given month (kg)/litterbag area (m^2)

Fig. 2.26: Litter trap for collecting litterfall

Table 2.14: Observations to be recorded for monitoring litterfall

Period of collection:................ Date of collection:...........................

Species	Trap No.	Litterfall (g)	Litterfall (kg m^{-2} $month^{-1}$)
A	1		
	2		
	3		
	4.....		
Average			
B	1....		

2.12.2 Litter decomposition

Litter decomposition is defined as the process through which dead organic material is broken down into particles of progressively smaller size, until the structure can no longer be recognised and organic molecules are mineralised to their prime constituents: H_2O, CO_2 and mineral components. Leaf litter decomposition is a fundamental process of ecosystem functioning which is closely linked to the nutrient supply for plant growth. The rate of decomposing litter is, however, largely governed by climatic factors and structural composition. The extent to which litter influences soil fertility and plant growth is determined mainly by its biochemical quality, decomposition rate, time of nutrient release and crop nutrient demand. The mineralisation of essential elements and process of formation of soil organic matter is determined to a large extent based on the rate of movement of essential nutrients through decomposition and thus acts as an important regulator of primary production.

Procedure

- Take litter bags of 15cm x 15cm size made up of nylon mesh of 1–2mm mesh size.
- Fill each bag with 20g of dried leaves.

Fig. 2.27: Litter bag for decomposition study and its placement in field

- Clean an area slightly larger than the litter bag for its placement and cover the litter bags with leaves which were displaced from that area.
- Place the litter bags randomly to determine the decomposition rate.
- Take out four litter bags at monthly intervals.
- Wash the litter bags with running water with a fine jet in the laboratory for removing adhering soil particles/other extraneous matter.

Fig. 2.28: Washing and preparation of litter samples for oven drying

- Dry the litter in the oven at 70°C to determine dry weight.
- Record observations in Table 2.13.

Table 2.15: Observations to be recorded for monitoring litter decomposition

Species	Month	Original weight (g)	Weight remaining (g)
A	Jan		
	Feb		
	March		
	April …		

Analysis of decay

The following decay analysis can be done from litter studies:

- Calculate the mean relative decomposition rate (MRD) by using the formula:
- MRD (mg g^{-1} day^{-1})= ln (W_1-W_0)/(t_1 – t_0); where W_0 is the weight of litter at time t_0; W_1 the weight of litter at time t_1, and t_1 - t_0 is the sampling interval (days).

Litter decays exponentially with time:

$$\frac{X}{X_0} = e^{-kt}$$

Where X is the weight remaining at time t; X_0 is the original mass; e is the base of the natural logarithm; k is the decay rate coefficient, and t is time.

Estimating half-life of decomposing samples:

The time required for 50 per cent and 95 per cent weight loss can be calculated as

$t_{50} = 0.693/k$, and $t_{95} = 3/k$, respectively

Where *t* is time and *k* is the decay rate coefficient

Nutrient changes during decomposition:

- Analyse the samples from litter bags from each collection date for their nutrient content (NPK) as per the standard procedures.

Nutrient retention:

The total release of nutrients from the leaf litter is estimated by the following formula:

$$\text{Percent absolute nutrient remaining} = \frac{C}{C_0} \times \frac{DM}{DM_0} \times 100$$

Where,

C_O = Original concentration of elements in leaf litter

C = Concentration after a given period

DM_O = Original mass of dry matter

DM = Mass of dry matter after a given period

2.13 Conclusion

Growth involves an irreversible increase in size which is usually, but not necessarily, accompanied by an increase in dry weight. Due to their fast growth and rapid maturation from shoot to culm, bamboo differ from timber species. The harvest time for bamboo is about three to five years as compared to 10–50 years for most timber species. Bamboo also possess high potential for biomass production and carbon sequestration and are therefore getting attention globally. Monitoring growth and biomass in bamboo plantations can help us in resolving many questions concerned with bamboo. Besides, it will also be useful in making decisions regarding choices of species and optimum times of harvest, which ultimately can be helpful for stakeholders involved in growing bamboo.

CHAPTER III

HYDROLOGICAL AND SEDIMENT (H & S) MONITORING OF BAMBOO-PLANTED MICRO-WATERSHEDS

Soil and water are the basic resources of any country which must be carefully conserved and judiciously utilised to sustain the ever-increasing human and animal population. To meet the demand for food, fibre, fuel wood and fodder, forest areas have been indiscriminately cleared, which causes enormous soil loss and results in degraded lands. The degraded lands are in fact ‘wasted lands’, although they have potential for growing fodder, fuel, fibre, fruit and minor forest products. Providing good vegetative cover to a degraded site is the final answer for its rehabilitation. However, at a highly degraded site, establishment of vegetation is a difficult task due to excessive runoff/debris movement, deficient moisture and absence of fertile soils. Engineering (also called mechanical or structural) measures are, therefore, often needed as a prerequisite to re-vegetation programmes in order to stabilise the slopes and create conditions conducive to plant growth by trapping fine soil and improve moisture status.

For rehabilitating the degraded lands, a number of bio-engineering based programmes are being conducted across the world by the government and non-governmental agencies. Out of numerous plant species employed as a measure for conserving natural resources, bamboo has emerged as one of the most suitable species for a bio-engineering approach for restoring the degraded lands. Data needed for hydrologic and sediment monitoring are rainfall, runoff and sediment yield. Hydrologic and sediment (H & S) responses prior to treatment, during treatment and post-treatment are necessary to monitor and evaluate the effectiveness of the measures or treatments. Data on runoff, soil loss and moisture status in bamboo plantations may be generated by establishing H & S monitoring setups in different climatic, topographic and edaphic conditions, and such information could be used in similar situations in un-gauged plantation sites. An indicative layout of the monitoring system is presented in Fig. 3.1.

In this chapter, basic principles are described including gauging devices, laying and shaping of experimental runoff plots, design and installation of gauging devices, observation, data collection and tabulation and maintenance of the monitoring system. Prerequisite information for installation of a H & S monitoring system:

i) Rainfall: magnitude daily/event wise, rainy days, intensity

ii) Land slope: degree & slope length

iii) Soil type: texture, soil depth (profile)

iv) Vegetation: crops/grasses/trees/bare land

v) Scale of monitoring: runoff plots/watershed

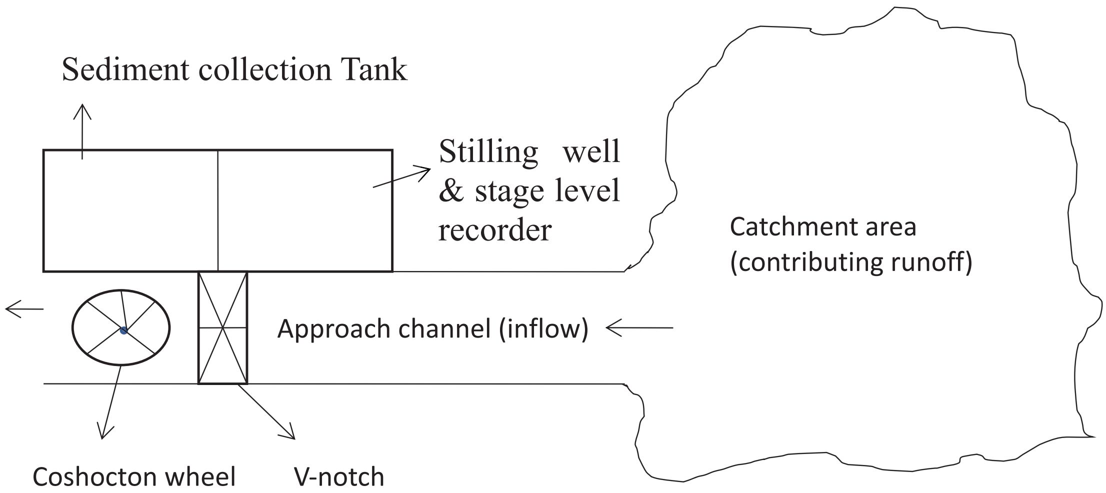


Fig. 3.1: Plan of H & S monitoring system

3.1 Basic principles of H & S monitoring

1. There should be a single exit (outlet) for outflow from the project/plot area
2. Surface flow/runoff should not flow into the project area from outside or flow out from the project area (except at the outlet).
3. The experimental plot should be well bunded all around the boundary of the plot with adequate height so that runoff should not overflow from the plot or inflow from outside.
4. A one-day maximum rainfall for 5—10 years' recurrence period is required for design and selection of devices.
5. The sediment monitoring stations are to be established at least two years prior to treatment and the hydrologic parameters monitored if the same plot is used for comparison of hydrologic response with treated and control situations.

3.2 Measurement of rainfall and evaporation

3.2.1 Rainfall

Measurement of rainfall is a process of sampling wherein the rainfall measuring devices are located at pre-determined points in the watershed and then the average value is determined for the area. A rain gauge is a device used for the measurement of rainfall. Rain is measured in millimetres (mm), centimetres (cm) or inches. Two types of rain gauges are employed for the measurement of rainfall, non-recording or standard rain gauges and recording types of rain gauge.

Non-recording rain gauge: it gives the total amount of rainfall between two consecutive time intervals in mm or cm. In India, observations are recorded at 08.30 hours local time and the rainfall so recorded is for the preceding 24-hour period, i.e. the rainfall of the date is the rain received from 08.30 hours of the previous date to 08.30 hours to date. A Symon's non-recording rain gauge is most commonly used in most countries and is shown in Fig. 3.2. The standard procedures regarding installation, operation and maintenance may be followed as set by the meteorological department of the respective country or World Meteorological Organisation (WMO).

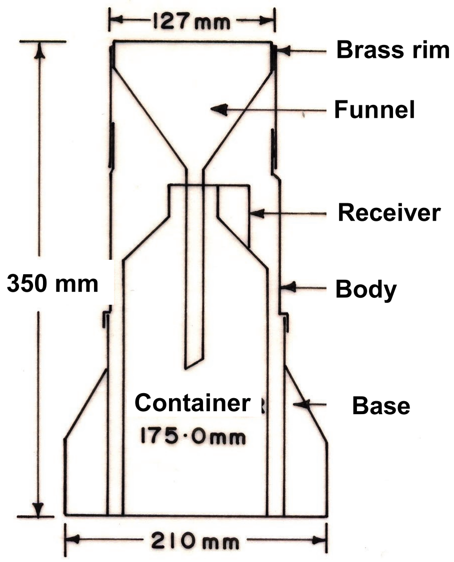


Fig. 3.2: Symon's non-recording rain gauge

Recording rain gauge

A recording rain gauge measures both the amount and the intensity of rainfall for a given event. There are three types of recording rain gauges which are commonly used in different places:

(a) float or syphon type,

(b) tipping bucket type and

(c) weighing type.

The time element is common in all three types and consists of a clock-driven drum carrying the chart. The difference among the three is the depth-recording mechanism. In India, syphon-type self-recording rain gauges are most widely used. The major advantage of this type of rain gauge is to generate rainfall intensity for the desired time intervals, which is required for analysing the soil erosion and hydrological responses of bamboo under different intensity classes.

3.2.2 Evaporation

Evaporation is the process by which water in the form of water vapour enters the atmosphere from open water surfaces or soil. Evaporation is measured by using an instrument called an evaporimeter (Class A Pan, Standard, Fig. 3.3) and the common unit is the millimetre (mm), centimetre (cm) or inch, similar to rainfall.

- An evaporimeter is circular in shape and is made of 22-gauge galvanised iron painted with white, with a 10.7cm diameter and a 25cm depth.

- It is mounted on a white-painted wood open frame which is 15cm above the ground level.
- It is filled with clean water up to 5cm below the rim of the pan.
- The water level is not allowed to drop more than 7.5cm below the rim.
- The water in the pan is changed regularly, at least once a week, to eliminate turbidity.
- Water added each day at a standard time is recorded. Normally, a measured volume of water is poured in a pan till the water level touches the tip of the pointer fitted in the stilling well. Thereafter, this volume is suitably converted into depth. Often, the pan is covered with wire mesh to prevent loss of water from the pan by the birds.

Fig. 3.3: Class A Pan, Standard Evaporimeter

3.3 Runoff and soil loss monitoring

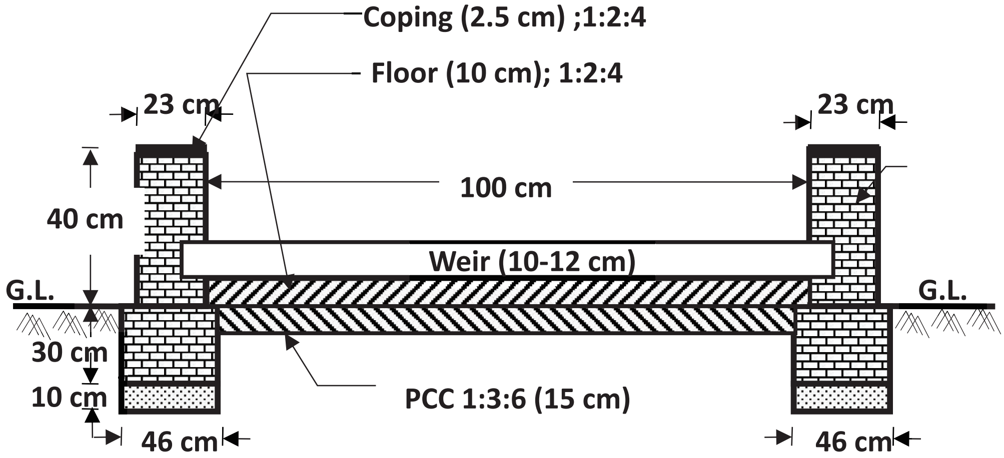
Surface runoff (also known as overland flow) is the flow of water that occurs when excess storm water, melt water or other sources flow over the Earth's surface. This might occur because soil is saturated to full capacity, because rain arrives more quickly than soil can absorb it or because impervious areas (roofs and pavements) send their runoff to surrounding soil that cannot absorb all of it. Surface runoff is a major component of the water cycle. It is the primary agent in soil erosion by water. The devices used for measuring runoff and soil loss are discussed below.

