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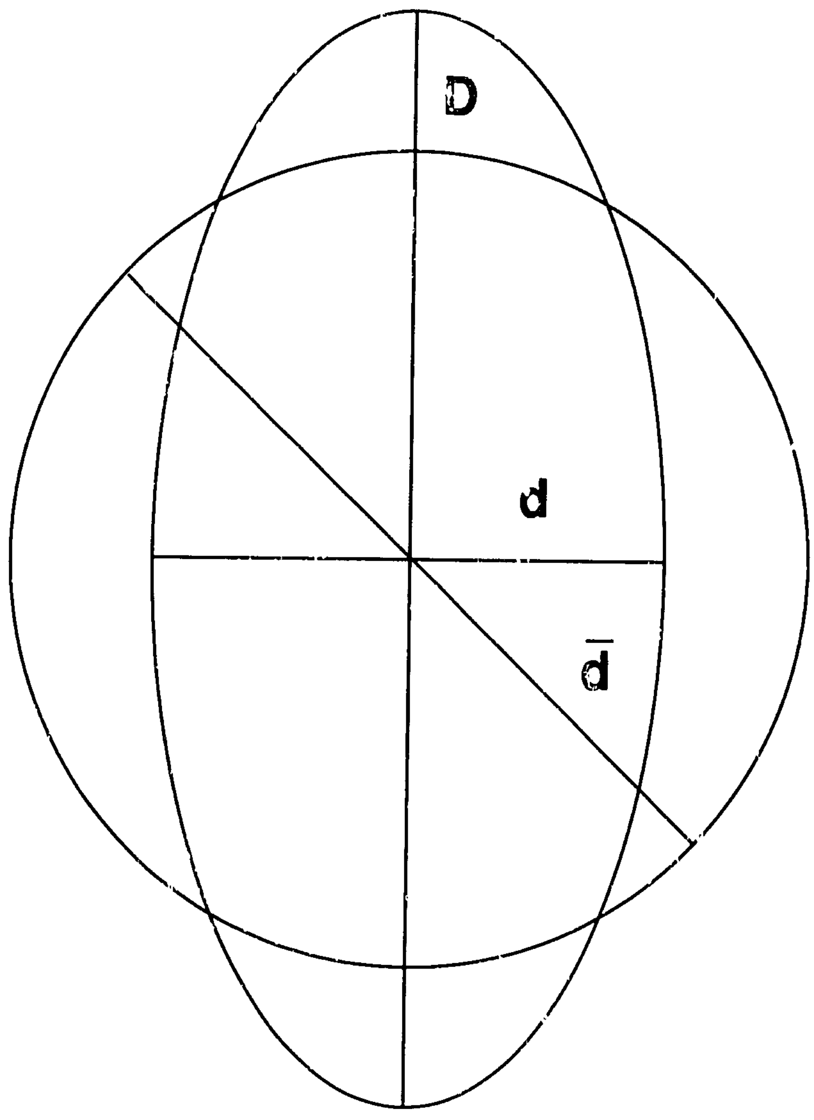
Field Trials Manual for Multipurpose Tree Species



C. Buford Briscoe

Multipurpose Tree Species Network Research Series

Field Trials Manual for Multipurpose Tree Species

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Multipurpose Tree Species Network Research Series

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1.0 Introduction

All research plans share the following essential elements:[1]

- o statement of objectives
- o background
- o treatment specifications
- o proposed method of analysis

The statement of objectives should be clear and concise and should assign relative priorities. It should also clearly define the population to be studied to help guide experimental design. When appropriate, it should briefly explain the importance of the study.

Background should include the reasons why the objectives are important and a summary of related work.

Treatments (procedures or materials whose effects are to be measured) must be stated clearly and in detail, and their relation to the objectives must be understood. Preferred treatments are those that indicate basic relations: nitrogen fixing versus non-nitrogen fixing, tolerant versus intolerant species, etc.

Any series of treatments may include a control (either a treatment found usually to give good results or no treatment at all). The control treatment must be randomized, replicated, and dealt with like other treatments. A no-treatment control is used particularly with applications of fertilizers or herbicides.

Other specifications usually include number of replications, plot size, season of treatment, general management practices applied to all treatments, and details on required equipment and materials.

Personnel and their individual responsibilities should also be specified.

Method of analysis is included as an important guide to experimental design. Commonly included are a sample form for summarizing results, a model of analysis of variance or covariance, and/or the primary form of equation to be used for regression analysis.

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[1] A classic textbook on design and analysis is *Experimental designs,* 2nd ed., by W.G. Cochran and G.M. Cox (New York: John Wiley & Sons, Inc., 1957).

A concise and clear description of field trial design, with model of a study plan, is contained in *Simple experimental design for forestry field trials*, revised ed., FRI Bulletin 71, by Ian Andrew (Rotorua, New Zealand: Forest Research Institute, 1986).

Network Experiments

The field trial experiments of the Forestry/Fuelwood Research and Development Project (F/FRED) networks have the following objectives:

- o provide a focus for network development
- o increase knowledge of growth, site requirements, and management practices of priority multipurpose tree species (MPTS)
- o improve forestry research methodologies

Cooperative research involves many countries, each with several research organizations and individual scientists working toward a common goal: knowledge of a specific species or problem using common methods and shared results over regionwide biological, physical, cultural, and economic conditions.

A cooperative experiment includes the following critical elements:

- o consensus objectives
- o common design and standard methods (modified only by general agreement)
- o common experimental materials
- o the same experiment conducted at multiple sites representing a range of conditions
- o thorough documentation of the biological, physical, and socioeconomic conditions of each research location
- o data exchange, professional interactions, and personal relationships among participants
- o intersite combined analysis of data
- o review and revision by all participants of methods, materials, and priorities to improve future research

What This Manual Is About

The *Field Trials Manual for Multipurpose Tree Species* is designed to help guide MPTS field researchers, whether for forestry or agroforestry objectives. In this context, the term *forestry* refers to the management of trees in groups for producing goods and services; *agroforestry* refers to production systems in which woody perennials interact with agricultural crops and/or animals for producing goods and services. This manual is not a comprehensive treatise on field-trial procedures. Its objective is to describe a system with a high reliability in the field, based on standard field methods and simple designs.

Section 2.0 reviews basic considerations in designing a statistically valid trial. Some examples, with possible field layouts, are included. Section 3.0 treats nursery practices, including germination of seeds, care of seedlings, lifting and transport. It does not discuss nursery location, establishment, or management. Field establishment and post-planting care (sections 4.0 and 5.0, respectively) describe what should be done but not how. The "how" depends greatly on local tools and practices, most of which are satisfactory if care is used.

Measurements (section 6.0) are considered in detail because they must be standardized to ensure meaningful comparisons between experiments, even those conducted by the same scientist.

Details given for recording data in section 7.0 are applicable only to the Information and Decision Support System (IADSS) prepared by the F/FRED Global Research Unit. The type of information is virtually universal to MPTS studies.

The specific forms described in section 7.0 are contained in the IADSS software (version 1.1). A final version of the summary forms is awaiting agreement by scientists in other networks and will be included in a future edition of this manual. Both the software and documentation will be available to research organizations in developing countries.

The codes contained in section 8.0 are provided to reduce the tedious detail of data entry, conserve computer memory, and speed analysis.

The appendices include field trial procedures already under way in the F/FRED-sponsored humid and sub-humid network and those planned for arid and semi-arid network trials. Because procedures logically will differ between networks, those included here should be considered as examples, but not necessarily models.

This manual emphasizes the need for standardized methodology. This does not imply that scientists should conduct identical experiments. It means that they should determine and express site and tree charcteristics in the same way so that variations represent experimental, not methodological, differences.

Who Should Use This Manual

The *Field Trials Manual for Multipurpose Tree Species* has been prepared for the research cooperators of the MPTS network sponsored by the F/FRED Project. However, we hope that, with periodic updates, this manual can aid any scientist interested in establishing and measuring field experiments of MPTS.

We also hope scientists will review the procedures contained in this manual and recommend changes and improvements. By early 1990, it should be possible to publish an updated version that describes an effective, fully integrated, and proven system for field trial establishment, care, measurement, and analysis. Thereafter, scientists and research organizations can confidently exchange and compare information from the summary forms.

Acknowledgments

This manual is an expansion of the *Manual for Multipurpose Tree Species Research Cooperators for the F/FRED 1987 Humid and Sub-humid Network Trials* (manual no. 2 in the Multipurpose Tree Species Network Research Series). Like the original, this work represents the contributions of a great many people, particularly the Asian cooperators in the MPTS research network. Detailed suggestions were made on early drafts by Celso B. Lantican (F/FRED), Hector Martinez (CATIE), Len Reynolds (ILCA), Janet Stewart (OFI), and David A. Taylor (F/FRED).

2.0 Design of Experiments

For good research design, remember the five Rs:[2]

- o Define the **RANGE** of conditions for testing.
- o **RESTRICT** each study to no more than a few, simple treatments.
- o **RANDOMIZE** treatments in each block, and locate blocks to minimize site variation within blocks.
- o **REPLICATE** every treatment, preferably four times.
- o **RECORD** everything planned and done.

If every plant of a given species that received the same treatment on the same site grew and produced at the same rate and quality, experimental design would be simple and cheap. Unfortunately, this is not the case. Each experiment must be carefully designed so that specific questions can be answered conclusively, including statistical validity.

Statistical analysis, however, is not always necessary. If the question is whether teak (*Tectona grandis*) and whitebark pine (*Pinus albicaulis*) will grow at the same rate if both are planted on a deep, well-drained, fertile soil in the humid tropics, every teak tree will probably grow taller and thicker than any surviving pine. Conversely, if both are planted in the sub-alpine zone on a temperate-region mountain, the pines will probably grow slowly, but the teak will die early during the first autumn. However, such clear answers to our questions are rare and would indicate an exploratory study with little background knowledge.

If teak and melina (*Gmelina arborea*) were compared in the humid tropics or whitebark and lodgepole (*Pinus contorta*) pines compared on an upper mountain slope, we could almost universally expect that some difference between means would be found. But the magnitude of individual measurements would overlap so that we could not decide by observation whether they are really different. Without statistical analysis, and thus, without an experimental design that permits it, we could not calculate the probability of differences caused by various treatments or other "random" factors.

Design and install every experiment in a way that permits statistical analyses. If the results are absolutely clear upon inspection and confirm or refute the hypothesis being tested, no analysis may be needed. But if analysis is needed, the design must permit it. Otherwise, valid interpretation is not possible.

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[2] For a comprehensive discussion on design and implementation of field-trial research, see *A manual on species and provenance research with particular reference to the tropics*. Tropical For. Paper No. 10, by J. Burley and P.J. Wood (London: Commonwealth For. Inst., 1976).

2.1 Range of Conditions To Be Tested

The first consideration in designing a trial is to define the full scope of conditions to be tested, known as the *range of inference*. If we are interested only in the trees in our own front garden, we can easily measure and determine differences. But if we are interested in all the trees in Country X, only some of the trees can be measured. It is highly unlikely that the few trees in our front garden could accurately represent all the trees in Country X. If we measure all the trees in our village, the results will probably not be representative. Even all the trees in a province or on an island are not representative of the whole country. The best sample representing Country X includes the opportunity to select from anywhere in that country. It must include the full variety of relevant conditions that occur within national boundaries. If not, the sample cannot be applied to areas where the conditions not included are found.