I) Ramser sampler

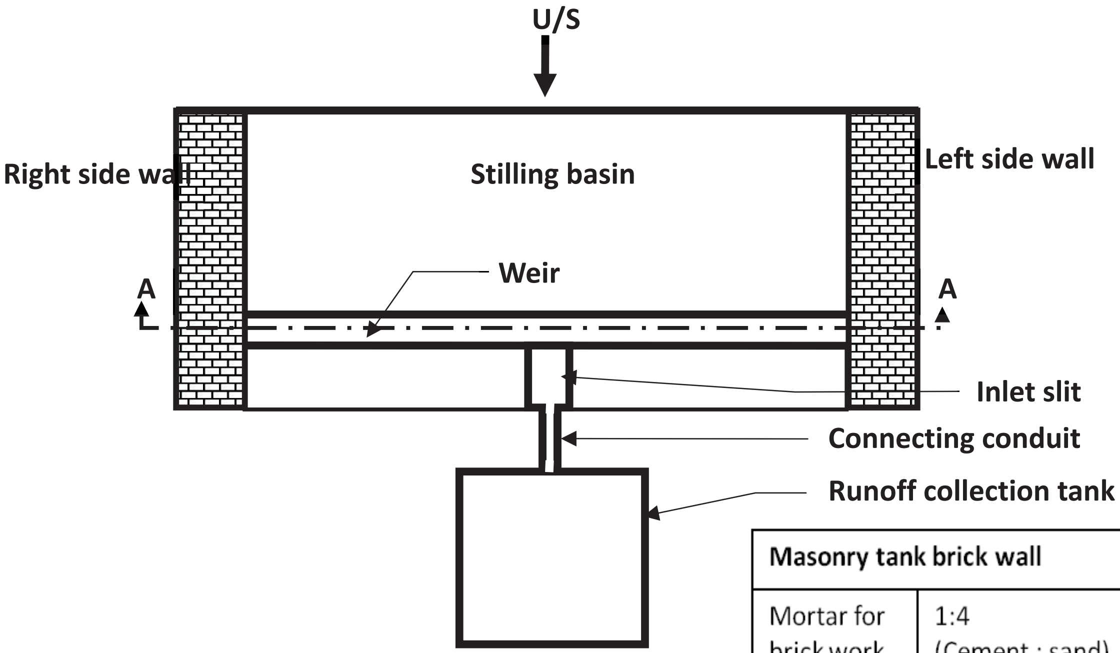
A Ramser sampler is a runoff gauging device normally used for small runoff plots having a size of less than 150sqm. It is suitable for gently sloping agricultural or pasture lands in arid and semi-arid climatic conditions. In medium to high intensity rain events, error level of the sampler gets higher due to sudden upsurge of runoff water on the weir and hydraulic jump, hindering the smooth flow into the sampler inlet-slit.

1. The sampler consists of a stilling basin, weir, inlet-slit, runoff collection tank, connecting pipe between inlet-slit and collection tank, tank cover.
2. Generally, one fortieth part of the total runoff, i.e. 2.5 per cent, is designed for collection and 97.5 per cent of the runoff allowed to drain away.
3. In the middle of the lower end of the plot, a stilling basin with a paved floor (100cm x 100cm) is constructed with left and right side walls of 40cm high and the lower end with the weir gently sloping outward.
4. A weir (SS sheet, 16–18 gauge) with dimensions: length, 120cm, and height, 10–12cm, is fixed on the paved surface.
5. The bevelled face of the weir is kept outward of the flow.
6. An inlet slit made up of SS sheet/GI sheet, 16–18-gauge with a slit opening 2.5cm and its height 20cm above the weir fitted just behind the weir.
7. An inlet slit is connected with a GI conduit or HDPE pipe (7.5cm–10cm diameter) to let the runoff into the collection tank.
8. The size of tank should not be less than the maximum runoff volume produced by the designed recurrence period of one-day maximum rainfall.
9. A masonry tank may be constructed on the downside of the weir or a ready-made plastic tank may also be used for the storing purpose.

A schematic diagram of the monitoring plan is illustrated in Fig. 3.4. and Fig. 3.5, showing a Ramser sampler setup in the research farm of Regional Research Centre (Chandigarh) of ICAR – IISWC, India. The major advantage of the sampler is that it is cheaper in fabrication and easy to establishing a monitoring setup for small plots.

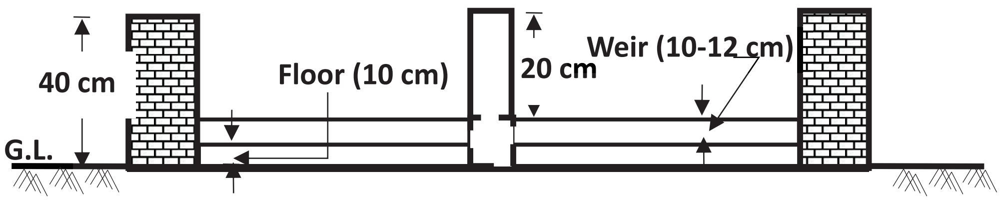


Elevation view of section AA



Masonry tank brick wall	
Mortar for brick work	1:4 (Cement : sand)
Mortar for Plaster	1:3 (Cement : sand)
Wall Thickness	23 cm

Plan of Ramser sampler



Front elevation view for downstream side

Fig. 3.4: Plan and elevation of Ramser sampler

Fig. 3.5: Weir section (front view) of sampler (L) and collection tank (back view) of the sampler

ii) Multi-slot divisor (MSD)

An MSD is one of the most popular devices used for monitoring the runoff and sediment from small plots or small watersheds. Runoff and sediment produced per day (24 hours) is computed with respect to occurrence of daily rainfall (24 hours). Event-wise estimation is not feasible using this device. Procedural steps in this device are:

1. Runoff is routed from a stilling basin of the runoff plot to a stilling tank where the heavier sediment particles are deposited.
2. Overflow from the stilling tank is then routed through the multi-slot divisor where a sample is obtained from a single slot and routed to a sample storage tank.
3. A second storage tank may be connected to the first, followed with or without divisors if runoff water is in excess in the first tank.
4. The divisor consists of a number of slots of equal dimensions fitted at the end of a rectangular-shaped divisor box which functions as an approach to the slots.
5. The device is based on the principle that a uniform horizontal velocity of approach is maintained in the divisor box through the entire head variations to obtain equal division of flow.

Any variation in the velocity distribution is likely to result in unequal division of flow, which in turn will introduce varying degree of error in measurement. The flow is assumed to be divided into equal parts when it passes through the slots. The water passing out from the central slot is led into a collection tank for measurement and water from rest of the slots is allowed to drain away. The essential parts of the MSD are presented in Fig. 3.6.

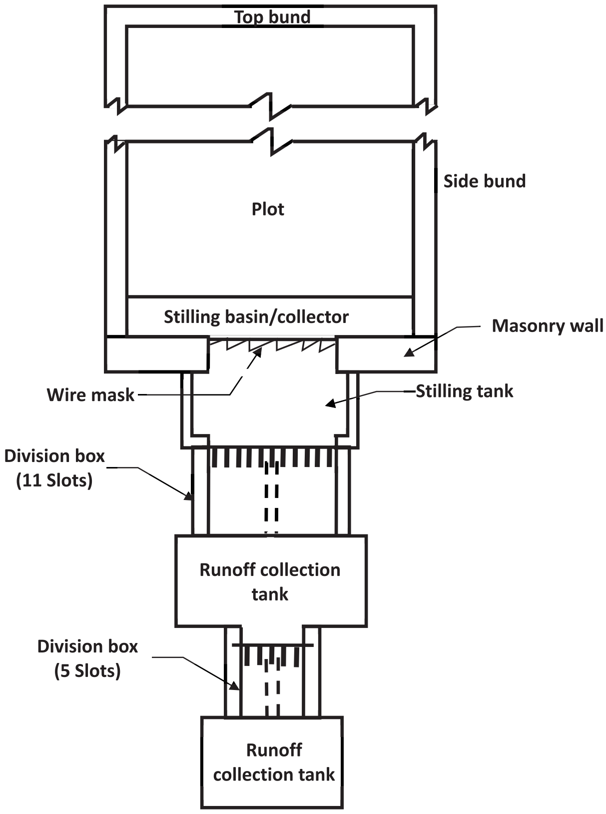


Fig. 3.6: Plan of multi-slot divisor runoff monitoring system

Stilling basin: To catch and concentrate the flow from the plot and divert the flow towards the stilling tank of the MSD, it is made like a rectangular trench on the lower end of the plot. Various types of stilling basins, differing in design and construction material, have been used. For smaller plots, brick masonry dikes or low walls converging towards the stilling tank are used to lead the flow directly into the stilling tank. In case of larger-width plots, a suitably designed gutter draining towards the stilling tank or directly into the divisor box may be used with advantage.

Stilling tank: To further still the turbulence of the incoming water from the basin, the stilling tank is placed just before the divisor in order to maintain a smooth sheet of water with uniform velocity distribution entering into the divisor box. The size of the tank depends upon the maximum soil loss expected from the design rainfall. In case of 1/100th-acre plots constructed at the ICAR – IISWC, Dehradun, stilling tanks two feet deep, two and a half feet wide and four feet long have been used with satisfactory results. The stilling tank can also be made by using 16–20-gauge plain galvanised iron sheet. For easy cleaning of the tank, removable screens (wire mesh) are sometimes placed across the tank instead of fixed baffle walls. The sediment deposited in the tank is also added to the observed soil loss in the collection tank.

Multi-slot divisor: It is made on the end of the stilling tank in a form of rectangular slots vertically over the base plate. The slots are in odd numbers so that the central slot is connected with the conduit leading to the runoff collection tank. Slots are housed in the divisor box which consists of a hood and spout and is connected to runoff collection tank.

- The divisor box which is made of sheet metal (20–24-gauge) and a plain galvanised iron sheet, covered with a lid.
- The functional part of the divisor is a slot plate which contains several openings or slots of identical size and shape.
- A precision strip consisting of a machined metal strip is attached to the upstream side of the slot plate, forming the bottom of the slots.
- The precision strip should be exactly horizontal with a flat smooth, crest to ensure smooth and uniform flow even under trickle-flow conditions.
- The flow from the central slot is conducted through a sheet metal conduit attached to the downstream side of the slot plate and is called the spout.

A metal cover, called the hood, is provided around the periphery of the slot plate on the downstream side. Detailed specifications of the multi-slot divisor are given in Fig. 3.7. For fabrication of the slot plate and precision strip, 16-gauge stainless steel is ideal for accurate results. The divisor box, spout and hood are made of 20–24 gauge plain galvanised iron sheet.

Design criteria

The multi-slot divisor is designed by considering the following criteria:

- Maximum runoff volume expected in 24 hours based on one-day maximum rainfall considering 10–25 year frequency (return period).
- Peak rate for runoff expected from the plot for the design frequency.
- Maximum soil loss expected from the heaviest storm.

Analysis of Rainfall: runoff analysis done at runoff experimental plots reveals that 60–70 per cent of the rainfall may appear as runoff depending upon the soil-cover conditions. To design the size of the stilling tank, the maximum sediment load expected from the heaviest storm for 24 hours is estimated. Such estimates vary considerably depending upon the cover, soil and climatic conditions. The estimate of soil loss can be suitably adjusted for individual situations. Once the number of slots has been fixed, the size of the slots based on the expected peak flow is determined. It has been observed in practice that with larger divisors having low flow depths the percentage accuracy is likely to be reduced considerably. It is therefore advisable to select a divisor which has a capacity just equal to the expected rate of runoff.

If the divisor ratio and the amount of runoff expected from the plot are known, the size of the collecting tank can be worked out. The accuracy of runoff measurement depends entirely upon the standard of accuracy achieved in fabrication of the multi-slot divisor and its installation. With careful fabrication and installation, the error can be kept within one per cent. The following points are taken into consideration while designing the MSD.

- Similarity of slots in size, shape and position.
- Approach channel cross-sectional dimensions.
- Approach channel smoothness.

- Horizontal set up of multi-slot divisor.

Number of slots: For deciding the number of slots, the following formula is used.

$$N = F \times \frac{3630 \times A \times P}{C}$$

Where; N, number of slots; R, maximum expected runoff percentage in decimal fraction; A, area in acres; C, volume of the storage tank in cubic feet; P, rainfall in inches. If the number of the slot works out to be more than 15, it is desirable to use two divisors in a series to obtain the required divisor ratio.