Obvious? Of course. But all too often a small sample from one seedlot of a species at a few sites is interpreted as if it were representative of the entire species for an entire province, island, or region. A study can be made of one half-sibling family, provenance, or species; it can be made of one village, district, or country. But if information is needed for a whole nation, the sample must be drawn from that whole nation.

The same consideration applies to other aspects. If you're going to study weight of thinning, include the heaviest to the lightest weights contemplated. If you plan to study range of sites, include the highest and lowest available, best and worst, wettest and driest. Failure to include extremes requires extrapolation of data, a process always fraught with peril.

Generally speaking, the extreme values tested for any variable should be outside the range considered practical. This a) confirms the expected limits by demonstrating reduced values or b) expands those limits. Either result is useful.

Selecting specific locations for a regional, cooperative study must include a preliminary selection and review to ensure that all critical combinations of site conditions (especially soils and climate) are included. If every cooperator simply chooses the site of greatest local importance, it is highly probable that many of the locations selected will include the same conditions while other, less desirable conditions will be left out. Most researchers prefer to work on (and tend to select for study) gentle slopes with deep soils. But a regionwide study of gentle slopes and deep soils provides no guidance to using steep slopes and shallow soils, which certainly exist and need care over millions of hectares.

When you plan to represent a factor that occurs continuously along a gradient, such as latitude, elevation, or depth of soil, you must include at least four well-distributed points. The critical reason for this requirement is that most biological relationships are curvilinear; indeed, a great many are sigmoid. A linear relationship can be defined and verified by three well-placed points, but a curvilinear relationship requires an absolute minimum of four points (Figure 2.1). When the curve is known to be sigmoid, the ideal definition is two points below the lower point of inflection, three along the linear portion of the curve (if such exists), and two points above the upper point of inflection (Figure 2.2). From such neatly arranged treatments, you can calculate a definitive mathematical model of the relationship.

Define the range of interest, then allow every sampling unit in that population an equal chance of being measured. To the extent this is not done, you run an unknown and incalculable risk of being wrong.

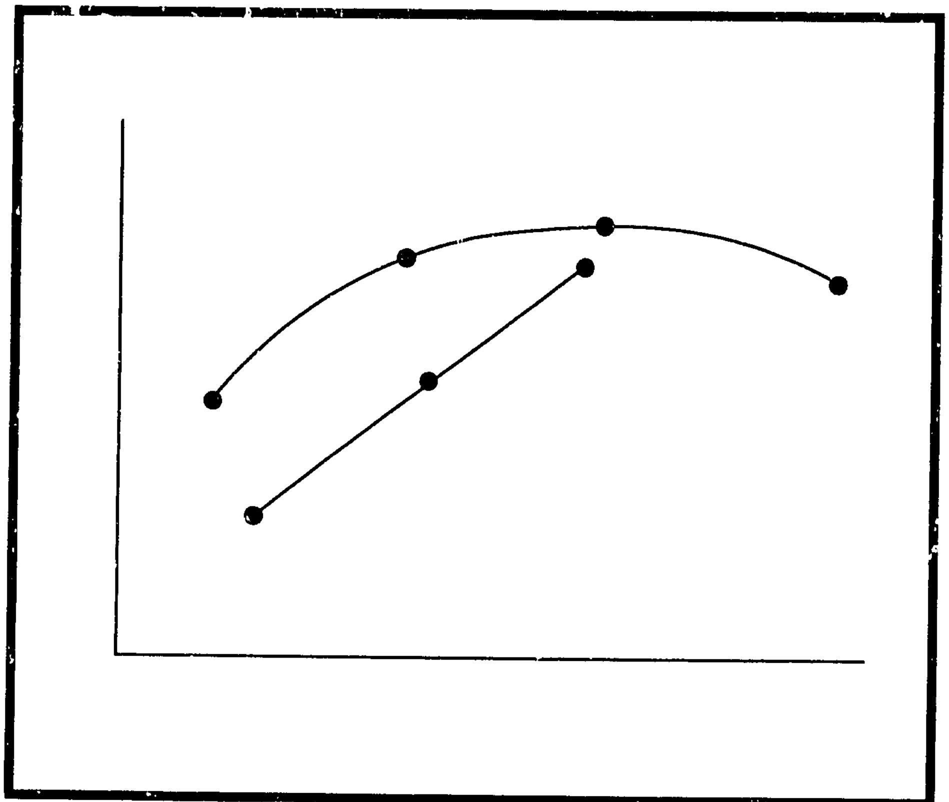

Figure 2.1. Definition of simple curves.

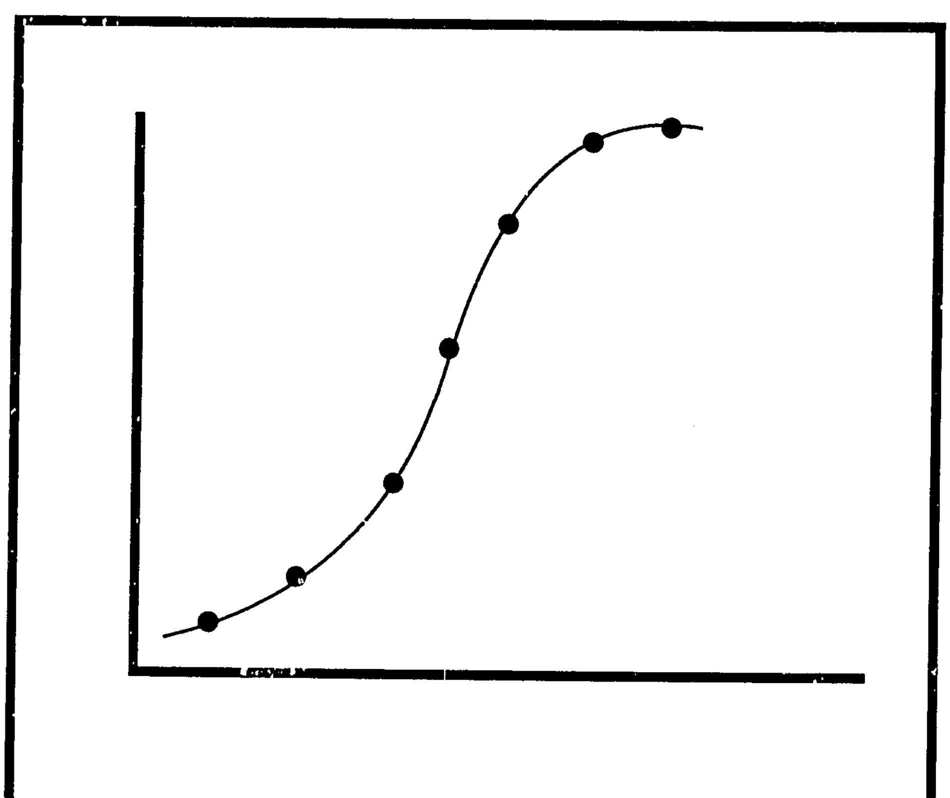

Figure 2.2. Definition of sigmoid curve

2.2 Simplicity

Over the life of tree experiments, many unplanned factors can affect the results. While you cannot avoid these factors, you can minimize their effects by keeping the study simple. If four species are being compared or if four cultural treatments of a species are being compared (and no other type of treatment is applied in either case), both the establishment and analysis are straightforward and robust. Even if grazing, fire, or other accidents occur at some plots, you can usually compare the surviving treatments with the loss of only a proportional amount of precision.

More complex designs involving interactions between different types of treatments are often capable of greater efficiency. On plowed and cultivated fields with chemical and moisture inputs supplied as needed for an annual or brief period, such designs serve well. For long-term studies on heterogeneous soil and site conditions and little control over impinging factors, the robustness of simple experiments is often more important than the potential efficiency of complex ones.

Restrict one experiment to a few treatments.

2.3 Randomization

Non-treatment factors can influence or even control the results of your experiment. A solid, laterite pan or salt layer near the surface influences tree survival and growth more than species or spacing. You can handle such undesired factors in various ways:

o re-define the population under study (the range of inference, section 2.1)

o hold the extraneous factor at a constant level

o partition the non-experimental factor

o randomize

Limiting the range of inference is a universal practice. Trees are almost never planted on solid rock, in open water, or on a surface salt layer. This is so invariable that tree planters never report leaving out lakes, rivers, salt flats, and rock ledges from their planting areas. Both planters and their audiences assume such omissions.

When you do plant species in these areas, such as *Prosopis tamarugo* on salt flats or *Rhizophora* on tidal flats, you must state the practices used or your audience will assume these sites are omitted. If your existing or proposed plans include planting such sites, you must include the sites in the related research.

Holding the extraneous factor at a constant level is also universal. In the nursery, all species and container types are irrigated as needed. In the field, either all species and spacings are cleaned or, alternatively, none are. You should define such practices, keep them at uniform levels for all experimental treatments, and record them as carried out.

Some variations must be included. If areas to be planted include hillsides, for example, the supporting research must also include hillsides.

In field plot research, partitioning such non-experimental factors is most frequently done by selecting an apparently uniform area called a block and installing one plot of each treatment within that block. If every treatment is included in every block and the positions are allocated at random, the arrangement is called a Randomized Complete Block (RCB) (Figure 2.3). This is neither the only possible design nor always the cheapest or most efficient. However, it is inexpensive, simple, and usually the most reliable for long-lived studies. Reliability is extremely important for investigations lasting several years.

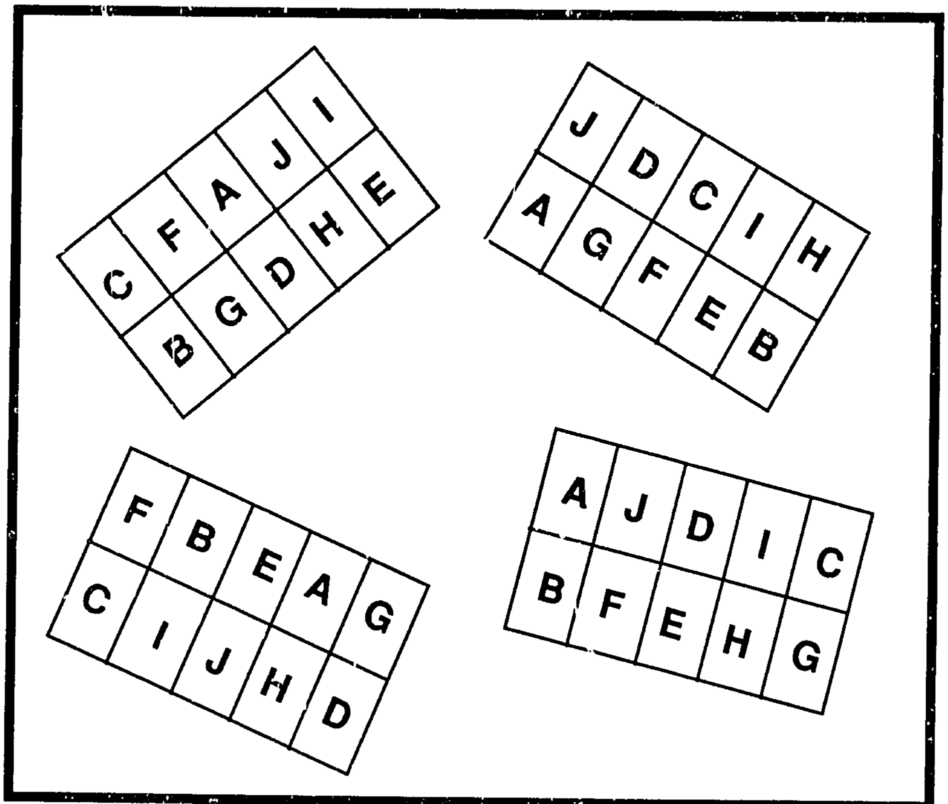

Figure 2.3. Examples of randomized complete blocks.