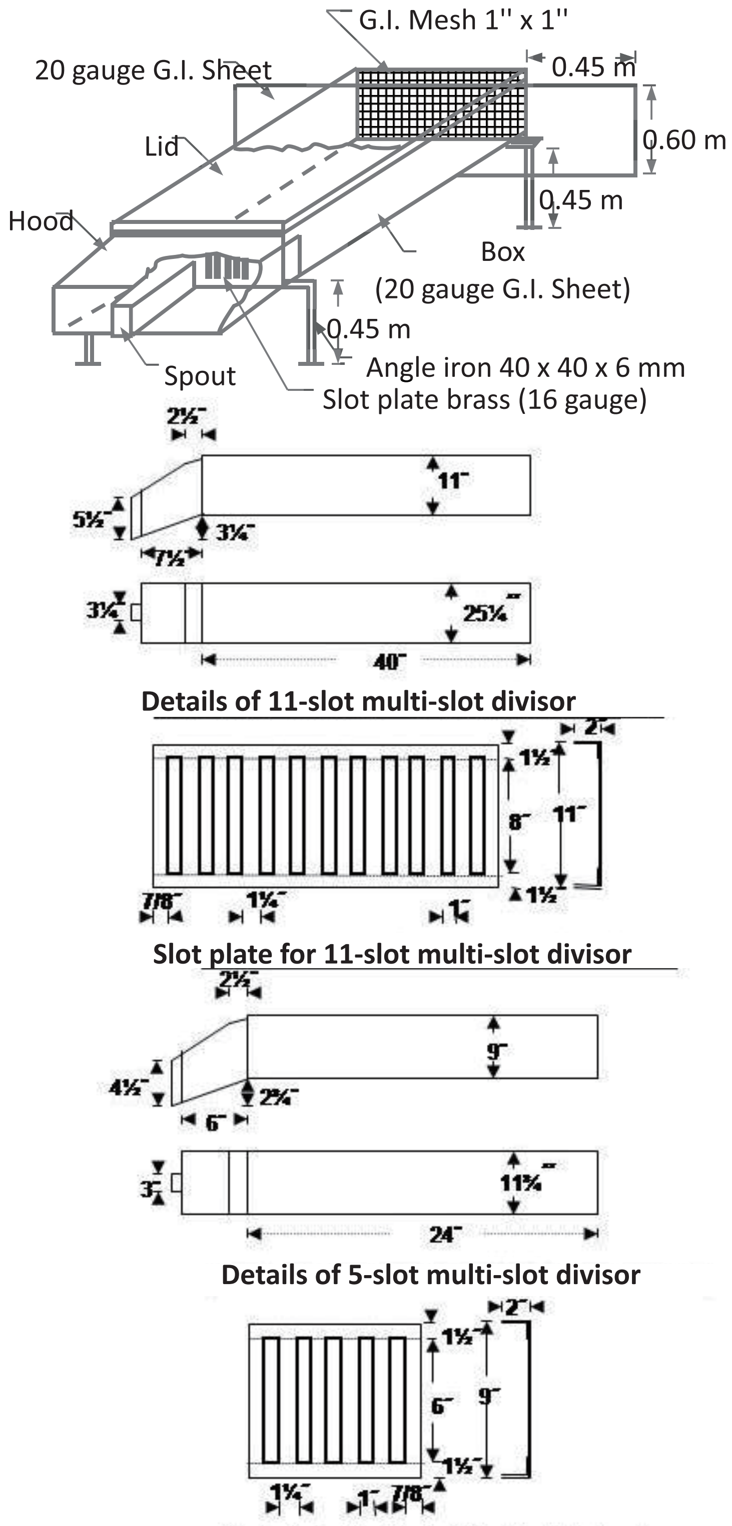
Runoff collection tank: A brick/stone masonry tank of capacity one cubic metre or more is constructed considering maximum one-day volume runoff water without overflow. In case of higher expected volume of runoff water, two or three tanks are preferred rather than one single large tank, as shown in Fig. 3.7 and data may be collected as per Table 3.1.

Installation of MSD: While installing the boundaries, correct orientation of the plot should be ensured. The multi-slot divisor should be installed on a level to ensure even flow in the divisor box and over the precision plate. The divisor box is generally installed on a masonry base. It is sometimes mounted on an angle iron frame which is secured on both sides by two foundation bolts fixed in masonry. This helps in adjustment of the level of the divisor. The box is also bolted to the edge of the stilling tank in the same permanent manner and positioned so that the floor of the box is levelled with the bottom of the inlet.

Proper drainage of the site is essential for removal of the water which is normally accomplished by providing masonry drains of sufficient capacity. The detail of such drainage system depends on the topographic conditions at the site and therefore no generalised specification can be laid out. Before operation, the MSD setup should be tested following procedures.

- The divisor box and connecting spout are leakproof and the precision plate is absolutely level. This is done by adding water in the stilling tank till the water level in the divisor box is just below the level of the precision plate crest. There should not be any leakage between the joints of the precision plate and the divisor box. Add more water till the water just begins to flow over the precision plate. The water should start flowing simultaneously through all the slots. If the water begins to flow only through either of the adjacent slots, it indicates that the precision plate is not level. Then the precision plate is made level by adjusting the levelling screws on both ends of the divisor base. Sometimes, it will be observed that the water begins to flow only through some of the slots not adjacent to each other. Minor unevenness can be corrected by carefully filling the crest of the precision plate.
- While the water is flowing through the central slot, it should be ensured that no water flows along the outside edges of the connecting spout.

MULTI-SLOT DIVISOR



Slot plate for 5-slot multi-slot divisor

Fig. 3.7: Design and specifications of multi-slot divisor

Table 3.1: Observation and data recording from MSD monitoring devices

Date	Rainfall (mm)	Runoff volume in collection tank (cum)	Convert runoff volume into depth (mm)	Soil loss	
				gram/litre (Sample)	t/ha (runoff plot)
Total					

iii) H-type flume

An H-type flume is set up to measure runoff from relatively large catchment area as compared to the Ramser sampler and multi-slot divisor devices. The flumes were developed and calibrated in the hydraulic laboratory by the Soil Conservation Service, United States Department of Agriculture, for measurement of runoff from watershed (Harrold and Krimgold, 1943). The major criterion of the flumes is to design for free-flow conditions. The error level in submerged condition has been observed to be very high, so it is recommended to install it only under free-flow conditions. In case of excessive amounts of coarse bed load, it is not recommended. A brief about the H-flume is described in this section as an option for hydrological and sediment monitoring. Advantages of flumes over other runoff measuring devices/setups are:

- The shape like triangular weirs facilitates accurate measurement of both low and high flows.
- The converging section of the flume makes it self-cleaning because of increased velocity and consequently the flume is suitable for measuring flows with sediments in suspension.
- It is simple in construction, rigid and stable in operation and requires the least amount of maintenance without affecting its rating.

There are three types of flumes, HS, H and HL, which have different specifications to suit varying ranges of flows without affecting the advantages listed above. HS flumes, with depths of 12.2, 18.3, 24.4 and 30.48cm, are available with calibrated rating curves and flow ranges from 0.065 to 0.82 cusecs. H flumes are more common and are designed for carrying the flow from 0.3 to 84 cusecs and depth ranges from 15.24 to 137.2cm, while HL flumes are designed to measure the flow from 20–117 cusecs and depth ranges from 60.96 to 121.92 cm.

The various dimensions of these flumes are proportionate to the size of the flume which is designated by the maximum depth of the water that can pass through it. In order to ensure reliable measurement, it is absolutely essential that the flume is constructed strictly in accordance with the specified dimensions. Mild steel sheets without any form of distortion (0.31cm thick) have been used in fabricating the flumes.

Installation and operation

The essential components of an H-flume are an approach channel, flume, intake, stilling well and stage level recorder (Fig. 3.8). An H-flume is generally equipped with a Coshocton- type sediment sampler with a sediment collection tank down to the H-flume. The length of the approach channel is normally kept > 4 times of depth of flume and the channel cross- section is so designed to accommodate the expected peak flow without turbulence. It is leakproof cemented channel.

- Flumes are fabricated with angle iron frames to facilitate their removal and reuse at other sites. These are fitted at the lower end of the channel.
- It is preferable to install the flumes on a concrete base for simplicity and convenience of installation.
- The vertical sides of the flumes converge and are cut back on a slope from the outlet to give a trapezoidal throat opening which increases with the depth of the flume.
- The intake consists of holes in one of the vertical sides of the flume located at a specified distance from the upstream edge of the flume.
- The lowest hole is flush with the bottom of the flume. The size and number of the holes depend upon the size of the well.
- A triangular-shaped opening (2.54cm x 2.54cm) at the bottom and 1.27cm diameter holes spaced 5.08cm apart with 61cm × 61cm wells have been satisfactorily used at ICAR – IISWC, Dehradun.
- Brick masonry stilling wells, 61cm × 61cm in size, have been used with a connecting channel, up to 76cm flumes. For a 91cm flume, a 91cm diameter stilling well has been constructed to facilitate construction and cleaning.
- The depth of the well should be about nine inches more than twice the size of the flume to avoid submergence of the counterweight.
- The bottom of the well should be 15–23cm below the floor of the flume to provide a sufficient depth of water to lift the float and also to provide space for depositing the sediment in suspension. Leakage of the wells is often experienced; this must be checked and rectified.

Fig. 3.8: H-flume installed at research farm of ICAR - IISWC, Dehradun (India)

3.4 Infiltration study

Infiltration is the process by which water on the ground surface enters the soil. Infiltration rate in soil science is a measure of the rate at which soil is able to absorb rainfall or irrigation. It is measured in inches per hour or millimetres per hour. Infiltration can be measured by the following method:

Cylinder Infiltrometer

For better accuracy, a double ring concentric cylinders infiltrometer is used for calculation of infiltration rate of the soils. The outer annual space with the same height of water as the inner space provides a buffer zone. Several infiltrometers of the same size are used in a field to replicate the measurement

Although different sizes of infiltrometers are in use, a 300mm diameter with 450mm depth is most commonly used. In case of a double ring infiltrometer, the outer diameter is 600mm to provide a buffer strip. Out of 450mm length, 150mm is generally driven into the soil. Rolling steel of 2–5mm thickness of each cylinder is used for fabrication of infiltrometer. The lower edge should be properly sharpened so that it can be driven into the soil with minimum of disturbance. A steel plate is placed over the top of the cylinder and a hammer is used to drive the infiltrometer uniformly into the soil. A hook gauge is fitted with an inner cylinder to measure the infiltration rate. Initially, water is added to a depth of about 200mm inside the cylinder. Fig. 3.9 shows the dimensional sketch of a double ring infiltrometer used to measure infiltration. As the infiltration rate is very high initially, measurements should be made at quick intervals initially and gradually the interval can be increased. The readings are tabulated as a cumulative depth of infiltration against time and the infiltration rates for various time periods are calculated (Table 3.2). Finally, the results are plotted as shown in Fig. 3.10.

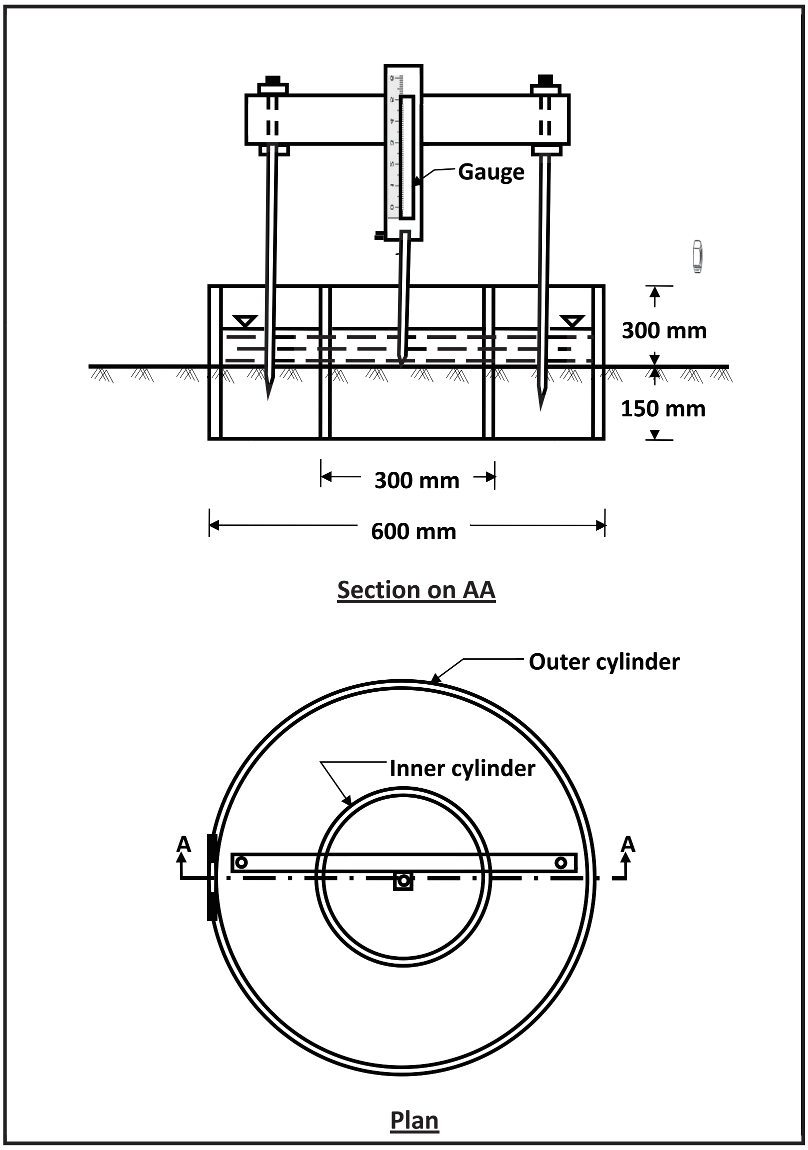


Fig. 3.9: Plan and section of double ring concentric infiltrometer

Data sheet for collection of observations

i) Date of observation:______________

ii) Location of experiment site: ______________

iii) Experiment plot no./ID:______________

iv) Age and height of bamboo plantation:______________

v) Soil moisture content (%):______________

vi) Soil type:______________

Table 3.2: Observation and data recording in the Infiltration study

Date/time	Before filling (cm)	After filling (cm)	Time interval (Minutes)	During period		
				Depth (cm)	Average rate (cm/hr)	Accumulated Infiltration (cm)
08:00 hrs	-	10	-	-	-	-
08:05	9.2	10	05	0.8	9.6	0.8
08:15	8.8	10	10	1.2	7.2	2
08:25	9.1	10	10	0.9	5.4	2.9
08:45	8.5	10	20	1.5	4.5	4.4
09:00	8.9	10	15	1.1	4.4	5.5
09:20	8.5	10	20	1.5	4.5	7
09:40	8.5	10	20	1.5	4.5	8.5
10:05	8	10	25	2	4.8	10.5
10:30	8	10	25	2	4.8	12.5

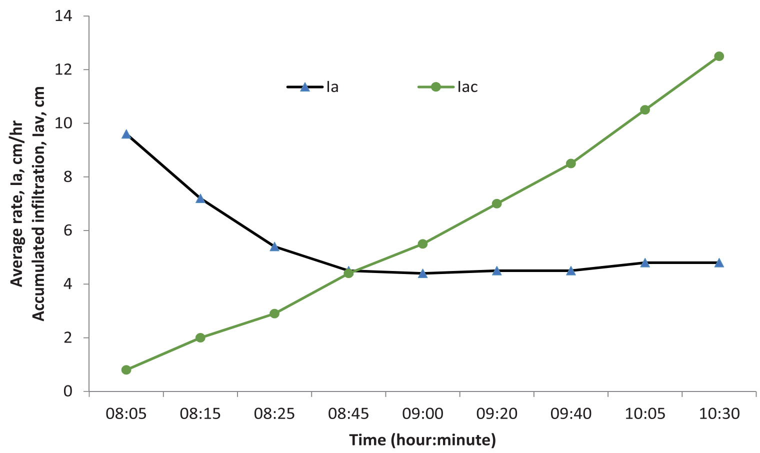


Fig. 3.10: Average infiltration rate and accumulated infiltration curve

3.5 Sediment (soil) measurement

Suitable arrangement for measurement of sediments (soils) is made with runoff gauging devices/setup. Sediment sampling is one of the simplest methods for sediment monitoring.

Before taking the sediment sample, the stored runoff along with sediment in the tank is required to be properly stirred so that the entire runoff can be homogeneous. Thereafter a sediment sample is collected in plastic bottles, preferably bearing a capacity of one litre from the tank and brought to the laboratory for determination of the sediment concentration of sample. A similar method will be followed for all the stations for collection of the sample.

Procedural steps for sampling soil loss analysis are:

- 100 ml of runoff are taken from the sample bottle (one litre) into a dish, and remaining sample amount is used for soil nutrient/carbon analysis.
- Add a 2.5 per cent alum solution (two to three drops) to the dish and allow the sediment to settle down.
- Pour the clean water out of the dish
- Keep the wet sediment (soil) in the water bath at 40-50^{o}C for two to three hours.
- (If a water bath is not available, an oven may be used. For oven drying, pour the clean water out and put the sediment mixed runoff (100 ml) in an aluminium dish & keep the aluminium dish (soil) in the oven at 30-35^{o}C for five to six hours.
- Find the weight of the dish after cooling
- Calculate sediment available in 100 ml runoff; thereafter calculate sediment availability in one litre of sample, and finally total runoff received from the plot due to the rain event. Data is recorded as per Table 3.3.

$$\text{Sedimentconcentration}(S) = \frac{\text{Total sediment weight}(\text{gort})}{\text{Sample volume}(\text{lorm}^3)}$$

Table 3.3: Observation and recording of runoff and soil loss

Date	Rainfall (mm)	Runoff (mm)	Runoff as per cent of rainfall	Soil loss (t/ha)

3.6 Rainfall partitioning

When it rains over a catchment, not all the precipitation falls directly onto the ground. Before it reaches the ground, a part of it may be caught by the vegetation and subsequently evaporated. The volume of water so caught is called interception. The intercepted precipitation may follow one of the three possible routes:

- It may be retained by the vegetation as surface storage and returned to the atmosphere by evaporation; a process termed interception loss;
- It can drip off the plant leaves to join the ground surface or the surface flow; this is known as throughfall and
- The rainwater may run along the leaves, branches and down the stem to reach the ground surface. This part is called stemflow. Drip occuring from periphery of the canopy and after cessation of rain event is also included in throughfall (Fig. 3.11).

Interception loss is solely due to evaporation and does not include transpiration, throughfall or stemflow. The amount of water intercepted in a given area is extremely difficult to measure. It depends on the species composition of vegetation, its density and also on the storm characteristics. Throughfall plus stemflow subtracted from gross rainfall recorded outside the canopy equals interception, i.e. in depth unit (mm, cm or inches). For measuring bamboo hydrological parameters such as stemflow, throughfall and interception, the following setup/equipment is generally used.

Throughfall

It is measured by keeping plastic catch cans similar to rain gauges under the canopy of the bamboo in three concentric circles; the first one is marked at 30-45cm from the plant and the second one is marked at 30-45cm inward from the canopy edge. The last one is marked along canopy edge. On each circle, three catch cans are placed to collect the throughfall as laid out in Fig. 3.11. It is not necessary to maintain a regular circular shape. The circles are marked in such a way that they can properly match with the canopy of the test clump. With this configuration of catch cans, spread of canopy in all directions is well covered for precise measurement of throughfall. Generally, the dimension of the catch cans is kept the same as the standard rain gauge. Different dimensions of catch cans may also be considered but the size needs to be calibrated with standard a rain gauge. Units of the throughfall are mm, cm or inches.

Stemflow

The stemflow collars are made up of a metallic sheet or from 500ml flexible plastic bottles. Nowadays, plastic bottles are improvised to fit with the stem. The bottom portion of the bottle with the matching size of the culm diameter is removed and one side is opened to insert the bottle in the bamboo culm. These flexible plastic collars are fitted around the entire circumference to the bamboo culm and made water tight with sealants (Fig. 3.12). The bottom of the collar is connected to the collector fixed on the ground. The volume of water collected by stemflow into the collection can is divided by cross-sectional area giving stemflow in depth units, i.e. mm, cm or inches.

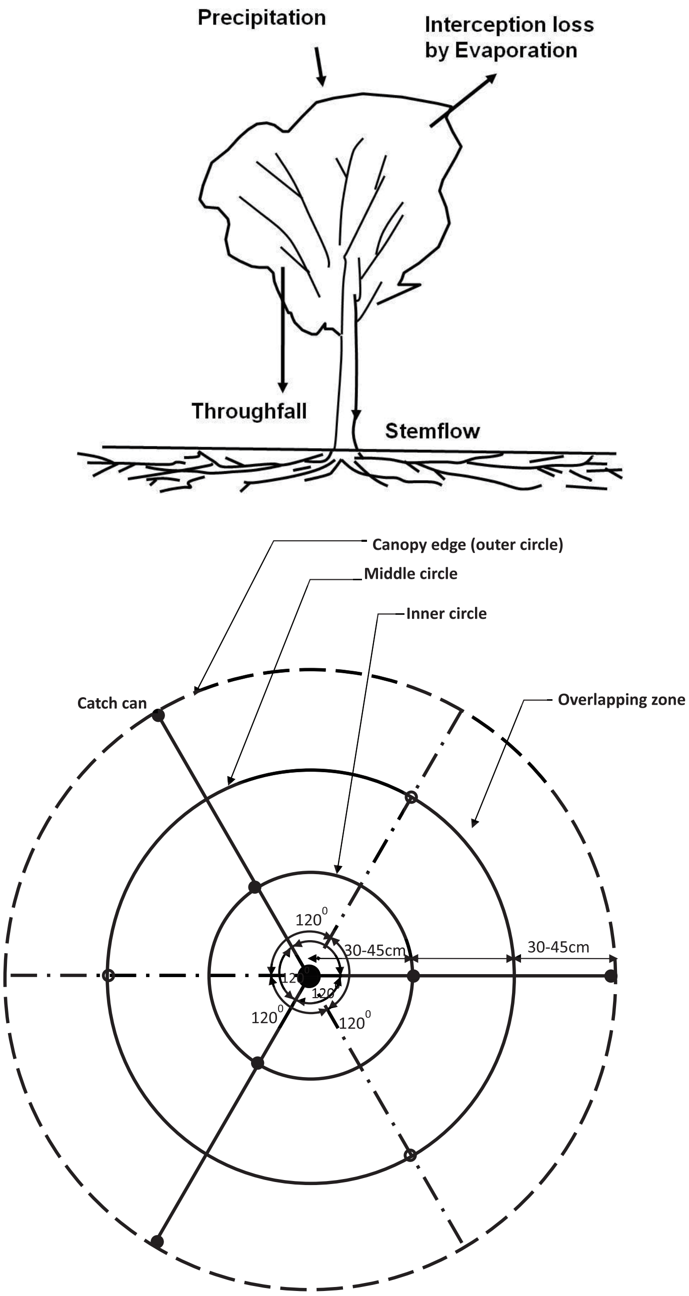


Fig. 3.11: Throughfall, stemflow, interception from the bamboo clump (L) and plan for measuring throughfall from the bamboo canopy (R).

Fig. 3.12: Plastic collars fitted to the bamboo culms to channelise the stemflow

Procedure

1. Cut a good quality polythene pipe of four to six centimetres in diameter into two parts longitudinally to form the collar for collecting the water flowing from the stem. The collar can also be made from plastic funnel.
2. Wrap the tube multiple times around the trunk in order to ensure a more complete collection.
3. Fix the cut pipe with the help of steel nails.
4. Seal the contact points between the stem and the pipe with hot paraffin wax.
5. Attach a plastic funnel of a suitable diameter to the two cut ends of the gutter and securely nail it.
6. Cover the funnel with nylon mesh to avoid contamination and choking of the funnel by litter, insects, etc.
7. Connect the funnel with a long pipe to the containers which collects the stemflow.
8. Measure the stemflow fall volume (ml) with the help of a measuring cylinder.
9. Measure the diameter of the canopy in different directions of the shading portion of the clump and calculate average diameter value.
10. Calculate the canopy area of clump using the equation $^{\pi}/_{4}\, d^2$, where d = average diameter of the shading portion, cm.
11. Calculate the stemflow (mm) using the equation:

$$\frac{\text{volume of stemflow in drum (ml)x 10}}{\text{crown projection area (sq cm)}}$$

12. Install standard rain gauges/containers of uniform size in all four directions below the clumps and outside the clumps randomly to measure the throughfall.
13. Calculate mean throughfall volume (ml) from the clumps by taking the average of all rain gauges/ containers.
14. Calculate mean throughfall depth (mm) by dividing throughfall volume with the cross- section of the container using the equation:

$$\frac{\text{volume of rainfall collected (ml)x 10}}{\pi r^2}$$

15. Calculate the depth of each rainfall event from the meteorological observatory.
16. Calculate canopy interception using the equation:

Canopy interception (mm) = Total rainfall in open (mm) – (stemflow (mm) + through fall (mm)).

3.7 Water budgeting

Estimation and accounting of all types of water inflow and outflow from/into the system or project area are nothing but water budgeting of a system or project area. 'System' refers to individual tree/plant, forest, grasses or other mixed vegetation and 'project area' refers to vegetation, forest or pasture lands with surface water bodies and groundwater or any other point of interest (Fig. 3.13). Development can alter the natural supply of water and severely impact an area, especially if there are nearby ponds or wetlands. A water budget is needed to determine the magnitude of these impacts and to evaluate possible mitigation actions. A water budget describes the various components of the hydrologic cycle. The water budget typically includes: Precipitation (P), Evaporation (E), Evapotranspiration (ET), Surface runoff (R) and Groundwater flow (GF).

Generally, the water budget is expressed as an equation comprising the terms:

$$\Delta S = P - E - ET \pm R \pm GF \qquad \dots (1)$$

where ΔS is the change in storage. For example, if the expression on the right-hand side of the equation is positive, storage will increase and the water level in the area of interest will rise. A positive change in storage is often termed a surplus, while a decrease in storage is termed a deficit. The change in storage is usually described with mm or cm. Water balance is estimated at the regional and local levels to understand deficits and surplus at both the spatial as well as temporal scales.

For water budgeting of forest lands (Fig. 3.13), the following relationship may be used

$$\Delta S = P - I_f - ET \pm R \pm GF \qquad \dots (2)$$

Interception is already included, which indicates the loss by evaporation, so in this case, ET includes major contribution from transpiration and evaporation from bare ground surface in the forest or pasture lands.

Interception by the forest/vegetation is expressed as:

$$I_f = P - (S_f + T_f) \quad \text{... (3)}$$

Runoff from projects may be computed by the equation given as:

$$R = P - I_f - I_s - S_r \quad \text{... (4)}$$

Evaporation from the overland or/and channel flow between the source to monitoring station (exit point) of the project area is also deducted from the precipitation if its amount is considerable. Normally, for short-term calculation of runoff on rainy days, the value of evaporation is very low.

Where; I_f, Interception loss by vegetation; Sr, Surface retention (Depression Storage); I_s, Infiltration; S_f, Streamflow; T_f, Throughfall; T, Transpiration.

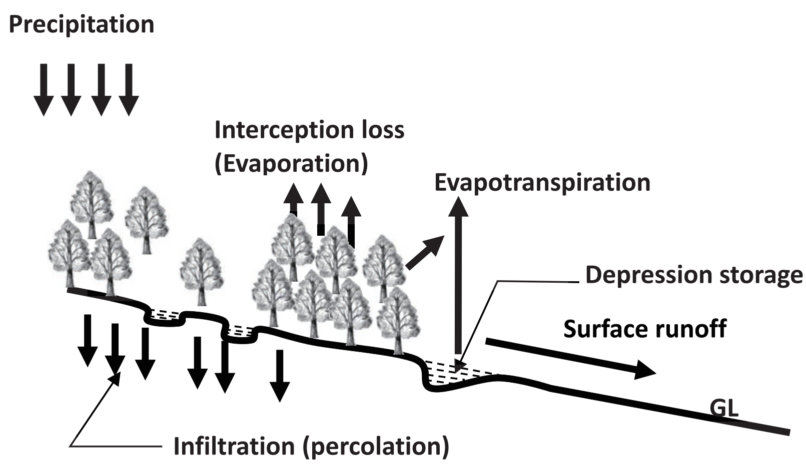


Fig. 3.13: Inflow and outflow components for water budgeting of a forest system

CHAPTER IV
SOIL HEALTH

4.1 Introduction

The chapter deals with different field methods to collect a composite and representative soil sample along with the different equipment used in soil sampling. A step by step procedure is described to determine soil texture, soil bulk density, particle density, porosity, soil moisture and computation of soil quality index. For determining physical, chemical and biological properties of soil, any standard lab manual can be followed.