Three key considerations in using the RCB design are:

1) Conditions within the block should be as uniform as possible. On a hillside, conditions commonly vary with position on the slope, so a block is usually rectangular and on the contour (Figure 2.4). On mostly level ground, conditions usually vary with distance in any direction, so a block is square. You should review the study site and establish blocks to minimize within-block variation.

   Plots should be laid out to include as much of the unavoidable variation as possible in every plot of the block. On a hillside, plots should run up and down; on level ground, rectangular plots are usually preferred to square ones.

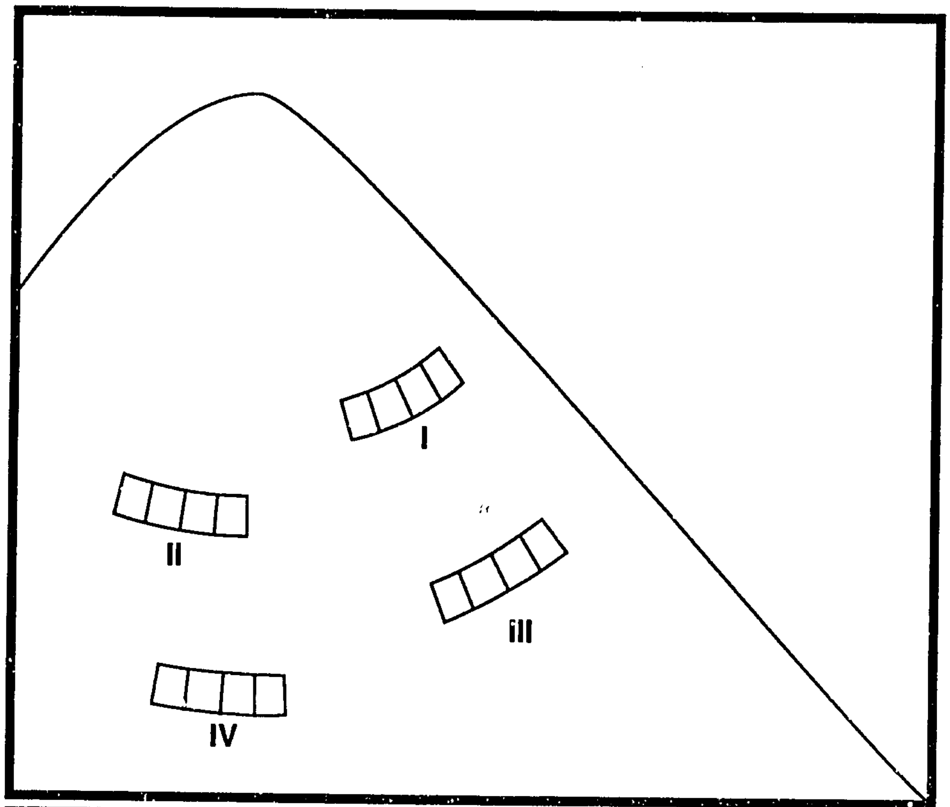

Figure 2:4. Hillside blocks on contours.

2) Assignment of treatments within each block must be randomized for that block. The calculation of error assumes complete randomization. Selecting one random pattern and repeating it would violate that assumption since every block would have the same pattern.

3) Treatment*block interaction should be avoided. If *Casuarina equisetifolia* and *Eucalyptus camaldulensis* are involved in a species trial and adjacent blocks are on excessively well-drained sand and on intermittently flooded heavy clay sites, *Casuarina* can be expected to grow better than *Eucalyptus* on the sand and the *Eucalyptus* much better on the clay. Thus, the species/soil interaction would be confounded with block and not attributable to either.

Randomize treatments within each block.

2.4 Replication

To measure the random error found within a treatment, you need two or more measurements (replications). If each block at a general location contains one plot of every treatment, the block constitutes a replication, and the terms are often used as if they were interchangeable. However, if a block lacks some treatments or contains two or more plots of some or all treatments, it obviously does not equal a replication. If a study is not based on complete blocks or if one or more treatments are replicated within a block, you must take care to distinguish between block and replication.

As indicated above, some replication is necessary; but because replications require more materials, labor, time, land, and money, you should seek the minimum number necessary. The two most commonly used criteria for determining "minimum" are *precision of estimate* and *probability of being correct.*

Precision of a sample is usually expressed by the width of the confidence limits about the mean. To say that the average height equals 10 ± 1 m is more precise than saying the average height equals 10 ± 2 m. The precision of estimate is 10% in the first example but only 20% in the second.

In a randomly distributed population, precision of a sample varies inversely with the square of the number of sample measurements. Cutting the precision of error in half requires four times as many measurements. The increase in cost is formidable.

The other, more common way to improve precision is by increasing the probability of being correct. In the first example above, the complete statement would be that the probability is 95% (or whatever percentage is appropriate) that the true mean is 10 m ± 1 m. Improving probability of being correct, under many conditions, is more economical than improving precision.

Table 2.1 shows the Student's t, which describes the distribution of random error about the mean in a normally distributed population. The product of a t-value multiplied by the standard error of a sampling mean indicates a band of values on both sides of the sample mean that can be expected to include the true population mean. The probability for testing that the true mean will not fall outside that band (in the sample, 95%) as a result of chance is selected by investigators, using their own criteria.

Table 2.1 Relationship of costs and reliability to t-value. [a]

No. plots	Df[b]	t.95[c]	Approx. total cost of plots (%)	Increased reliability (%)
1	0	Infinity	-	0
2	1	12.71	100	Infinite
3	2	4.30	50	196
4	3	3.18	33	35
5	4	2.78	25	14
6	5	2.57	20	8
7	6	2.45	17	5

[a] The t-value is abstracted from R.A. Fisher and F. Yates, *Statistical tables for biological agricultural and medical research* (Edinburgh: Oliver and Boyd, Ltd. 1943).

[b] Df = Degrees of freedom (about equal to number of measurements or plots minus 1).

c t.95 = Student's t distribution at the 95% probability that results are not by chance. A similar pattern is encountered at any probability level.

For statistical purposes, one plot has zero degrees of freedom, a t value of infinity, and is useless. For two plots, the difference between treatments must be almost 1,300 % of the standard error to be significant whereas cost (number of plots) has only doubled. For three plots, cost increases 50% and a significant difference is reduced to less than 200% of the standard error. For four plots, the 33% cost increase is still slightly less than the 35% reduction in significant error. For five plots, the 14% improvement in probability of accuracy is much less than the 25% increase in cost, and the ratio of benefit to cost continues to decrease with additional measurements.

Thus, for any acceptable precision and level of confidence, the probability of being correct increases faster than cost up to 4 replications (for a probability of 95 to 99, the most used). For five replications or more, cost increases accelerate in comparison to probability of accuracy. Two or three plots would be cheaper to install, but variation is often so large that lost precision outweighs the economy of implementation.

Replicate always. Use four replications unless special circumstances encourage modification.

2.5 Records

To maintain continuity and understanding of your work and to communicate your results reliably and understandably, you must maintain written records of all procedures and circumstances. The experience of researchers throughout the world has demonstrated repeatedly that adequate records are kept only when record-keeping is an integral part of the study design.

Your records should include:

- o actual site conditions
- o treatments planned
- o exact location of the study sites
- o treatments actually applied
- o reasons for deviating from original plan
- o phenological observations
- o recommendations for applying the same type of study elsewhere

See section 7.0 for a more detailed discussion of records.

Record everything planned and done.

3.0 Nursery Procedures

General tips to remember:

- o Keep the nursery clean; disinfect materials and supplies.
- o Carry out small-scale germination tests, including mechanical or hot water scarification, before sowing main seedlots.
- o Grow new species in containers, but test other methods for improved survival, vigor, and cost efficiency.
- o For accustomed species, use the nursery techniques that are best for each.
- o Prevent roots from extending beyond container and entering soil.
- o Use minimum-required amounts of pesticides, fertilizer, and shade.
- o Water newly germinated seedlings daily, gradually reducing the frequency as you increase the amount.
- o Weed frequently and well.
- o Replicate seedlots in the nursery.
- o Grade seedlings, preferably by diameter at the root collar, and keep uniform lots together.
- o Avoid heating, desiccation, and physical damage while transporting and transplanting trees.

3.1 Introduction

Nursery production of planting stock is an essential prelude to most forestry field trials. Many manuals and reports fully describe nursery operations.[3] Most are summarized briefly here, but some aspects that have been at times neglected or perhaps misstated are discussed in more detail.

The foundation of sound nursery practice is the recognition that seedlings are baby trees. Like all infants, they are delicate, sensitive, and require tender loving care.

The design of nursery experiments should follow the general guidelines for other experiments, with appropriate modifications. This discussion considers nursery work primarily as a part of a

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[3] Two good examples with a tropical orientation are *From seed to trial establishment*, DFR User Series No. 2, by E.J. Carter (Australia: CSIRO, 1987); and *A technical guide for forest nursery management in the Caribbean and Latin America*, General Technical Report SO-67, by L.H. Liegel and C.R. Venator (New Orleans, Louisiana: USDA Forest Service, 1987). Despite the geographical restriction implied by the latter title, the guide contains much valuable information applicable throughout the tropics and subtropics.

larger study, not an end in itself. Nursery research proper has more in common with horticultural and agronomic studies than with forestry field trials.

The objective of nursery work as part of a field trial is usually to produce planting stock of high and uniform quality without confounding nursery treatment with species or other planned field treatments.

For example, if four species are to be planted to compare growth, the seedlings of all four should be as vigorous and well-grown as possible at the time of outplanting. Two types of problems work against this ideal: variability of conditions within the nursery and of species requirements.

Despite supervisors' best efforts, conditions throughout the nursery are seldom uniform. Almost invariably, there are low spots where the beds become waterlogged or even flooded, high or sandy droughty spots, and shady, sunny, or windy spots.

Control this undesired variation as you would in the field by selecting homogeneous blocks and then randomly assigning treatments (or seedlings to be assigned to specific treatments) within the blocks.

Unfortunately, this precaution is seldom observed. Instead, relatively large, healthy, vigorous stock of a particular species is outplanted with unhealthy, retarded, or spindly stock of another. It is no surprise that the species of good stock commonly shows superior initial development in the field.

Although vigorous stock may be the result of superior genetic composition, it too often results from unplanned discrimination in nursery treatment. Each seedlot should be replicated at several locations in the nursery (preferably four), along with replications of all the other seedlots. This is a simple and important technique that nursery operators can apply at little or no added cost.

The problem of different requirements among species is harder to eliminate and complicates randomized replication. Successful establishment of teak is most commonly attained using bed-grown stumps (Figure 3.1) with diameter at the root collar (drc) > 15 mm and pruned to a 2 to 7 cm stem height and 15 to 18 cm tap root, without branches and with lateral roots < 2 cm long. *Cedrela*, however, seems to grow better in beds with drc > 10 mm, all leaves stripped off, stem and branches intact, and roots pruned just enough to permit economical planting. Most tropical *Pinus* spp. and many other evergreens consistently do better if drc is > 6 mm and if grown in containers that are carefully removed at the moment of planting.