4.2 Soil sampling and processing

Soil sampling is perhaps the most important step for all physical and chemical soil analysis. As a very small quantity of soil is taken to represent huge soil mass, it becomes extremely important to get a truly representative soil sample of the field. A good sampling plan should provide a measure of the average fertility level of a field and a measure of how variable it is. If a sample is not representative of the field or it is incorrectly taken, the resulting analytical data is meaningless, or at best, difficult to interpret. Some of the vital steps are noted below:

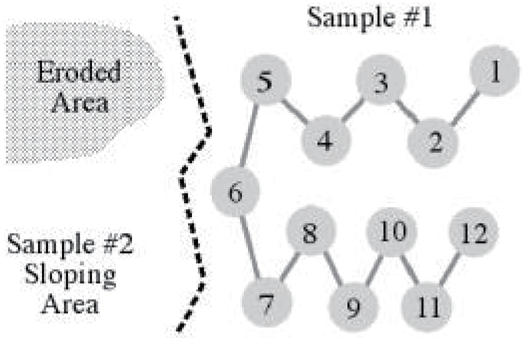
- The sample should truly represent the field it belongs to.
- A homogenous and uniform field can be treated as a single sampling unit.
- Any variations with regard to topography (slope, steepness, geomorphology); contrast in soil texture, colour or change in land use and management are some of the important factors that should be taken into account for sampling. Separate samples are required from areas differing in these characteristics.
- Soil sampling from recently manured or fertilised plots must be avoided.
- Sampling from border areas of a field and channels or near to field bunds would not be representative of true sampling.
- Large areas may be divided into appropriate number of smaller homogeneous units for better representation.

4.2.1 Sampling procedure

A soil sample should be composed of several subsamples representing a seemingly uniform area or field with similar cropping and management history as stated above. There is no universally accepted number of subsamples for different field situations. However, the following points can serve as guidelines to decide number of samplings:

Composite sampling

i. At least 10–12 subsamples should be taken per hectare (ha) in a zigzag pattern covering an entire area for obtaining one composite sample to provide a uniform distribution of sampling sites. The subsampling process is shown in the following figure's zigzag pattern (Fig. 4.1).



Source: Hunnings and Donohue, 2009

Fig. 4.1: Sub-sampling process for collecting soil samples

ii. Depending upon the purpose or specific plans, the number of subsamples may vary from five to 25 borings or subsamples per composite sample.

ii. Fewer subsamples are needed where little or no fertiliser has been used.

iii. More numbers of subsamples are needed where fertility gradients might be developed due to hand broadcasting of fertilisers and/or cropping-livestock systems. Indeed, banding of fertiliser poses serious problems for reliable sampling.

v. Thus, the number of subsamples taken by farmers should be realistic, considering the particular field situation.

vi. Reduce the bulk sample to about 500g to 1.0kg by a quartering method in which the entire soil mass is spread, divided into four quarters, the two opposite ones are discarded and the remaining two are remixed. This process should be continued repeatedly until the final desired sample is obtained.

Take a composite sample from each area as follows:

- Scrape away surface litter, if any.
- Take a uniform core of soil from surface to plough depth (15cm) by means of a soil auger or soil tube or create a V-shaped cut up to a depth of 15cm with sharp tools as shown below:

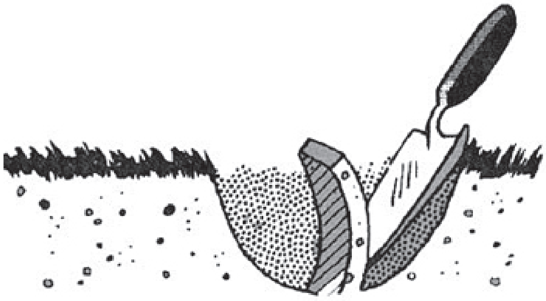


Fig. 4.2: V-shape method for collecting soil samples

- Take soil from six to eight random spots in a zigzag pattern in the field, collecting them in a clean place
- Mix well the soil collected from different spots of the field and take ½ kg composite sample
- Air dry the sample under shade. Do not dry the soil in the sun or by artificial heating with a stove or furnace, etc.
- Label each sample with the name

4.2.2 Sampling time

Soil samples can be taken any time that soil conditions permit, but sampling directly after fertilisation or amendment application to soil should be avoided. For most of the physical soil parameters the most appropriate time is immediately after harvest. In other land-use systems, the time of sampling may vary.

Samples taken during the growth period will help in knowing the nutrient status of the soil in which plants are actively taking up nutrients. It is important to sample at similar times year after year for comparing analyses at regular time intervals.

4.2.3 Sampling depth

For most purposes, soil sampling is done to a depth of about 10–20cm. In some cases, sampling to a depth of 60–100cm is desirable, especially for monitoring leaching of nutrients and doing a water balance study. Depth-wise soil samples should also be taken where there is a specific necessity.

Fig. 4.3: Depth-wise collection of sample

4.2.4 Sampling tools

A uniform slice should be taken from the surface to the depth of insertion of the tool; the same volume of soil should be obtained in each subsample. Augers generally meet these requirements. In areas where the topsoil is dry, e.g. during summer, topsoil sampling can be done by a metal ring, by digging out the soil inside the ring, because it is almost impossible to sample dry topsoil with an auger. Soil samples for micronutrient analysis should be taken using a stainless steel auger, or at least ungalvanised auger (because galvanised coating is zinc oxide). For research purposes, generally augers are used for field sampling. In case sampling tools are not available, a spade can be used as instructed below:

- Dig a V-shaped hole 15cm–20cm deep. Then take a fine thick slice from the smooth side.
- Trim the sides leaving a fine strip, then dump this strip into a clean bucket. Break the clods[14] and mix thoroughly.
- Remove large rocks, pieces of sod, earthworms, etc. Put the soil into the sample container and label the box clearly.
- For moist soil, the tube auger or spade is considered satisfactory. For harder soil, a screw auger may be more convenient.

4.2.5 Reduction of Sample Size

When a very large sample is collected, it is necessary to reduce the size of the sample for ease of storage and handling. The bulk sample must be reduced in size, and the subsample taken for analysis should represent the soil characteristic of the field under investigation. Sample splitting can be performed with a mechanical sample splitter, such as a riffle sampler[15], by which the sample is divided in half by a series of chutes. This process can be repeated as many times as necessary.

Another way for reducing sample size is by quartering. The sample is spread uniformly over a plastic sheet and divided into four equal portions (Fig. 4.4). Portions two and three are collected and thoroughly mixed, whereas the remainder is discarded. This process of quartering can be repeated as many times as necessary until the proper size of sample is attained.

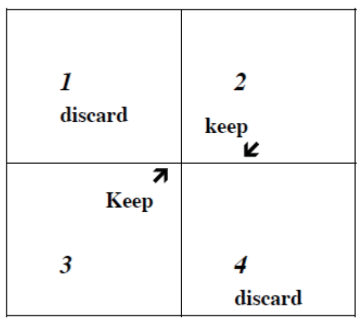


Fig. 4.4: Reduction of sample size by quartering

14 They are artificially structured units, formed at or near the surface by cultivation.

15 It is a static and fractional subsampling device that can be used for dividing a lot of dry particulate material into two half-lots.

4.2.6 Preparation and Laboratory Processing

Handling in the laboratory

As soon as the samples are received at the soil preparation facility, they should be checked with the accompanying information list (including sample number, depth and date of sampling that must be written on the bags received from outside and on a sample card placed inside the bag). Information regarding samples should be entered in a register and each sample must be given a laboratory number.

Fresh samples are needed for determination of nitrate, nitrite and ammonium forms of nitrogen. These samples should not be dried and the results expressed on an oven-dry basis by separately estimating moisture content in the samples. If short-term storage is unavoidable, this must be done in a fridge at temperatures close to 0°C (but not below zero). Lag time between field sampling and analysis must be minimised. Otherwise, storage time will inevitably introduce an additional factor influencing analysis results.

Drying of the soil samples

The soil-fresh samples received in the laboratory should be dried in wooden trays. The trays can be numbered or a plastic tag can be attached and care should be taken to maintain the identity of each sample.

During drying, the soils are allowed to dry in the air. Alternatively, the trays may be placed in racks in a hot air cabinet (the temperature should not exceed 35°C and humidity should be between 30 and 60 per cent). In general, excessive oven-drying of the soil affects the availability of most of the nutrients present in the sample and should be avoided.

Preparation of soil samples

After drying, the samples are ground with a wooden pestle and mortar in preparation room (which is separate from the main laboratory) and clods and large aggregates are crushed and mixed. Remember that:

- Pebbles, concretions and stones should not be broken during grinding.
- Care should be taken not to break the individual soil particles during the grinding process.
- The entire sample should be passed through the sieve, except for concretions and pebbles of more than 2mm.
- The purpose of grinding is to reduce heterogeneity and to provide maximum surface area for physical and chemical reactions. Various devices are used for crushing and grinding soils.

After grinding, the soil is screened through a 2-mm-sieve. The coarse portion on the sieve should be returned to the mortar for further grinding (except for concretions, pebbles and organic residues). Repeat sieving and grinding are necessary until all aggregate particles are fine enough to pass through the 2-mm-sieve. It is necessary to reduce the size of the large sample for ease of storage and handling.

Remember, if the soil is to be analysed for trace elements, containers made of copper (Cu), zinc (Zn) and brass must be avoided during grinding and handling. Sieves of different sizes can be obtained in stainless steel. Aluminium or plastic sieves are useful alternative for general purposes.

After the soil samples are prepared they should be properly labelled and send to a laboratory for the analysis of physical chemical soil analysis.

4.3 Soil texture

Soil texture, or particle size distribution, is a rather stable soil characteristic which influences the physical and chemical properties of the soil. There is a direct relation between particle size and the total surface area of particles in a given weight of soil. Soil texture indicates the coarseness or fineness of the soil as determined by the relative proportions of the various-sized primary particles in the soil mass. The various size groups used by the International Society of Soil Science are as follows:

Soil separates	Diameter limits (mm)
Coarse sand	2.0-0.2
Fine sand	0.2-0.02
Silt	0.02-0.002
Clay	< 0.002

4.3.1 Textural class

The textural class into which a soil sample is placed depends upon the size of the particle, which dominates its make-up. Three broad yet fundamental groups of soils are recognised: Sand, clay and loams. Sand group includes all soils in which the sand separates make up 70 per cent or more of the material weight, e.g. sand and loamy sand.

A soil to be designated as clay must carry at least a 35 per cent clay separate and in most cases not less than 40 per cent. So long as the percentage of clay is 40 per cent or above, the characteristics of this separate are distinctly dominant and the class name is sandy clay or silty clay. Loam group, which contains many subdivisions, is more difficult to explain. A loam has a relatively even mixture of sand, silt and clay. Its classes are sandy loam and silty loam.

4.3.2 Field method (**feel method**) *to determine soil texture*

Soil texture is capable of being judged to a close approximation by the sense of feel in the field. It is quantitatively estimated by mechanical analysis in the laboratory.

- Feel of fingers: Take a pinch of soil sample, moisten it to field capacity and rub between thumb and fingers and note the feel of the fingers (Fig. 5.5). Sand feels gritty and its particles can be easily seen with the naked eye. Silt, when dry, feels like flour or talcum powder and is slightly plastic when wet. Clay feels very plastic, exhibits stickiness when wet and is hard under dry conditions (Table 4.1). For further confirmation, other properties like ball formation, stickiness and ribbon formation are also studied.

Fig. 4.5: Feel method for soil texture

- Ball formation: Roll the moist soil at field capacity between fingers and thumb (Fig. 5.6) and note the characteristics of the ball formed as given in Table 4.1.
- Stickiness: Roll the ball between fingers and note whether the soil sticks/stains the fingers or not.

Fig. 4.6: Ball formation for determining soil texture

Table 4.1: Criteria for judging soil texture (by Feel Method)

Feel of fingers	Ball formation	Stickiness	Texture	Symbol	Textural class
Very smooth	Forms hard ball	Definitely stains the fingers	Heavy	c	Clay
Smooth	Forms moderately hard ball when dry	Definitely stains the fingers	Moderately heavy	sicl, cl	Silt clay loam or clay loam
Powdery (Flour-like)	Forms firm ball	Definitely stains the fingers	Medium	l	Loam
Moderately gritty	Forms easily broken ball	Definitely stains the fingers	Moderately light	sl	Sandy loam
Gritty	Will shape but not form ball	Stains fingers slightly	Light	ls	Loamy sand
Very gritty	Does not form ball	No staining	Very light	S	Sand

Ribbon formation: Press the moistened soil ball between the thumb and forefinger in an attempt to form a ribbon with the soil (Fig. 4.7). As the thumb and forefinger are pressed together, the soil will extrude, forming the ribbon. The motion should be repeated several times to test the cohesiveness of the ribbon, attempting to form a continuous ribbon. Ribbon is formed by rubbing the paste between forefinger and thumb. It is recommended to use your left hand, in order to keep your right hand clean for writing.