If the three species mentioned above are pruned equally to stumps, teak will do best, almost regardless of other conditions. Similarly, stripping will favor *Cedrela*, and containerization will favor *Pinus*. Thus, **precisely equal treatment is discriminatory.** Many investigators use containers for all species, presumably on the grounds that containers favor more species than any other single treatment. As a temporary solution, it is a reasonable compromise. But it is not an adequate long-term substitute for growing each species in accordance with its particular needs. For any species of continuing interest, optimum nursery practices should be determined and used prior to any field study.

For any nursery test or short-term field trial, the initial tree dimensions should be recorded and tree **growth**, not tree **size**, should be analyzed as the dependent variable.

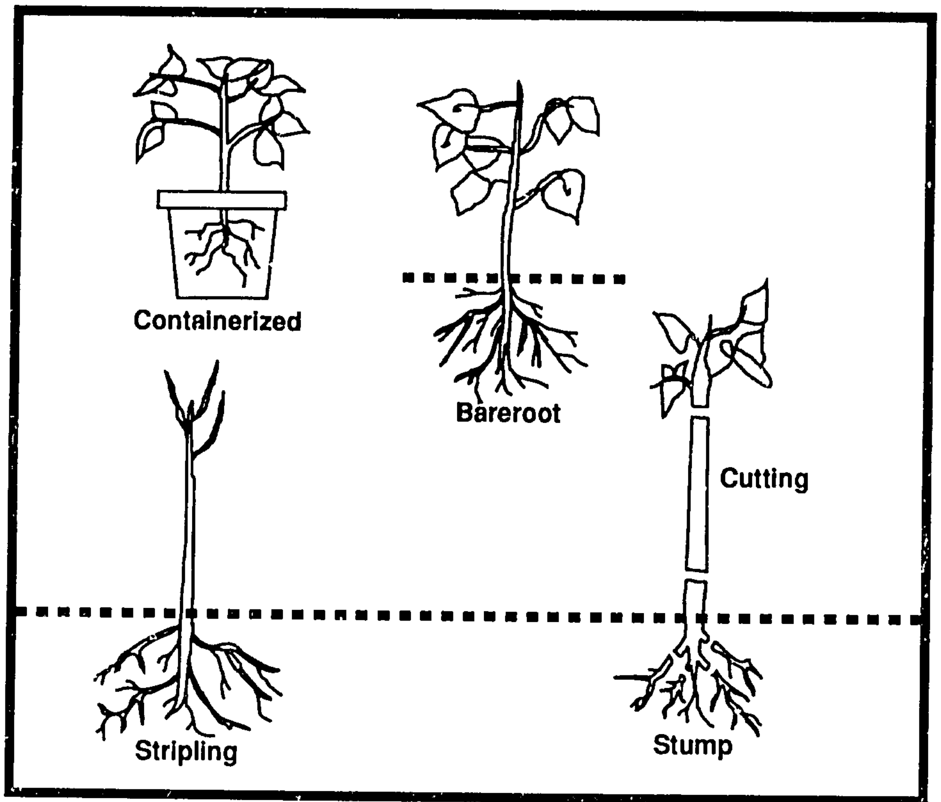

Figure 3.1. Forms of planting stock.

3.2 Seed Treatment[4]

Seeds should be of known origin (see sections 2.5 and 7.0, records H-K). Except for fruit trees and ornamentals, trees are almost invariably from wild populations. Great variation is normal, and germplasm is often unknown and unclassified below the species level. Nevertheless, sufficient information has been accumulated to demonstrate clearly that the quality of races and provenances differs within many species. Many organizations are moving tentatively toward genetic improvement, even biotechnology, with no clear idea about the original source, range, or quality of their germplasm. For those who have not kept such records in the past, **the time to begin is now.**

Even a cursory inspection of seed from several trees of the same species reveals differences in size, color, and shape. Other, more important differences probably exist, such as thickness of seedcoat, moisture content, and oil content.

In treating seeds for maximum germination, certain guidelines have emerged over time. Many kinds of seeds have a water-resistant coating that can be softened or removed by treatment in hot water (water volume 5 to 10 times seed volume). However, protein coagulates at temperatures exceeding 50°C, so hot water treatments above this temperature will kill seeds if cooked until thoroughly heated.

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4 An excellent, thorough discussion of all aspects of tree seed handling is contained in *A guide to forest seed handling with special reference to the tropics*, FAO Forestry Paper 20/2, by R.L. Willan (FAO, 1985).

Since many field quarters do not have a thermometer, the most common nursery treatment is to soak the seed in water brought to boiling temperature 100°C at sea level and then removed from the heat. For greater safety, some nurseries allow the water to cool three to five minutes before soaking the seed.

If 30 seconds at 100°C does not degrade the seed coat sufficiently to permit imbibition, 30 minutes should not be tried as an infallible alternative; 30 minutes at 100°C will kill most kinds of seed. For small seeds, about five seconds may be the maximum. For any species of continuing importance, a series of calibrated tests should be carried out to determine species norms, then confirmatory tests performed with each new seedlot. Because the durability of seed coats often increases with storage time, seeds of the same seedlot often need longer treatment after prolonged storage.

When seeking correct treatment to increase seed germination, first try a) no treatment, b) a 24-hour soak at room temperature, and c) a 5-second dip in boiling water. Depending on the initial results, you can then try progressively shorter cold-water soaks or progressively longer dips in boiling water. The progression in boiling water may be in geometric steps: 5, 10, 20, 40, 80 seconds in water that is boiled and then removed from the fire immediately before putting the seed in. Remember, as mentioned above, that water volume should be at least 5 to 10 times seed volume.

Soaking seed 12 to 24 hours at room temperature following hot water treatment is often helpful and rarely harmful. Swelling of the seed during the cold water soak is a uniformly reliable indication of successful scarification.

Although sulfuric acid is almost invariably mentioned as an alternative method for treating seeds, it is best forgotten. It is dangerous, expensive, often difficult to obtain, and rarely better than safer and cheaper methods.

Mechanical scarification is often successful in improving or hastening germination of hard seeds. For limited numbers of large seeds, a nail clipper works well; sandpaper or a small, triangular file is also quite satisfactory, and an electric drill works fastest. A hot, high-resistance wire is effective, quick, and convenient if electricity is available.

Whatever the tool, take care not to damage the embryo. Damaging the cotyledon is somewhat less critical, but if too much of it is removed, subsequent growth is reduced.

Until the seed morphology of a selected species is known, flat, oval seeds are best nicked at the rounded end, winged seeds nicked at the point of the seed proper farthest from the hilum (but not on the wing itself), kidney-shaped seeds nicked on the convex side, and round seeds nicked near the end opposite the point of attachment to the tree (Figure 3.2). The chief disadvantage of nicking individual seeds is that it becomes extremely tedious to nick large seedlots or many small seedlots, even with the hot wire.

For physical scarification of large quantities of seed on a regular basis, a number of machines have been developed to rasp or tumble the seed. A small concrete mixer is often modified for the purpose.

Fleshy fruits, such as *Gmelina* or *Spondias*, should have the pulp removed before drying, storing, or sowing. Small quantities can be removed fairly well after fermenting for two days, then

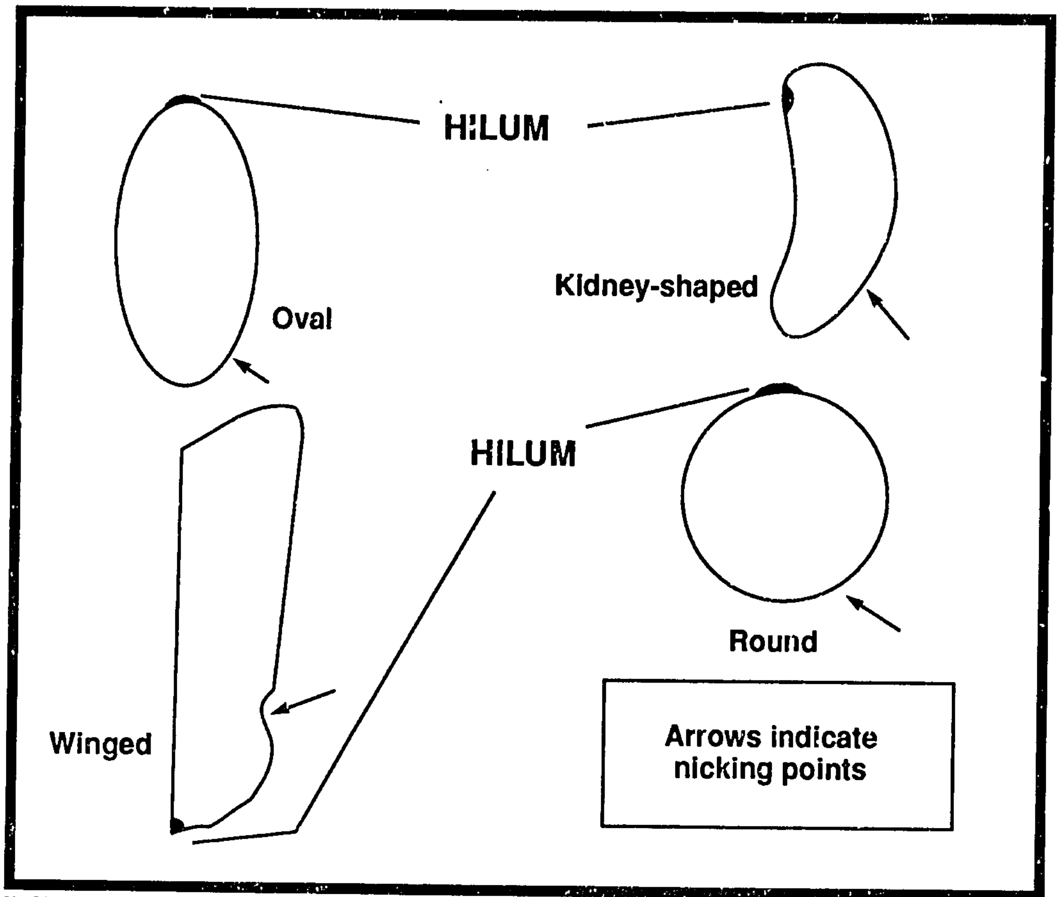

Figure 3.2. Scarification points by seed shape.

manually cleaned in water. Do not ferment in large containers or thick piles where excessive heating may occur. Large quantities can be cleaned by a modified coffee de-pulper.

Most seeds can be stored well at temperatures of 3 to 5°C and a moisture content of 6 to 8 %. To maintain such a low humidity in a moist atmosphere, such as in most household refrigerators, seed is best stored in a filled, sealed container. Metal cans are best, but carefully closed plastic bags are often a satisfactory substitute.

Many temperate seeds and a few tropical ones, such as *Eucalyptus deglupta*, can be stored even more effectively for long periods at temperatures of -15 to -20 °C.

Examples of species that accept or even require higher moisture content (about 35 to 40 %) are *Quercus* and *Castanea* for temperate zones and *Hevea, Swietenia*, and *Dipterocarpus* for the tropics.

You should run germination tests if the providing agency did not or if the seed has had prolonged storage since testing. Withdraw a sample representing the entire seedlot and test a minimum of four replications of 10 to 100 seeds per replication. For better accuracy, check, record, and remove germination daily to avoid errors caused by mortality or disappearance of germinated seedlings.

Many species benefit from or require inoculation: *Rhizobia* or *Frankia* is used for nitrogen (N)-fixing trees and mycorrhizal fungi for species that do not fix nitrogen. Many N-fixing trees also benefit from the presence of mycorrhizae.

The symbiont fungi that form mycorrhizae with pines have been studied more thoroughly and effectively than have fungi found with other trees. Pines require mycorrhizae for vigorous field development. Some species and strains of fungi are considerably more effective than others, and the most effective (in most tests to date) vary with site and stage of pine development. This is not surprising, but means that a single, pure strain of fungus may not be the best inoculum for all sites and all ages. The superiority of the best tested is sufficient to encourage continued testing, but on a small-scale as with any new technology.

N-fixing bacteria for trees also vary in infective capacity and in effectiveness of fixing nitrogen in the plant roots. Testing N-fixation can be more rapid than testing mycorrhizae because evaluation is apparently quicker. Mycorrhizae are effective if tree growth and development are vigorous over the rotation of the tree. N-fixing bacteria are effective if an abundance of nodules with pink, red, or brownish interiors are found. For long-lived tree development, it would not be surprising to find that the most effective strains of bacteria, like those of the fungi, may vary with site and stage of tree development.

The N-fixing bacteria, often in mixture with chopped peat or similar diluent, are usually applied by mixing inoculant in water (1 g in 4 liters of water or a gum-arabic solution has been recommended) and steeping the tree seed immediately prior to sowing. Mycorrhizal fungi are more commonly applied to the soil one to six weeks after germination. Both can be supplemented by re-inoculation of the soil at any time, even after field planting. Field inoculation is much more expensive than the same operation carried out in the nursery, however, and is less effective, especially on dry sites. Some pure strains of *Rhizobia* can be purchased.

In general, soil taken from around the roots of vigorous trees of the same species nearby in the field provides an adequate, but not necessarily the best, inoculum. Using untreated soil opens the possibility of introducing a pathogen. In practice, using soil from under a healthy, vigorous stand has rarely, if ever, caused a problem after dry basal bark has formed.

3.3 Containers and Beds

Date of sowing should be controlled by the planned date of planting in conjunction with the time necessary for the species to attain plantable size. Most fast-growing species take three to six months to reach plantable size, but each nursery must determine its own rate of development for each species.

In permanent nurseries, the most important single factor in seedling health and vigor is good soil. In most of the tropics, a green manure fallow every third year is an important (and in some places essential) step in developing such soil.

Various containers have been and are still being used. Currently, the most popular is a black polyethylene sack, approximately 10 x 15 cm when flat and perforated with 8 to 12 holes from the bottom up to half total depth. If containers are closely grouped or covered with soil, the black coloring is not necessary. Black plastic is more durable in sunlight than clear plastic; but because black absorbs more heat, it is especially important to shade seedlings in exposed black pots.

Plastic bags are popular because they are relatively cheap and convenient to use; however, the round shape encourages undesirable circling of the roots, and the drainage holes, although essential, permit the roots to emerge and enter the underlying soil.

To keep roots from penetrating into the soil, move the bags periodically to break off all escaped roots, set them on a sheet of plastic to prevent roots from entering the soil, or do both. Where rainfall and drainage conditions may cause saturation or flooding, avoid using plastic sheets.

A more effective method is to suspend the filled bags at least 30 cm above the ground (Figure 3.3). Using this method, known as *air pruning*, the growing tips of roots starting to exit are killed as they enter the open air. This also promotes development of fine roots inside the bag and inhibits or prevents circling of the roots. This method is an effective and efficient way of growing containerized seedlings once the initial cost of the support has been paid. A similar effect can be obtained when growing seedlings in flats by painting the bottom of the flat with a copper-based paint.

Locating, digging, transporting, and cleaning soil to fill the bags are also expensive, so use the smallest adequate bag. Since bag volume varies directly not only with the length but also with the square of the diameter, tall, slender bags require less soil than do short, wide ones.

Beds and containers should be well-drained and usually above mean ground line to prevent waterlogging, improve aeration, and reduce root rot.

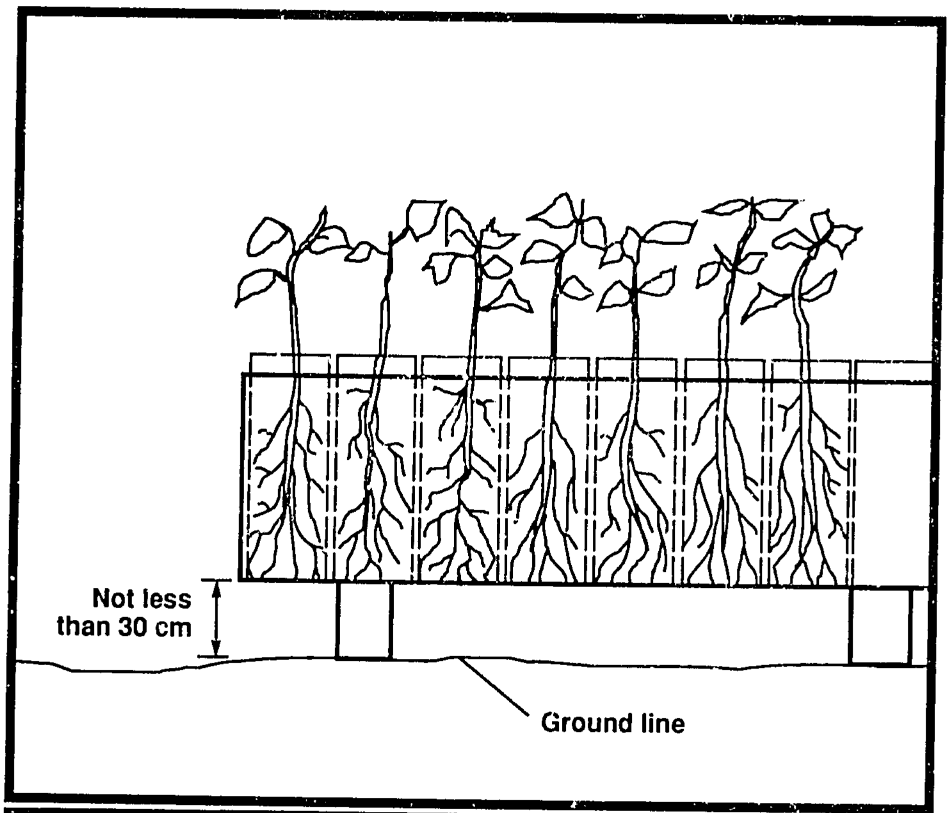

Figure 3.3. Air-pruning seedlings.

Preferred soil mixes vary with species and nursery. A commonly recommended mixture is 50% clay, 40% sand, and 10% compost (by volume), at a pH of 6.0 to 6.5. If fertilizer is added, the quantity is low, perhaps 10 g of 10-20-10 per liter. For N-fixing species, frequently only phosphorous is added.

Where transportation is extremely difficult, root-trainers, plastic bullets, and other small containers are sometimes used. In such cases, a special medium with low dry weight and high moisture retention is superior to soil mixes. Pests and diseases are commonly less of a problem. However, such containers are suitable only for producing trees of a size commensurate with the normally small containers. Success then requires better initial care, especially planting into moist soil and regular cleaning.

Various soil sterilizing methods are available if soil pests or diseases are a problem. Deciding which is best depends on local prices. If wood is abundant and cheap, heat sterilization (at least 60°C for 30 minutes) is often the cheapest method for small nurseries.

If soil is sterilized with chemicals, **supervisors should insist that all recommenued safety precautions are followed**. Ill effects on unwary users are often delayed but can be serious, even fatal. Persistent chemicals also cause soil contamination and subsequent degradation.

Mulching of soil surface effectively increases soil moisture, but organic mulches sometimes promote disease and pest attack. Dry gravel inhibits the spread of damping-off disease.

Irrigation by capillarity from below reduces foliage diseases in many cases, and also prevents mechanical damage by large drops or strong spray pressure to eucalypts, *Anthocephalus*, and other small seedlings. However, soil must be thoroughly drained between irrigations to prevent root rot.

Sprinkle irrigation in the morning reduces chances of developing fungi or mold on the leaves. Late afternoon irrigation is a more efficient use of water.

Overwatering and irrigation with stagnant water can cause various problems. Frequent, superficial application of water, especially manual sprinkling with hoses or watering cans, can cause roots to concentrate near the surface. Plants suffer severely if such watering is skipped through neglect or system problems. This pattern of irrigation also promotes salt accumulation at the surface, with attendant problems.

3.4 Culture

Care of the seedlings (culture) is necessary from the time seed is sown until the planting stock is dispatched to the field. The small size of the plants and their concentration in a small area (10 to 400 per sq m) makes care relatively economical and permits close supervision. However, the first three months after germination are the most delicate. The high density on the ground means that a spatially limited problem area affects a substantial number of trees. Consistent, alert care by nursery personnel is essential.

In many countries, all but the heaviest nursery work is done by women. They are considered faster and more skillful than men at sowing, weeding, pricking out, and other jobs requiring manual dexterity. Both men and women, however, benefit by careful training before work begins and by careful supervision while work continues.

Nursery care also means providing the proper amount and quality of water, a satisfactory rooting medium, and freedom from excessive competition, especially weeds.

3.5 Protection

First and foremost:

- o keep tools clean
- o use fresh supplies
- o keep the nursery neat and tidy
- o dispose of overgrown seedlings
- o sterilize both the container and rooting medium of seed flats or containers before re-using
- o use sunlight as a sterilizer only for dry tools and objects

Most newly-germinated seedlings are susceptible to damping-off fungi, cutworms, and grubs. Sterilization of the soil before sowing and a proper watering regime are the best control methods and are usually adequate. (See section 3.3.)

Sow seed fairly sparsely to prevent over-dense stands of seedlings; mix small seed with sand to aid dispersal, or use a wet needle, especially for sowing directly into the container. Sowing directly into the container is usually cost effective only with seed of high viability.

Careful pricking out of the seedlings before the seedcoat is dropped or the first leaves initiated will reduce mortality and transplant shock. It will also prevent the quick spread of damping-off and other fungal diseases.

Snails and slugs, lizards, large insects, birds, and rodents can be kept off the seedlings by covering beds with a fine screen or the new, lightweight spun fiber. Slugs and earwigs will drown in shallow containers of beer. Large caterpillars can be picked off and mashed or dropped into a container with a film of kerosene on water. Persistent lepidopteran attacks can be controlled by spraying the larvae with *Bacillus thuringensis*. Most aphids and similar insects can be removed with a strong stream of water, especially when used with soap or detergent.

Beating pest larvae into water to form a solution has been reported frequently. When sprayed on the plant, the solution allegedly serves as a repellant against the pest species used. No results of controlled experiments have been seen for this treatment.

Once past the initial succulent stage, the best pest and disease control is using the appropriate species/culture combination plus nursery cleanliness. This combination is usually the only practicable control method, although agricultural quarantines can help postpone the problems.

Locally available pesticides may be used. At present, foliar spray of Malathion is probably the most common for insects and Captan or Benlate for fungi.[5] (Pesticides may damage or eliminate desired mycorrhizal fungi and N-fixing bacteria; Captan has been reported as severely damaging. Alternating two or more pesticides is often more effective than repeated use of one. Except for a type of outbreak assumed to be rare, the long-term usefulness of such a treatment is questionable.)

3.6 Grading Stock

In addition to what should be the universal practice of separating out unhealthy or spindly seedlings, containerized stock is often graded by size during the nursery phase to minimize domination of short seedlings by tall ones.