Ribbons can be classed into three broad categories:

i. Good Ribbon – The ribbon does not break and has very little cracking along the sides.

ii. Medium Ribbon – The sides of the ribbon crack deeply and eventually the ribbon will break and fall off.

iii. Poor Ribbon – No ribbon formed (no cohesiveness) or the ribbon breaks with the first applied pressure and does not cohere.

Fig. 4.7: Ribbon formation for determining texture grade

Shearing manipulation: The behaviour of the soil during bolus and of the ribbon produced by shearing (pressing out) between thumb and forefinger characterises the texture. The following grades of texture are commonly recognised and may be defined by the behaviour of the moist bolus as set out in Table 4.2. The approximate percentage content of clay (particles less than 0.002mm in diameter) and silt (particles between 0.02–0.002 mm in diameter) are given as a general guide where appropriate but other soil properties affect texture, as discussed below.

Table 4.2. Grades of soil texture

Texture grade	Behaviour of moist ribbon	Approx. clay content (%)
Sand (s)	Coherence nil to very slight; cannot be moulded; single sand grains adhere to fingers.	Around 5%
Loamy sand (ls)	Slight coherence; can be sheared between thumb and forefinger to give mineral ribbon of about 6.5mm; discolours fingers with dark organic stain.	5 to 10
Clayey sand (cs)	Slight coherence; sticky when wet; many sand grains stick to finger; will form minimal ribbon 6.15mm–1.3cm; discolours fingers with clay stain.	5 to 10

Texture grade	Behaviour of moist ribbon	Approx. clay content (%)
Sandy loam (sl)	Bolus just coherent but very sandy to touch; will form ribbon of 1.3cm–2.5cm; dominant sand grains are of medium size and are readily visible.	10 to 15
Loam (1)	Bolus coherent and rather spongy; smooth feel when manipulated but with no obvious sandiness or 'silkiness'; may be somewhat greasy to touch if much organic matter is present; will form ribbon of about 2.5cm.	About 25
Silt loam (sil)	Coherent bolus, very smooth to silky when manipulated; forms ribbon of about 2.5cm.	About 25, and with silt 25% or more
Sandy clay loam (scl)	Strongly coherent bolus sandy to touch; medium- sized sand grains visible in finer matrix; will form ribbon of 2.5cm.	20 to 30
Clay loam (cl)	Coherent plastic bolus; smooth to manipulate; will form ribbon of 3.8cm to 5cm.	30 to 35
Silt clay loam	Coherent smooth bolus; plastic and silky to the touch; will form ribbon of 3.8cm to 5cm.	30 to 35 and with silt 25 or more
Sandy clay (sc)	Plastic bolus; fine to medium sands can be seen, felt or heard in clayey matrix; will form ribbon of 5cm to 7.5cm.	35 to 40 and with silt 25%
Light clay (cil)	Plastic bolus; smooth to touch; slight resistance to shearing between thumb and forefinger; will form ribbon of 5cm to 7.5cm.	35 to 40
Medium clay	Smooth plastic bolus; handles like plasticine; can be moulded into rods without fracture	
Heavy clay (c:H)	Smooth plastic bolus; handles like stiff plasticine; can be moulded into rods without fracture; has firm resistance to ribboning shear; will form ribbon of 7.5cm or more.	50 or more

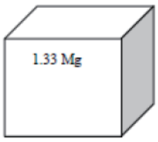
4.4 Soil density and porosity

Soil density is the dry mass per unit volume. This measurement is usually expressed in grams per cubic centimetre (g/cm^3) or megagrams per cubic meter (Mg/m^3). Soil has two densities, bulk density (D_b) and particle density (D_p). The difference between these two soil properties lies in the volume measured (Fig. 4.8). Bulk density values represent the density of the soil as a whole, including solids and pore space. Particle density values represent only the mass per unit volume of the soil solids; pore space is not included. Soils containing a high proportion of pore space to solids have low bulk density values. Conversely, compacted soils with decreased pore space have a higher mass per unit volume ratio and higher bulk density values.

Bulk density values provide an extremely useful conversion factor for calculations involving soil mass and soil volume. Bulk density measurements are also used to calculate the total pore volume in a soil as well as the weight of soil to be moved during an excavation. High bulk density values may indicate the presence of compact layers in soil that could restrict root and water penetration.

In the field 1 m^3, of a certain soil appears as

Solids and pore spaces



To calculate bulk density of the soil:

Volume=1m^3 (solids + pores)   Weight=1.33Mg (solids only)

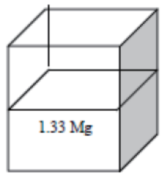
Bulk density = $\frac{\text{Weight of the oven dry soil}}{\text{Volume of soil (solids+pores)}}$

Therefore Bulk density, $D_b = \frac{1.33}{1} = 1.33\text{Mg/m}^3$

If all the solids were compressed to the bottom, the cube would look like

½ pore spaces

½ solids



To calculate solid particle density:

Volume=0.5m^3 (solids only)   Weight =1.33Mg (solids only)

Solid particle density = $\frac{\text{Weight of solids}}{\text{Volume of solids}}$

Therefore Solid particle density, $D_p = \frac{1.33}{0.5} = 2.66\text{Mg/m}^3$

Fig. 4.8: Comparison of soil bulk density and particle density

4.4.1 Measurement of bulk density

Two methods are commonly used to determine soil bulk density: one uses samples of disturbed soil, and the other uses samples of undisturbed soil. The second method uses consolidated soil masses, like clods and cores[16].

i) Bulk density of a disturbed soil sample

This method is used when it is not possible to take a consolidated sample of soil, as in sandy soils and soils of greenhouses and nurseries because they are loose and very friable[17].

Procedure

- Fill a pre-weighed 100ml-graduated cylinder with air-dried soil.
- Compact the soil in the cylinder by tapping the cylinder firmly 15 times on the palm of the hand.
- Record the volume of the packed soil in the cylinder.
- Record the weight of the cylinder and the soil.
- Calculate the weight of the soil.
- On a separate sample, determine the moisture content of the soil sample and calculate the oven-dry weight of the soil in the cylinder.
- Calculate bulk density.

16 Cylindrical samples of soil for tests and examination.

17 It refers to the degree of cohesion or adhesion of the soil mass, its resistance to disintegration and is strongly affected by moisture content.

Calculation

BD (g/cm) = [Weight of oven-dry soil (g)] / Volume of soil sample (cm^3)

$$BD\ (g/cm^3) = \frac{\text{Weight of oven-dry soil (g)}}{\text{Volume of soil sample } (cm^3)}$$

Note: Bulk density is commonly calculated on an oven-dry basis, but for certain uses it is calculated on a wet-soil basis.

ii) Bulk density of an undisturbed soil sample

The core method

Procedure

- Carefully drive a thin-walled steel tubing or pipe (of known weight and volume) into the soil with a block of wood and a hammer. Be careful to avoid compaction of the soil during collection of the cores. After careful removal of the soil core, examine it and trim the ends carefully (Fig. 4.9).

Fig. 4.9: Soil cores being used to collect samples

- Weigh the soil and tubing.
- Calculate the weight of the soil sample alone by subtracting the weight of the steel tubing.
- Take a portion of this soil for the determination of soil moisture.
- Knowing the moisture content of the soil core, calculate the oven-dry weight of the soil sample.
- Calculate the bulk density in g/cm^3 by dividing the weight of the soil core on an oven-dry basis and by the volume of the soil core, which is the volume of the steel tube.

Vol. of soil core (cm^3)

Volume = Area X Depth

Where: Area of a circle = πr^2

(Where r = the radius of a circle)

Depth = Depth of the sample ring

Calculate the BD in g/cm^3 and Mg/m^3

$$BD\ (g/cm^3) = \frac{Wt.of\ soil\ core\ (dry\ basis)(g)}{Vol.of\ soil\ core\ (cm^3)}$$

Values of BD of undisturbed cores are of practical significance as they indicate soil aggregation and structure under field conditions.

4.4.2 Measurement of particle density by graduated cylinder method

The Graduated Cylinder Method is very simple and rapid. The particle density of most soils varies from 2.60 to 2.75 g/cm^3. An average particle density value of 2.67 is commonly used as the specific gravity of soils.

Procedure

- Weigh 40g of soil in a 100ml-graduated cylinder.
- Add 50ml of water to the soil in the cylinder. Be sure that no soil material is on the inner walls of the cylinder.
- Stir thoroughly with a stirring rod to displace the air, and rinse the stirring rod and the inner walls of the cylinder with 10ml water.
- Allow the mixture to stand for five minutes and record the volume of the soil including the 60ml water.
- Determine separately the moisture content of the soil sample by the gravimetric method. The amount of moisture should be added to the amount of added water to obtain the total amount of water used.

Calculation

Volume of total solids = Volume of (soil + water) – Volume of added water

Volume of (soil + water) = as shown on graduated cylinder

Volume of added water = 60ml + soil moisture (ml)

Volume of total solids (cm)

$$Particle\ density\ (PD), g/cm^3\ = \frac{Oven - dry\ wt.of\ soil\ (g)}{Volume\ of\ total\ solids\ (cm^3)}$$

Calculation of per cent pore space

The pore space (voids) is the portion of bulk soil volume not occupied by solid particles. It is filled with air and water. Depending on pore size, pore spaces are given the name macropores (large) or micropores (small). There is no sharp line of demarcation between the two pore sizes.

$$\% \text{ Pore Space (PS)} = \frac{PD - BD}{PD} \times 100$$

Example

A soil sample weighs 110g and contains 15 per cent moisture. The volume of the soil sample is 75ml. The sample displaced 36.8ml water. Calculate BD, PD and %PS.

Oven-dry weight = 110 x 100/115 = 95.65g

BD = 95.65/75 = 1.3g/cm^3

PD = 95.65/36.8 = 2.6 g/cm^3

%PS = 100(2.6-1.3)/2.6 = 50

4.5 Soil moisture

The soil moisture content of soil is the quantity of water it contains. Water content is used in a wide range of scientific and technical areas. Moisture may be present as adsorbed moisture at internal surfaces and as capillary condensed water in small pores. Water is held in soil by adhesive and cohesive forces.

The amount of water present in soil can be expressed as mass of water per unit in total mass of soil. Soil water can be measured by the gravimetric method. The gravimetric method is based on the principle that the water in porous material is lost by evaporation on heating and the porous material undergoes an equivalent loss in its weight. Water content for gravelly and stony soils on gravimetric basis can be misleading. A specific mention of gravel and stone percentage should be made while presenting the data on these soils.

Requirement: Moisture determination cans, analytical balance, drying oven and desiccator[18]

Procedure

- Accurately weigh a metal can with lid (W_1).
- Place about 50g of soil in the can and weigh accurately along with the lid (W_2).
- Place the can with the lid under it in a drying oven at 105°C for 24–48 hours, or until a constant weight is reached.
- Remove the can from the oven, cover it tightly with the lid and place in a desiccator to cool.
- After cooling, weigh the can accurately with the oven-dry soil in it. Record the weight (W_3).
- Compute per cent moisture content on oven-dry basis.

Calculation

Weight of water = $W_2 - W_3$

Weight of oven-dry soil = $W_3 - W_1$

18 A glass container or other apparatus holding a drying agent for removing moisture from specimens and protecting them from water vapour in the air.

1. Moisture % by weight (oven-dry basis)= $\frac{W_{2-W_3}}{W_{3-W_1}} \times 100$ = θ_w

2. Moisture % by volume = θ_wx bulk density

4.6 Soil quality

Soil quality is defined as the capacity of soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health. It is assessed by measuring key soil attributes or indicators. Soil quality indicators are categorised by physical, chemical and biological indicators which help in monitoring changes in soil quality by assessing changes in these indicators

Field method to evaluate soil quality index

Soil health indices are decision tools that effectively combine a variety of information for multi-objective decision-making. Researchers/stakeholders can use such decision tools to identify the best species or most sustainable management practices which improve soil health. A set of sustainability indicators have been designed to assess the condition of particular plantation. Soil health indicators should be selected according to the soil functions of interest and defined management goals for the system.

Three main steps involved in assessing soil quality are:

- Choosing appropriate soil indicators that reflect sustainable management goals.
- Transforming those indicators into standard scores.
- Combing the indicators scores into soil health indices.

Methodology

- Qualitative indicators of soil, which are relevant to farmers and the biophysical conditions of the region, should be selected.
- Each indicator is valued separately and assigned with a value between 1 and 10 (1 being the least desirable value, 5 a moderate or threshold value and 10 the most preferred value) accordingly to the characteristics presented by the soil depending on attributes observed for each indicator (Table 4.1).
- For instance, in the case of the soil structure indicator, a value of 1 is given to a dusty soil, without visible aggregates; a value of 5 to a soil with some granular structure whose aggregates are easily broken under soft finger pressure; and a value of 10 to a well-structured soil whose aggregates maintain a fixed shape even after exerting soft pressure. Values between 1 to 5 and 5 to 10 can also be assigned accordingly.
- Once the values are assigned to the indicators, they are added and divided by the number of measured indicators. A mean value for soil quality and another for crop health is then achieved.

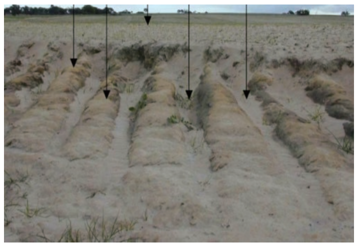
Table 4.1: Soil health indicators with its corresponding characteristics and values (values between 1–10 can be assigned to each indicator)

1. Soil structure

Established value	Characteristics	Estimated value* (User's judgement)
1	Loose, powdery soil without visible aggregates	
5	Few aggregates that break with little pressure	
10	Well-formed aggregates difficult to break	

2. Soil compaction

Established value	Characteristics	Estimated value (User's judgement)
1	Compacted soil, flag bends readily	
5	Thin compacted layer, some restriction to a penetrating wire	
10	No compaction, flag can penetrate all the way into the soil	



3. Soil depth

Established value	Characteristics	Estimated value (User's judgement)
1	Exposed subsoil (soil depth < 25cm)	
5	Moderately shallow soil (25–50cm)	
10	Deep soil with soil depth at least > 50cm	

4. Status of residue

Established value	Characteristics	Estimated value (User's judgement)
1	No visible sign of residue; soil colour appears pale or light	
5	Presence of decomposing residues or mulch material; soil colour appears to be brownish	
10	Residue in various stages of decomposition; most residue well decomposed; soil colour appears to be dark or blackish	

5. Soil colour, odour and organic matter

Established value	Characteristics	Estimated value (User's judgement)
1	Pale, no presence of humus, no smell of decomposing residue or rotten residues	
5	Light brown, odourless, some presence of humus or little smell of rotten materials	
10	Dark brown or blackish appearance, fresh odour and abundant humus	

6. Soil water retention (moisture level after irrigation or rain)

Established value	Characteristics	Estimated value (User's judgement)
1	Dry soil, does not hold water	
5	Limited moisture level available for short time	
10	Reasonable moisture level for a reasonable period of time	

7. Soil cover

Established value	Characteristics	Estimated value (User's judgement)
1	Bare soil fallow with sparse vegetation	
5	Less than 50% soil covered by residue or live cover at least for six months	
10	More than 50% soil covered by residue or live cover at least for nine months	

8. Erosion

Established value	Characteristics	Estimated value (User's judgement)
1	Severe erosion; presence of small gullies	
5	Evident but low erosion signs	
10	No visible signs of erosion	

9. Presence of invertebrates and insects

Established value	Characteristics	Estimated value (User's judgement)
1	No signs of earthworms or insect presence or activity	
5	A few earthworms and arthropods present	
10	Abundant presence of invertebrate organisms	

10. Microbiological activity

Established value	Characteristics	Estimated value (User's judgement)
1	Very little effervescence after application of hydrogen peroxide (H_2O_2)	
5	Light to medium effervescence	
10	Abundant effervescence	

**To be assigned by user*

Rating

- Plantations with an overall value lower than five in soil quality are considered *below the sustainability threshold* and rectifying measures should be taken to improve the low indicators on these farms.
- The indicators are more easily observed by using an *amoeba* type graph as it allows a person to visualise the general status of soil health, considering that the closer the amoeba approaches the full diameter length of the circle, the more sustainable the system is (a 10 value). The amoeba shows which indicators (below five) are weak, allowing the prioritising of the interventions necessary to correct soil, plantation or system deficiencies.
- At times it may be possible to correct a set of deficiencies just by intervening on one specific attribute (increasing the species diversity or the soil organic matter) which in turn affects others.
- For example, by adding organic matter, in addition to increasing the soil's water carrying capacity, it is also possible to augment soil biological activity and improve soil structure. The average values of various farms can be plotted, allowing researchers to visualise how each plantation fares in relation to the threshold level (five) of soil health (Fig. 4.10).

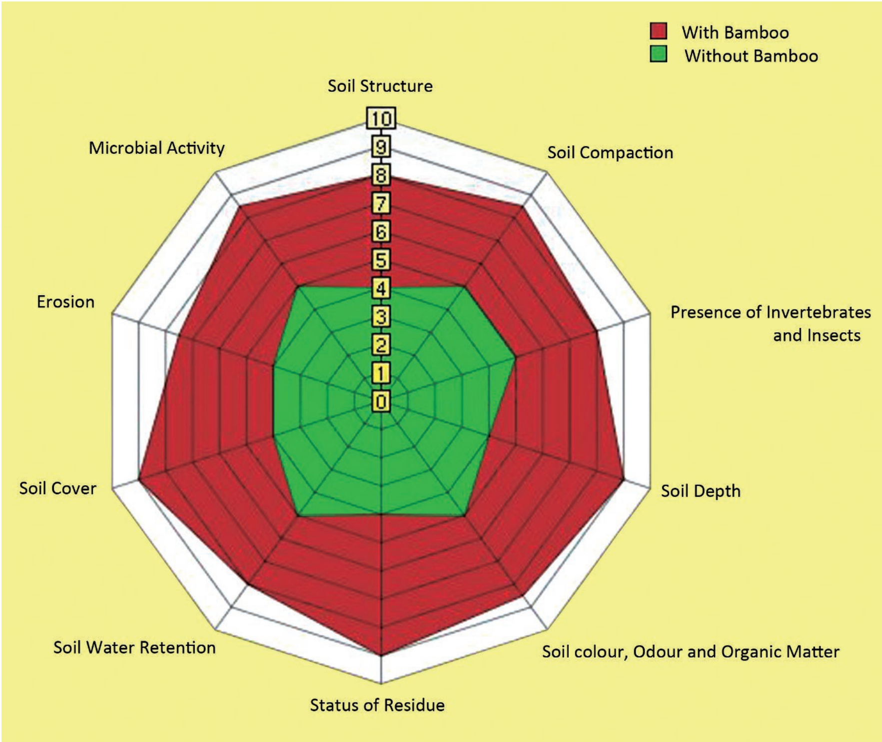


Fig. 4.10: Spider web representing the soil quality status of two different practices (with and without bamboo)

4.7 Conclusions

Assessment of sustainability is an important challenge. The methodology presented here allows to measure the sustainability in a comparative or relative way, either by comparing the evolution of time of the same plantation/land use system, or by comparing two or more plantations/land use systems under different species/management practices or transitional stages. The comparison of various systems allows for identifying the healthier systems. Such a tool will permit individuals to make management decisions directed at improving the attributes performing poorly and thus improving system functions.

ECONOMICS
(BENEFIT-COST ANALYSIS AND INTANGIBLE BENEFITS)

5.1 Introduction

Farming, as an occupation, is a source of income for a farm family. It entails the use of available resources required for achieving the goal of maximum production leading to profit-making. Since farming is now considered mainly as a business enterprise, decision-making is required by the farmer for judicious use of scarce farm resources (which have alternative uses) for achieving multiple objectives – food production and income generation – on a sustainable basis. Thus, farming as a business requires an application of economic principles. Application of the economic principles helps in better decision-making by the farmer.

The decision regarding which production activities (crops, livestock, fishery, etc.) should be taken up; what should be the combination of these production activities; how much to produce from each of the selected production activities; what should be the size of each production activity; which technologies should be adopted for these production activities, etc. can be made using economic principles to achieve multiple objectives.

Perennial crops like bamboo require a special type of economic analysis called Benefit-Cost Analysis (BCA), which integrates the principles of time value of money, opportunity cost and discounting. This chapter educates readers on how to calculate the economics of bamboo cultivation using illustrative examples. Rules to determine whether an investment has been profitable or not have been indicated. In addition to tangible economic benefits, the bamboo crop also provides intangible benefits which need to be evaluated. Valuations of intangible benefits of bamboo such as soil conservation and soil organic carbon enhancement are also illustrated in this chapter.

5.2 Cost of cultivation

A farmer can increase his/her income either by increasing production and/or by reducing the cost. Cost plays an important role in a farmer's decision-making (as in the case of any production enterprise) because the profit generated from the enterprise depends to a good extent on the cost incurred in cultivation or production. Cost, *by its own accord,* is the value of the inputs that get used up in producing an output, and since those inputs *are not available for alternative use anymore*, the extent of availability and utilisation of resources as per their quantity and price is one of the deciding factors in quantity of production of an output and generation of profit. Thus, cost of cultivation of a given farm production activity (output) affects the level of production of that farm enterprise (output) and also the profit-making from that enterprise. Since the prices of inputs (as well as outputs) are not under the direct control of the farmer in a competitive market, the option to reduce the cost through rationalisation of resource use is important.

Calculation of costs of perennial crops

The production process of a perennial crop like bamboo is significantly different from that of annual crops; therefore, the method of calculation of cost of cultivation of such crops is different. The distinguishing feature of perennial crops from annual crops is the long gestation period. In addition to this, perennial crop returns are over a longer time span, wherein major portions of the cost are incurred in the initial period (i.e. there is no close and apparent synchronisation in occurrence of costs and returns – the costs and returns occur in different times) and the returns vary according to the age of the crop, which again, entails a different approach of calculation.

The long gestation and productive periods of bamboo require the estimation of its costs of cultivation in two parts, i.e. establishment cost and maintenance cost. The establishment cost is the cost incurred in the initial stage of plantation along with expenditures incurred in the non-productive stage. The maintenance cost is incurred during the productive stage for maintenance of the plantation so that it continues to remain alive and gives output in the subsequent part of its life. An example of **establishment cost** of one hectare of a bamboo plantation (400 plants per ha) at a constant price, in the first six years out of 20 years of life, is as follows:

Please note: The below tables and cost calculations are shown as a representation model for undertaking similar calculations by readers in their own locations.

Activity	Cost in USD					
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Material Input						
Planting material (bamboo saplings), including 10% mortality replacement	12	1	1	0	0	0
Fertiliser (50gm DAP per plant @ USD0.15/kg)	3	0	0	0	0	0
Plant protection (Chloropyriphos 0.5 lt @ USD18.58/lt)	9	0	0	0	0	0
Irrigation (15 Nos. @ USD7.74/irrigation)	116	116	116	116	0	0
Subtotal	141	117	117	116	0	0
Labour Input	0	0	0	0	0	0
Land preparation (clearing of bushes)	103	0	0	0	0	0
Digging of trench, refilling (@ USD0.70/trench)	279	0	0	0	0	0
Planting and staking (@ USD0.23/plant)	93	9	9	0	0	0
Weeding and interculture – from second to 20th year (@ USD 0.08/plant)	0	31	31	31	31	31
Watch and ward – cost from first to 20th year (USD/year)	46	46	46	46	46	46
Harvesting – seventh year onwards (@ USD0.08/plant)	0	0	0	0	0	0
Subtotal	521	87	87	77	77	77
Contingency (@ 5%)	26	4	4	4	4	4
Grand total	688	208	208	197	81	81

Under the same example, the **maintenance cost** at constant price during the productive life, i.e. seventh year to 20th year, is as follows:

Activity	Cost in USD		
	Year 7 to 10	Year 11 to 19	Year 20
Material Input			
Planting material (bamboo saplings), including 10% mortality replacement	0	0	0
Fertiliser (50 gm DAP per plant @ USD0.15/kg)	0	0	0
Plant protection (Chloropyriphos 0.5 lt @ USD18.58/lt)	0	0	0
Irrigation (15 Nos. @ USD7.74/irrigation)	0	0	0
Subtotal	0	0	0
Labour Input	0	0	0
Land preparation (clearing of bushes)	0	0	0
Digging of trench, refilling (@ USD0.70/trench)	0	0	0
Planting and staking (@ USD0.23/plant)	0	0	0
Weeding and interculture – from second to 20th year (@ USD0.08/plant)	124	279	31
Watch and ward – cost from first to 20th year (USD/year)	186	418	46
Harvesting – Seventh year onwards (@ USD0.08/plant)	372	1115	124
Subtotal	681	1811	201
Contingency (@ 5%)	34	91	10
Grand total	715	1902	211

The returns from bamboo vary according to the age of the crop. Bamboo poles are harvested from the seventh year onward (three poles/plant up to the 10th year and four poles/plants up to the 20th year). Valued @ USD0.54/pole, the gross returns as per the given example vary from USD650.15 to USD866.87 per year.

5.3 Benefit-cost analysis

BCA, also known as CBA, is an analytical tool for judging the economic advantages or disadvantages of an investment decision by assessing its costs and benefits. The BCA is also defined as a systematic process for calculating and comparing benefits and costs of an investment or a project accrued over a long period of time (at least more than a year). Therefore, it is applied for evaluation of such a long-term investment or project in which there is a stream of benefits and costs that are obtained over several years.

For BCA, benefits and costs are expressed in monetary terms and are adjusted for the time value of money so that all flows of benefits and flows of project costs over time (which tend to occur at different points in time) are expressed on a common basis in terms of their net present value.

Broadly, BCA has two main purposes:

1. To determine if an investment/decision is sound (justification/feasibility) by verifying whether its benefits outweigh the costs, and by how much.
2. To provide a basis for comparing investments/projects – which involves comparing the total cost of each option against its total benefit.

5.4 Identification of benefits/outputs and inputs

The first step in this is to identify the benefits from the investment/project and quantify them. In the case of bamboo plantations, biomass production in the form of culms over the years of bamboo's long, productive cycle is the most tangible economic benefit.

Similarly, costs, which are in much larger number than benefits, in the form of various inputs used for establishing a bamboo plantation, are identified and quantified along with time requirement of each. These can be:

- Manpower (agriculture labour, subject matter specialists, etc.)
- Animal power (bullocks, mules, etc.)
- Equipment (tractors, cultivators, etc.)
- Purchased raw material (planting material, fertilisers, manures, pesticides, water, fuel, etc.)

5.5 Valuing inputs and outputs

The next step after identification and quantification of the benefits and costs is their valuation. The inputs used and outputs produced by bamboo plantations differ in physical terms. Therefore, without valuation of each input used and output produced by using respective price, it will not be possible to aggregate them for judging the economic efficiency of the investment.

The price may be market price (when perfect competition is there); shadow price (when imperfect competition is there); surrogate market price (when input used and output produced have no market value themselves, but there exists a clear substitute for them for which market value exists) or cost price (assigned some value on the basis of personal judgement). Therefore, any of these kinds of prices, in this order of preference, must be used to evaluate the benefits and costs. Otherwise, any benefit or cost not valued will not be accounted in the evaluation using BCA.