Grading is also common when selecting seedlings (containerized or bareroot) for outplanting. Extensive literature deals with such grading, most of it from temperate zone experience and research. Below are available guidelines:

- Resting or dormant stock at time of outplanting is less susceptible to transplant shock. Species that sprout well without losing apical dominance, such as *Pinus caribaea hondurensis* and *Leucaena* spp., can be top-clipped to eliminate succulent tissue and increase survival.

- Larger stock usually has a higher survival rate and faster growth than small stock, if properly planted. The tendency to cram large stock into too-small holes can negate the benefits of large size stock.

- Physiological grading is generally more effective than morphological. That is, a seedling resting but physiologically poised to initiate growth develops well in the field. One actively growing at the time of planting often suffers from inadequate moisture even if the soil is wet. Species with paired or whorled leaves, such as *Gmelina* or *Bixa orellana*, commonly grow in clearly-defined height spurts. Recognizing their resting stage is usually easier than with species of indeterminate growth, such as *Eucalyptus* or *Leucaena*.

  Resting can be induced during the dry season by withholding water. Unfortunately, most planting is done during the rainy season when withholding water may be difficult.

- Morphological grading is usually based on size. Tests uniformly show that diameter at root collar (drc) is a better indicator of survival than is seedling height (h), and is often a better indicator of growth. Mature, brownish bark at the base of the seedling also indicates hardier stock than soft green bark.

3.7 Lifting and Transport

Time and money devoted to careful lifting and transport are usually more effective than equal investments spent on chemical insect and disease control. The basics for lifting and transport are simple, although not always easy.

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5 Mention of a product is for information only and should not be considered an endorsement.

Prevent avoidable mechanical damage.

Avoid distorting the container or subjecting it to shocks of throwing or dropping. A floor cover of 2 to 5 cm of grass or leaves greatly reduces the vibration of containers being carried in trucks. For bareroot and stumped stock, root cuts should be smooth and at right angles to the axis being cut. Stem cuts of opposite-leaved species, such as *Gmelina* and *Tectona*, should be at a 45° angle at a node to reduce persistent forked stems. For alternate-leaved species, stem cuts should be perpendicular to the axis just above a node. Long strips of damaged stem or root bark invite invasion by disease organisms. Broken tips of roots or branchlets increase transplant shock and reduce vigor far more than cleanly pruned ones.

Keep roots moist.

Water potted stock as needed before transport, while awaiting planting in the field, and, to the extent feasible, during the initial establishment phase after planting.

Most silvicultural texts advise hardening off the seedlings by reducing water during the last few weeks before outplanting. Compliance with this sound advice is greatly complicated by the desirability of planting during the rainy season when withholding water is almost impossible. Whether or not pre-transport watering is reduced, container soil or packing material should be thoroughly moist but not saturated when the seedling leaves the nursery.

At the planting site, heel in and/or store the stock in shade if planting is delayed more than half a day. If planting is delayed more than one day, thoroughly water the stock periodically and on the day of planting, if possible.

To prevent desiccation during transport, keep roots moist. If transport exceeds 30 minutes or if speed exceeds 40 kph, protect seedlings from the sun and the wind. Plastic or cotton covers should not touch seedlings. Seedlings stored in plastic bags under the tropical sun are quickly boiled to a condition more fit for serving as food than for planting.

4.0 Establishment

General reminders:

- o To determine survival or stand yields, plots should contain a minimum of 8 to 12 trees at the final measurement. Smaller plots are cheaper, more uniform, more sensitive, and can give reliable growth and yield of individual trees.
- o Site preparation should be affordable, but should avoid soil erosion. Prepare micro-catchments on arid sites and ridges on waterlogged sites. Maintain weed control.
- o Plant close for early, high yields of small products. Plant wide for fast growth and large products. Systematic designs are more cost effective than randomized ones.
- o Try direct sowing for any combination of abundant cheap seed, large seeds, good site, good brush control, and dense planting.
- o Dig planting holes adequate for the root system.
- o Control strongly competitive plants.

Establishment consists of preparing the site for planting, selecting the spacing, and sowing or planting the trees.

4.1 Plot Size

General guidelines:

- o Plot area is determined by spacing between trees and the number of trees.
- o Spacing depends on species, management objectives, and silvicultural system.
- o The number of trees per plot can vary from one to virtually any finite number; 250,000 is the largest known number observed by me, but it was not a replicated study.

  A 1-tree plot is cheaper to establish and care for than any larger number. It is usually cost efficient for studying the development of single trees, but is a) nearly useless for determining yields per hectare, b) inefficient for determining survival, c) susceptible to producing missing plots, and d) strongly influenced by competition of surrounding vegetation.

- o Accurate record-keeping for 1-tree plots requires competent and careful field personnel to avoid mixing data between plots.
- o The smaller the plot, the less internal variation; that is, the less plot experimental error. (On highly broken topography or variable soils, this may be a critical consideration.)
- o Large plots may include much site variation, are expensive to establish and maintain, but provide reliable data on yield per hectare.

- o If the plot includes unmeasured border rows, the smaller the plot, the greater the percentage of unmeasured (wasted) trees.
- o Generally, plots containing 8 to 12 trees at the final measurement are statistically reliable for areal yield calculations, convenient to work with, inexpensive, and reasonably small.

4.2 Site Preparation

An essential step before field establishment is site preparation. This is the removal of unwanted plants and materials, before planting new trees, to reduce excessive competition for light, soil nutrients, or moisture. A plowed and harrowed field provides such an ideal site. Many tree sites, however, are not easily plowed. Where plowing is possible, such intensive site preparation is frequently not financially justifiable for trees alone. Where the trees are to be intercropped with food or fodder plants, intensive site preparation by plowing, subsoiling, harrowing, leveling, bedding, terracing, or even irrigating may well be profitable.

The most common method of site preparation in tropical countries is probably slashing all existing growth, allowing it to dry out, then burning the area over. The resulting ash enriches the soil, and the lack of soil disturbance greatly reduces the danger of erosion. The effectiveness of the cleaning varies greatly with the type of existing vegetation and temperature of the fire. Used with an advanced forest fallow, the fire may be hot enough to sterilize the soil surface and kill weed seeds in the top centimeter or so. The same method used with a light cover, particularly grass, may invigorate existing plants and actually increase rather than reduce competition.

On some sites, particularly those exposed to constant wind, trees may benefit more from protection by existing vegetation than suffer from its competition. This situation is common along coastlines and open ridges. Where there is no wind or where soil moisture is scarce, any competition by a plant with an established root system may outweigh the benefits of the protection offered.

On arid sites, preparing deep holes for only partial refilling may be essential. Further improvement of development on arid sites may be obtained by constructing micro-catchments (Figure 4.1) or by using pitcher irrigation (a pitcher or other container is buried beside the tree and is periodically filled with water, which leaks out slowly to irrigate the tree).[6] Such operations are unlikely to provide direct advantage financially where there are other demands for labor. Similarly, preparing mounds or drainage ditches on swampy sites may be advantageous biologically but represent a financial loss unless the landowner is reimbursed for his investment. For the government, of course, the social and economic benefits may compensate for the cost, and in many countries such site preparation has demonstrated long-term national benefits.

4.3 Spacing

Selecting the spacing is an unavoidable decision that precedes any form of artificial regeneration. Although detailed research results are not available for many multipurpose trees and sites, the following are reliable guidelines:

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[6] See *Reforestation in arid lands* by Fred Weber with Carol Stoney (Arlington, Virgina: Volunteers in Technical Assistance, 1986).

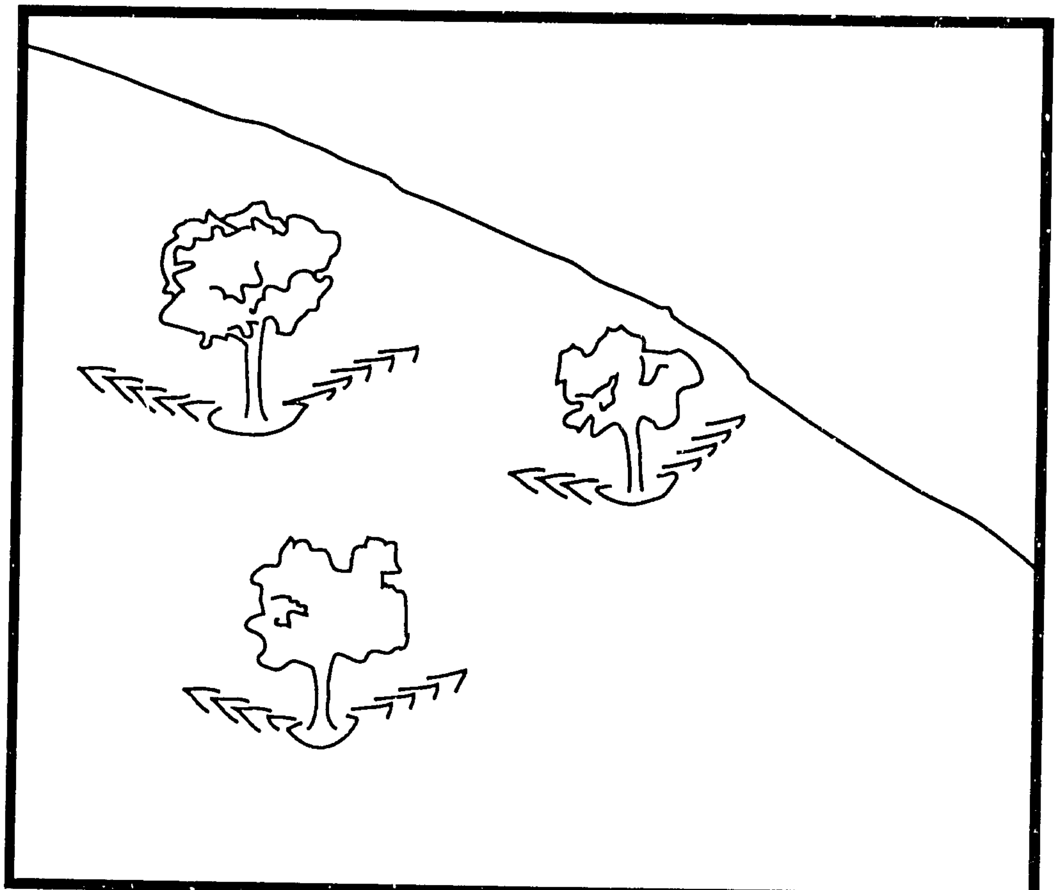

Figure 4.1. Micro-catchments.

- Closer planting provides earlier domination of the site by the trees with related reduction of weed growth.

- Wider spacing provides faster mean diameter growth and usually faster mean height growth on a given site. When the young trees first dominate the site, the closer-spaced trees often surge ahead of those more widely spaced. The advantage is temporary, however, as the more widely-spaced trees catch up and gradually outgrow the narrowly-spaced trees.

- Closer spacing provides greater woody biomass per hectare unless stand growth stagnates, usually with substantial mortality.

- Wider spacing provides material earlier for any given use based on product size. For larger products and/or high compound interest rates, wider spacing may mean a substantial financial advantage.

- Dominant trees at closer spacing remain comparable to those at wider spacing much longer than does the equivalent stand mean value. Even after suppression and mortality begin, for most species, a few dominants continue to grow vigorously.

- To obtain the same product size, spacing on poor sites should be wider than on good sites since wider spacing means more rapid growth.

- o If early crown closure is an important management objective, spacing should be closer on poor sites since trees grow more slowly on such sites.

- o Closer spacing provides earlier and more natural pruning and usually more well-formed stems per hectare. The pattern of percentage of good stems varies with genotype, as well as with the specific range of spacings under consideration.

- o For most species, coppicing following clearcutting is more reliable and vigorous at wide spacing. Coppicing following thinning may even be impossible at close spacings.

- o Growth and development of trees are affected little by rectangularity of spacing, as compared to square spacing, up to a ratio of at least 2:1. However, this factor may be important if distance between rows is four or more times that of distance between trees within a row. This means that tree growth in closely planted rows (as in many alleycropping hedgerows or fodder production areas) differs from growth in evenly distributed stands.

In the absence of more concrete information, carry out spacing studies using the type of distribution expected in actual use. For example, to study the spacing effects in hedgerows, establish a study of hedgerow spacing rather than classic, equi-spaced studies at varied densities. Hedgerow plantings are not comparable to equal numbers of trees per hectare at approximately square spacing. Similarly, development of 2- or 3-row hedgerows is not determinable from results of 1-row studies at reduced inter-row spacings. The same is true, of course, for windbreaks, individual trees, or other special distributions.

Traditionally, spacing has been studied in replicated plots of three or four spacings over a rather narrow range of values, with all plots of the same area. As discussed in section 2.0, the entire range of potential economic conditions should be included. Past failure to include these has left us without information about the spacings appropriate for the production of fodder, firewood, and small-sized materials.

Any useful study of spacing requires sufficient care to ensure that the nominal spacing is maintained in fact.

The Nelder wheel (and similar clinal designs using fan, rectangular fan, and plaid layouts) is an efficient and economical method of studying a wide range of spacings in a small area.[7] The wheel-shaped block is laid out with a fixed, selected angle between the spokes (Figure 4.2). The distance between trees in a spoke increases with distance from the hub. The most common, logical progression maintains the distance between trees in a spoke equal to the distance between spokes at that specific distance from the hub, but other ratios of rectangularity may be used if desired.

Spacing to the four nearest neighbors of each tree varies. The adjacent spokes are equidistant, but the outside neighbor in the same spoke is farther away than is the inside neighbor, and neither is exactly the same distance as to the trees in adjacent spokes. The differences are usually minor, however. The ideal progression of spacing provides parameters for regression modeling.

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[7] Whether devoted to a single species or many, the Nelder wheel is probably the most effective demonstration block design to date.

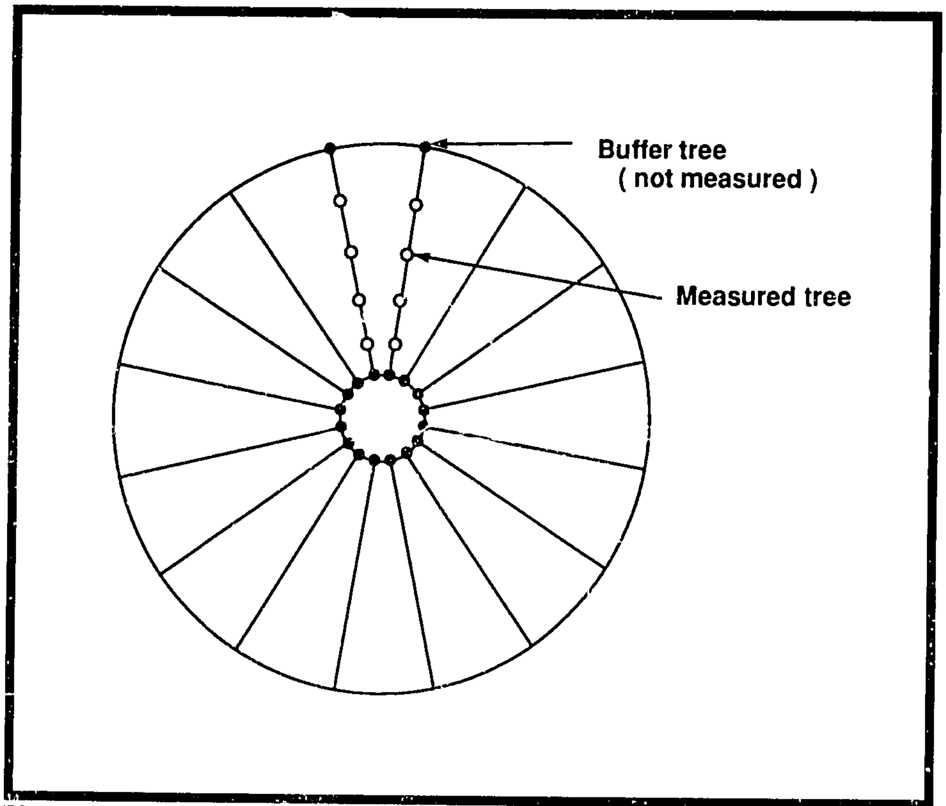

Figure 4.2. Nelder-wheel spacing block.

The spokes may be of the same species, providing a super-abundance of data. More efficiently, species (or provenances) may be compared for relatively long-term development by devoting fans of five or more contiguous spokes to a species, with replication within the wheel or in multiple wheels (Figure 4.3). Such a design allows species comparison, a spacing study of each species, and the interactions of species and spacings.

For a more sensitive comparison when less variation is expected (such as between provenances), each spoke may be planted to a different provenance (Figure 4.4). Again, replication is necessary. Provenance, spacing, and interaction analyses are possible.

Plot layout is sometimes done by laying out angles between spokes with a transit or similar device and marking planting hole locations along a rope or chain flagged at the proper distances. Perhaps more common is the use of flagged rope with a stick cut to the proper length between spokes at a fixed distance from the hub (Figure 4.5).

Systematic designs lack the randomness assumed in most statistical methods. However, with uniform layout (as required for any block) and adequate replication, the differences encountered may be assumed real, although the probability of their reliability cannot be stated with confidence.

More important is using common sense. If *Pinus kesiya* is planted in a single spoke adjacent to *Gmelina arborea* and *Acacia mangium*, on most sites and conditions it will be overtopped at close spacings within the first growing season and suppressed quickly thereafter. It is possible to use early measurements of the pine; but once overtopped and suppressed, its development will be representative only of overtopped and suppressed pine.

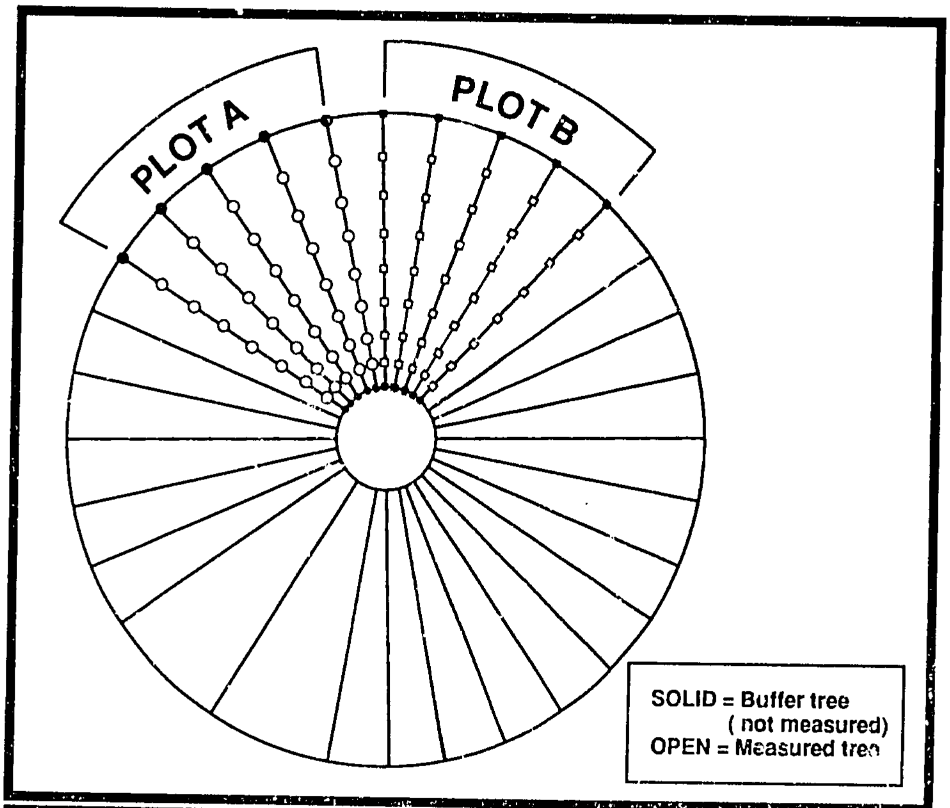

Figure 4.3. Nelder wheel, showing multi-spoke plots.

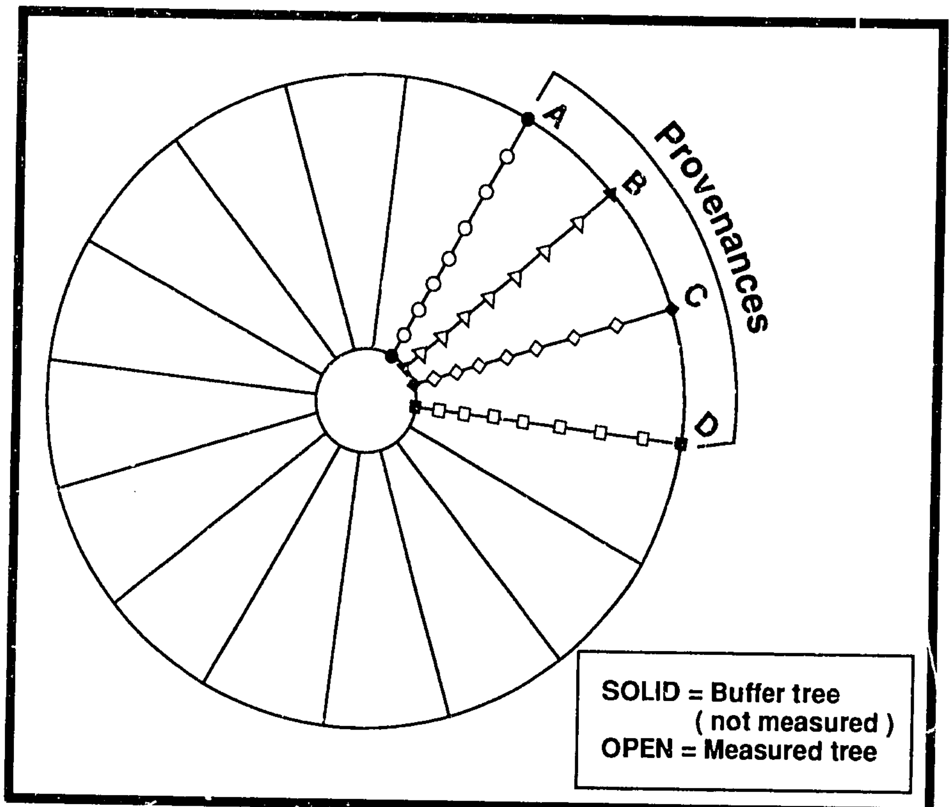

Figure 4.4. Nelder wheel, showing 1-spoke plots.