For any (and each) input or output, a constant price, which is the average of five years of prices of that input or output, instead of current prices, is used for valuation. The average price of the project period, i.e. the active operation phase, is used for any (and each) input or output. This is done to remove the price effect, i.e. price changes occurring in the market on which the investment project has no influence. Price indices can be used to find prices of different years if the price of any one year of the period of evaluation is known.

Period of analysis

It is the economic life of the project, or the life till benefits and costs occurred. In the case of a bamboo plantation, it can range from 15 to 30 years.

5.6 Economic evaluation

The basic objectives of economic evaluation are to measure the project worth by comparing the values of goods and services produced or conserved with the cost incurred **after taking into account all effects of action taken**.

Time value of money

Money and time have a strong relationship. This is evident from the interest one earns/pays for the usage of the principal amount. The value of money increases with time because it can be used in any profitable enterprise that will give the highest rate of return. Since the costs and returns from a bamboo plantation are accrued over a long period of time (years), and there is no close and apparent synchronisation in occurrence of costs and returns – the costs and returns occur at different times (the major portion of the costs are incurred in the initial period and the returns vary according to the age of the crop). Hence, the time value of money must be taken into account during the evaluation.

Opportunity cost principle

Opportunity cost is the benefit that a person foregoes by choosing another best alternative. For example, if the money invested in a bamboo plantation would have been invested in some other next-best profitable enterprise (such as a bank deposit), then the interest earned is the opportunity cost. Hence, the opportunity to earn the returns from alternative investment (bank interest) is lost/forfeited.

Discount rate

For taking into account the above two effects of the action taken in investing for establishing a bamboo plantation, aggregated value of benefits and of costs in each year are adjusted for time value of money for estimating their respective PV in the first year of the project by using the interest rate of a fixed-term bank deposit as the discount rate. So the bank's rate of interest is taken as the discount rate. From a social/environmental point of view, a lower discount rate is taken. In case of risk, a higher discount rate is taken.

The discount rate is yet another name for the rate of interest society should charge itself for the opportunity cost of time. Time is the most irretrievable loss for all. As time goes on, opportunities are inevitably lost. Therefore, one wishes to use time as efficiently as one can. The appropriate rate of discount is that rate which represents the rate of return on an alternative investment of equal degree of risk.

The discount rate taken has a strong inverse correlation with the period of analysis. The higher the discount rate, the shorter will be the period of analysis because discount rates act progressively to reduce the PV of benefits or costs. Therefore, two important factors decide the period of analysis of a project: (i) the expected useful physical life of the project and (ii) the level of discount rate.

- When a bank interest rate is used as the discount rate, the period of analysis is the technical life of the project (e.g. a bamboo plantation can give a profitable output for 20 years). Here, profit-earning is the ultimate aim. It is also called Financial Analysis.
- When an aim of ‘no profit, no loss’ or continuance of environmental/social benefits from the bamboo plantation are adopted, a longer period of analysis (an extra 10 years) is undertaken with a lower discount rate. It is also called Economic Analysis.

5.7 Discounted measures of project worth

Discounted measures are adjusted values to incorporate the time value of money. The measures that come under this are described below.

Net Present Value (NPV)

This is simply the discounted value of gross benefits minus the discounted value of costs. The general formula for NPV is:

$$NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1 + i)^t}$$

where, Bt = Benefits at time t; Ct = Costs at time t

i = Discount rate (%); t = Life of project

Decision rule: Accept the project if NPV > 0; otherwise, reject. The higher the NPV, the better the project. Select that project which has highest NPV.

Payback period (PBP)

It refers to the length of time it will take to recover an initial investment. It is the number of years after the project initiation that the cumulative NPV becomes greater than zero, i.e. positive, and thereafter continues to remain so.

Benefit Cost Ratio (BCR)

It is defined as the ratio of present value of gross benefits to the present value of total costs.

$$BCR = \sum_{t=1}^{n} \frac{B_t / (1 + i)^t}{C_t / (1 + i)^t}$$

Decision rule: If BCR $\geq$ 1.0, accept the project; otherwise, reject. The projects with higher B:C ratios are selected on the basis of their rankings based on BCR, till the budget is exhausted. For a set of mutually exclusive alternatives, choose the costliest alternative if the incremental benefit costs ratio exceeds unity; otherwise, choose the less costly alternatives.

Internal Rate of Return (IRR)

It is the rate of discount which makes the present value of benefits equal to present value of costs. IRR is the discount rate r, such that

$$\sum_{t=1}^{n} \frac{B_t - C_t}{(1 + i)^t} = 0$$

In the absence of spreadsheet software with mathematical functions (e.g. Microsoft Excel), IRR can be calculated as follows:

$$\text{Last discount rate which yields a positive present value} + \frac{\text{The present value for the discount rate which gave the lowest positive total present value}}{\text{The sum, without regard to sign, of the above number plus the present value for the discount rate which yielded the first negative present value.}} \times \text{Difference between the two discount rates mentioned in this formula} = \text{IRR}$$

Decision rule: Select the project if r $\geq$ i; otherwise, reject. 'r' is the internal rate of return and 'i' is the rate of interest to be paid on the money to be invested.

BCA of perennial crops

BCA of the same example of one hectare of bamboo plantation (400 plants per ha) with 20 years of life and a discount rate of 10 per cent is as follows:

Item	Costs (USD)	Benefits (USD)	Net Benefit (USD)	Discount Factor (@ 10%)	Present Value of Costs (USD)	Present Value of Benefits (USD)	Present Value of Net Benefits (USD)	Cumulative of Present Value of Net Benefits (USD)
Year 1	688	0	-688	1	688	0	-688	-688
Year 2	208	0	-208	0.909	189	0	-189	-877
Year 3	208	0	-208	0.826	172	0	-172	-1049
Year 4	197	0	-197	0.751	148	0	-148	-1197
Year 5	81	0	-81	0.683	56	0	-56	-1253
Year 6	81	0	-81	0.621	50	0	-50	-1303
Year 7	179	650	471	0.564	101	367	266	-1038
Year 8	179	650	471	0.513	92	334	242	-796
Year 9	179	650	471	0.467	83	304	220	-576
Year 10	179	650	471	0.424	76	276	200	-376
Year 11	211	867	656	0.386	82	335	253	-123
Year 12	211	867	656	0.35	74	303	229	107
Year 13	211	867	656	0.319	67	277	209	316
Year 14	211	867	656	0.29	61	251	190	506
Year 15	211	867	656	0.263	56	228	172	678
Year 16	211	867	656	0.239	50	207	157	835
Year 17	211	867	656	0.218	46	189	143	978
Year 18	211	867	656	0.198	42	172	130	1108
Year 19	211	867	656	0.18	38	156	118	1226
Year 20	211	867	656	0.164	35	142	108	1333
Total					2206	3539	1333	
					BCR 1.60		NPV	

The investment is profitable as it has a positive NPV of USD1333 and BCR of more than one, i.e. 1.60. The PBP in the above example is 12 years, which indicates that till the 11th year, the investment is in a loss. The IRR of the investment is 18.07 per cent, which is significantly higher than the discount rate of 10 per cent, thereby indicating the investment to be very profitable.

5.8 Intangible benefits of bamboo crops

In addition to tangible benefits in the form of bamboo timber, bamboo plantations also provide intangible benefits. Intangible benefits are benefits that are difficult to measure (quantify) and valuate (monetise). Bamboo plantations conserve soil, thereby helping prevent erosion and improve soil health along the way. In addition, benefits of living biomass and soil organic matter content in bamboo stands have been reported. Bamboo plants mature within seven years (compared to 30–50 years for other trees), providing these intangible benefits much earlier as compared to other tree species.

Soil conservation

Erosion carries the topsoil off fields, which reduces the land's productivity. Though some, but not all, yield losses can be offset from a land being used for production purposes by increasing use of fertilisers, it can be assumed that the productivity of soil can be maintained if the lost nutrients and organic matter are replaced artificially. The resource value of soil conserved with bamboo plantations can be imputed in the form of cost of replacing the lost soil nutrients that would have been otherwise lost in the absence of a bamboo plantation on the land. Under this approach, the loss of nutrients with soil erosion is valued in terms of the annual marginal cost of their replacement. The basic premise of the replacement cost method is that the cost incurred by replacing the productive assets damaged by an economic activity can be measured and interpreted as benefits if the damage was prevented. This approach is possible if data on nutrient loss and market price of nutrient are readily available.

The soil conservation effects of bamboo studied at the research farm of Regional Research Station of ICAR – IISWC, located at Vasad (Gujarat), have shown that a bamboo plantation retains 80–100 per cent of rainwater. This water is either used by the vegetation or recharges the groundwater. The sediment yield is reduced to 1.4 t/ha in a high rainfall year, which is 10–20 times less than an untreated watershed. Further, the studies conducted at the research farm have also shown the conservation effect of bamboo plantation on improved soil health over a period of time. The nitrogen, phosphorus and potash content of soil in ravine lands of this region ranges between 101–470 kg/ha, 24–95kg/ha and 216–470kg/ha, respectively. This works as a lower and upper bound for the nutrients in the soil conserved as a result of a bamboo plantation.

In ravine lands, FYM is applied by farmers in small quantities prior to planting, but the quantity is too small to replace the nutrients lost through soil erosion. Hence, only chemical fertilisers are used for replacement of nutrients lost. Further, nitrogen is closely related with carbon in the soil under plantation. Since evaluation of carbon is done separately, the benefit of this nutrient need not be summed up in the nutrients saved. The price of phosphorus (USD0.34 per kg) and potash (USD0.12 per kg) nutrients can be imputed from prices of fertilisers Di Ammonium Phosphate (DAP – USD21.52 per 100 kg) and Murate of Potash (MoP – USD6.90 per 100 kg) for economic analysis. The value of nutrients thus saved through bamboo plantations is estimated to be USD33–86/ha, with an average value of USD59 in the 20th year of the plantation. Average nutrient content in the ravine land of Vasad (Gujarat) region of India is given in Table 5.1.

Table 5.1: Average nutrient content in the ravine land of Vasad (Gujarat) region of India

Nutrients	Lower value (kg/ha)	Higher value (kg/ha)	Lower value (USD/ha)	Higher value (USD/ha)	Average value (USD/ha)
P_2O_5	24	95	8	32	20
K_2O	216	470	25	54	39
Total			33	86	59

Note: Price of phosphorus (USD0.34 per kg) and potash (USD0.12 per kg) nutrients utilised

Soil organic carbon enhancement

Carbon stock build-up under a bamboo plantation comprises living biomass and soil organic matter. While the former is depleted with the harvest of bamboo, the latter is retained in the soil as long as the bamboo plantation lasts. The carbon build-up in the soil under a bamboo plantation can be taken as a scenario that the degraded ravine land with no vegetation would have lost not only the soil nutrients but also the opportunity of building the soil carbon under the plantation. Therefore, the intangible benefit of carbon build-up is the additional benefit, which if valued at the shadow price of carbon, augments the utility of the bamboo plantation.

In a study at the research farm of Regional Research Station of ICAR – IISWC, located at Vasad (Gujarat), soil samples taken from bamboo plantation sites after 20 years of plantation, and similar samples taken from the fallow lands from different depths, were averaged for comparison (Table 5.2).

Table 5.2: Soil carbon under bamboo plantations

S. No.	Conservation land use	Organic carbon (kg/m^2) at different depths of soil profile							
		0–15 cm	15–30 cm	30–45 cm	45–60 cm	60–75 cm	75–90 cm	90–105 cm	Total
1	Ravine land under bamboo plantation	1.32	0.71	1.17	0.91	0.94	0.77	0.64	6.47
2	Fallow ravine land	0.45	0.59	0.42	0.32	0.33	0.14	0.12	2.37
	Difference								4.10

The cumulative soil carbon build-up was higher under bamboo plantations than in the fallow ravine lands. The analysis revealed a soil carbon build-up of 41t/ha (4.1kg/m^2) over fallow ravine land. This carbon build-up remains in the soil if a plantation is maintained for a longer period, following the recommended cycle of harvesting 30 per cent of mature culms per clump. Imputing a value to this at a shadow carbon price of USD 20 per ton of carbon works out to be USD820/ha.

Including the values of the two intangible benefits into benefit-cost analysis of bamboo plantations will improve the BCR to 1.67 and NPV to USD1478.90. Whereas the PBP will remain the same 12 years, the IRR will improve to 18.44 per cent.

5.9 Conclusion

Cost of cultivation of a given farm production activity plays an important role in decision-making about the activity as it affects level of production (output) and also profit from that enterprise. Since input prices are not under direct control in a competitive market, cost can be reduced through rationalisation of resource use. The long gestation and productive periods of bamboo require estimation of its cost of cultivation in two parts, i.e. establishment cost and maintenance cost. The returns from bamboo vary according to the age of the crop. BCA is applied for evaluation of a long-term investment or project in which there is a stream of benefits and costs that are obtained over several years, e.g. cultivation of bamboo which naturally has long gestation and productive periods. BCA determines if an investment is sound/feasible by verifying whether its benefits outweigh the costs, by how much and providing a basis for comparing long-term investments/projects. For BCA of bamboo cultivation, data of benefits and costs (identification and quantification) and their valuation are essential. The data is required year-wise for the cultivation duration. The valuation is done by using an average price of each output or input, which will be repeatedly used in every year's calculation. In addition to tangible production benefits, bamboo plantations also provide intangible environmental benefits of soil conservation, which are provided within seven years of planting, much earlier than many tree species. These intangible benefits can be imputed in the form of cost of replacing the lost soil nutrients (replacement cost) that would have been otherwise lost in the absence of a bamboo plantation on land.

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RESEARCH METHODOLOGIES FOR FIELD MONITORING, ANALYSIS AND EVALUATION OF RESOURCE CONSERVATION ASPECTS OF BAMBOOS

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