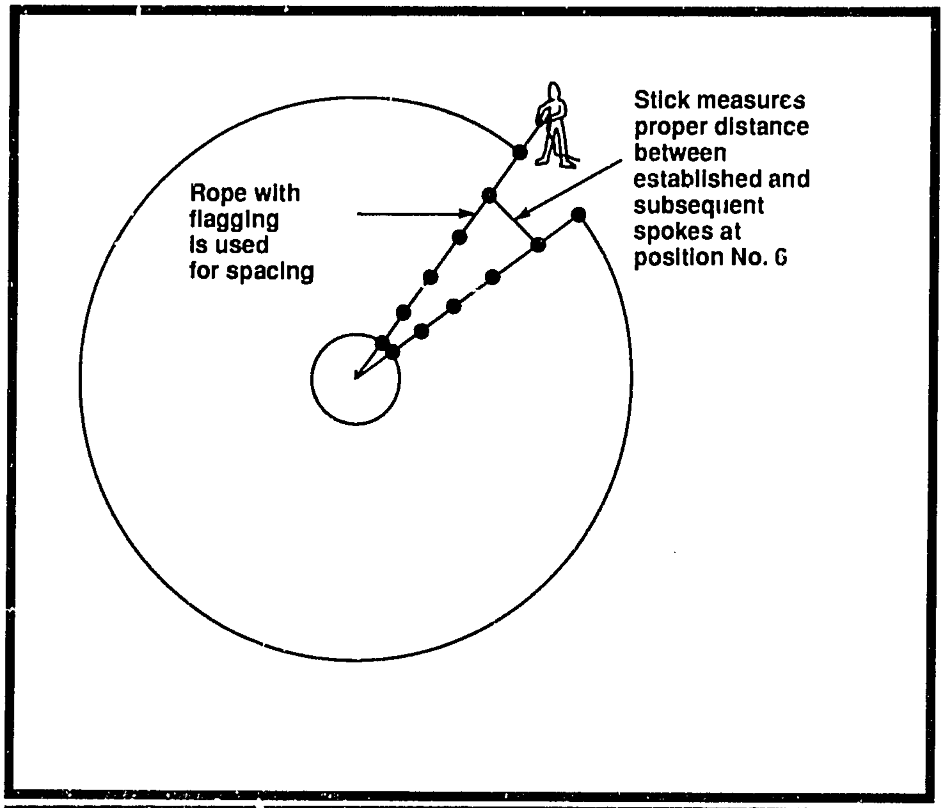

Figure 4.5: Field laying out of Nelder wheel.

Most practitioners assign species on the basis of estimated vigor and/or plant species in fans, not single spokes. A critical responsibility of any technician is to recognize if and when a study is no longer testing conditions for which it was designed: competition, weather, pests, or other extraneous factors may nullify the effects of the initial treatments within any type of design.

4.4 Sowing

With adequate seed supply, reasonably good site conditions, and post-planting care, direct sowing is as efficient and more economical than planting when close spacing is desired. The great advantage is the elimination of the nursery phase. The great disadvantage is that the tender, young seedlings are exposed to field conditions.

In general, the larger the seed (and thus the greater the store of food reserves) the more probable success (assuming good-quality seed with high capacity to germinate). The most important site consideration is adequate moisture. In the nursery, seedlings are watered daily during the early weeks. Moisture must be equally available in the field to attain comparable growth and development, and direct sowing may be impractical if the rainy season is short and irrigation not possible.

Cleaning is essential unless site preparation has ensured the absence of weeds. If even part of the area to be afforested has a severe weed problem, that part should be planted, not direct sown. This is especially true if the weeds are climbing vines.

After eliminating drought and weeds, high germination is perhaps next most important. To accomplish this, treat the seeds as if they were to be sown in the nursery. Use a water soak, hot water scarification followed by soaking, or another appropriate method.

Most seeds swell visibly when they imbibe water. Germination and survival in the field can be improved if you sow only swollen seeds. Further improvement is possible if you hold the moist and swollen seeds at air temperature for a few days, and then sow them just as germination begins. On the other hand, dry seed of resistant species may be sown before the rains when labor is more available.

If insects, birds, or rodents are abundant, pre-sowing control or protection may be necessary.

Root development of direct-seeded trees is often distributed better and freer of diseases than roots of nursery seedlings.

4.5 Planting

The same precautions for lifting and transport to the field discussed in section 3.7 apply throughout the planting process: avoid mechanical damage, and keep roots moist.

Most kinds of containers must be removed immediately prior to planting. The ball of earth with enclosed roots is then placed in a hole, and soil is added and firmed. These actions are commonly the most destructive stage of the planting process.

Removal of the container and insertion of the ball of earth into the hole must be done without disturbing the earth or breaking the fine roots. Far too often, the earth is badly separated during removal from the container.

Sometimes the ball of earth and enclosed roots are deliberately mashed flat to force them into a hole that is too small. The result is a badly broken and damaged root system, negating most of the benefits of 3 to 6 months of care and expense. Other times the ball of earth is planted well but then mashed down with the heel of the foot.

It is preferable to place the flat portion of the foot adjacent to the tree, and then apply your weight to the foot.

Another common mistake is planting in a shallow hole, with the ball of earth one-third or more above the ground line so the roots are exposed at the first rainy or windy spell.

The common recommendation to plant with the nursery ground line at exactly the field ground line is good, if followed precisely. However, when any deviation or surface erosion is expected, the tree should be planted deeper than in the nursery. Most species do not suffer from deeper planting as long as green leaves are not buried. In areas periodically inundated, no green leaves should be covered by stagnant or warm water for more than a few days.

The same problems are equally serious with bareroot seedlings. More common with bareroot stock, however, is forcing the roots into a J-shape by pushing long roots into a shallow hole. If a hole deeper than the root length cannot be provided, prune the roots cleanly to fit the hole.

In arid and semi-arid regions of Asia, large pits are often used, from 25 x 25 x 25 cm to 50 x 50 x 50 cm or more. Such pits generally increase survival and early growth, and eliminate root distortion from initial crowding. They also increase costs considerably as compared to the minimum-sized holes standard in the rest of the world. Hard data on benefits or costs are rare. This would be a valuable subject for supplementary study.

The coiling of overgrown roots in the bottom of a container is more serious than simple deformation of long roots in a shallow hole. This can be prevented by air pruning (as mentioned in section 3.3) and often by using containers that are rectangular in cross section or that have vertical ridges or grooves. At planting time, coiled roots can be eliminated only by cutting them off about 2 cm above the bottom of the container, or the twisting can be stopped by 1 to 3 equi-spaced vertical slashes of the root system with a sharp knife. The desirability to remove or slice coiled roots is recognized generally; however, it is not done often enough.

Where soil is waterlogged part of the year, initial survival and growth are usually improved by planting on raised ridges or furrows, constructed by scraping topsoil from the unused area onto the planting line.

In arid and semi-arid regions where soil salts are concentrated near the soil surface, ridges are more effective than beds. The seedling should be planted about halfway down the side of the ridge to avoid salt concentration at the tip of the ridge.

No matter how experienced the planters, their participation in a short training session is time well spent. Even more important than instruction in specific planting techniques is realizing that trees are living organisms. If the planters are farmers, have them compare the trees to a delicate, local crop, such as tobacco. The stem of a tree is much more robust, but the root tips are equally fragile.

5.0 Post-Planting Care

General reminders:

- o Prune frequently while branches are small; leave about 40% live crown for rapid growth. Minimize lopping.

- o Coppice for medium products; pollard above browsing height for smaller products. Cut annually or more frequently for maximum fodder, annually or less frequently for maximum small wood. If fodder is limited, use cut-and-carry instead of letting animals browse.

- o Thin heavily for continued effects or large products; thin lightly for minimum stand disturbance or small products. Use crop-tree release if tree values vary markedly; thin stands overall for trees of uniform or low unit-value.

- o Harvest trees according to products desired and species characteristics. Most multipurpose tree species (MPTS) are mildly to strongly intolerant, so should be cut in strips or groups to allow full light to the regeneration for at least part of the day. Many MPTS coppice or pollard well if cut when young, and for small products need not be replanted regularly.

Care of trees from planting to harvesting is an essential and continuing process too often underestimated and underfunded. Those who have never grown trees through a rotation frequently assume the trees will survive and grow without care once established. In natural forests, thousands of trees die for every one that matures. Growth of the surviving trees averages about 5% of the increment of those in well-managed plantations. Once the investment has been made to establish trees artificially, it is uneconomical to abandon them to natural forces and conditions.

5.1 Cleaning and Weeding

Although the terms *cleaning* and *weeding* are often assigned slightly different meanings, usage is not consistent between regions. The terms are considered synonymous here to mean removal of undesirable vegetation from around young trees prior to the first thinning.

Regardless of site preparation, observe the following cleaning guidelines:

- o Remove competing vegetation that touches or overtops the tree seedling (Figure 5.1).

- o Remove all competing vegetation within 50 cm of the seedling. (Take care not to remove topsoil near the tree.)

- o Remove sod grass and rhizomes within 1 m of the seedling.

- o If material is available, cover the adjacent, cleared circle with mulch to prevent weed re-growth, erosion, and to cool the soil surface (Figure 5.2). Organic mulch should not touch the tree stem, particularly where rodents or insects are a problem. Where termites attack the young trees, only a non-organic mulch of stones or plastic may be acceptable.

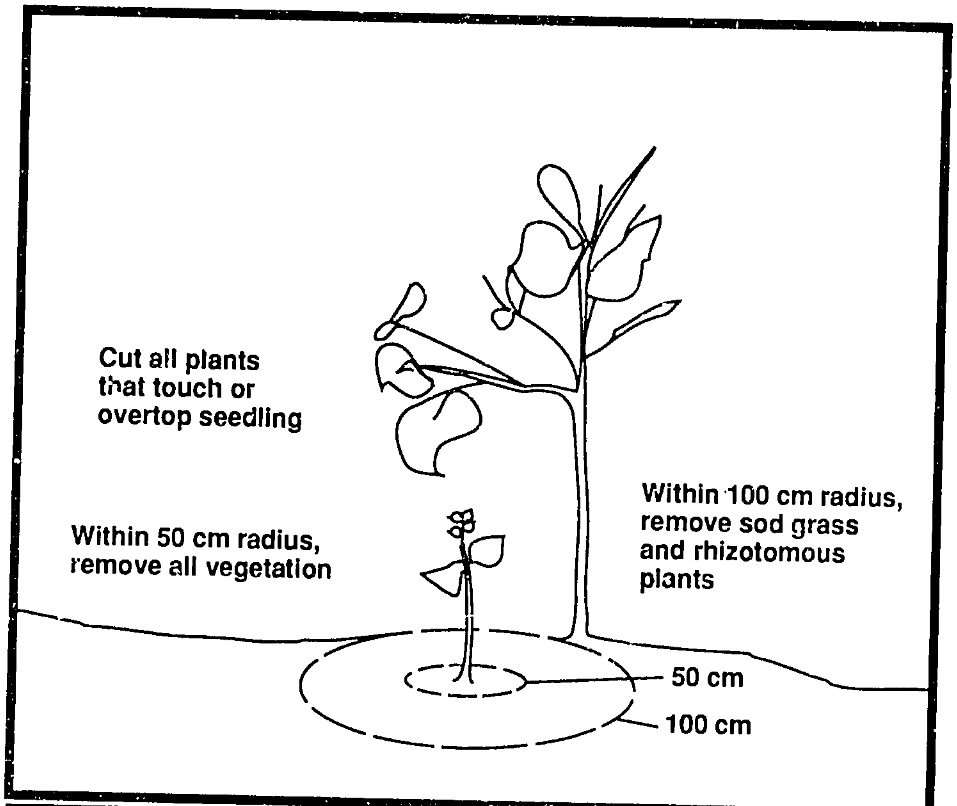

Figure 5.1. Cleaning guidelines.

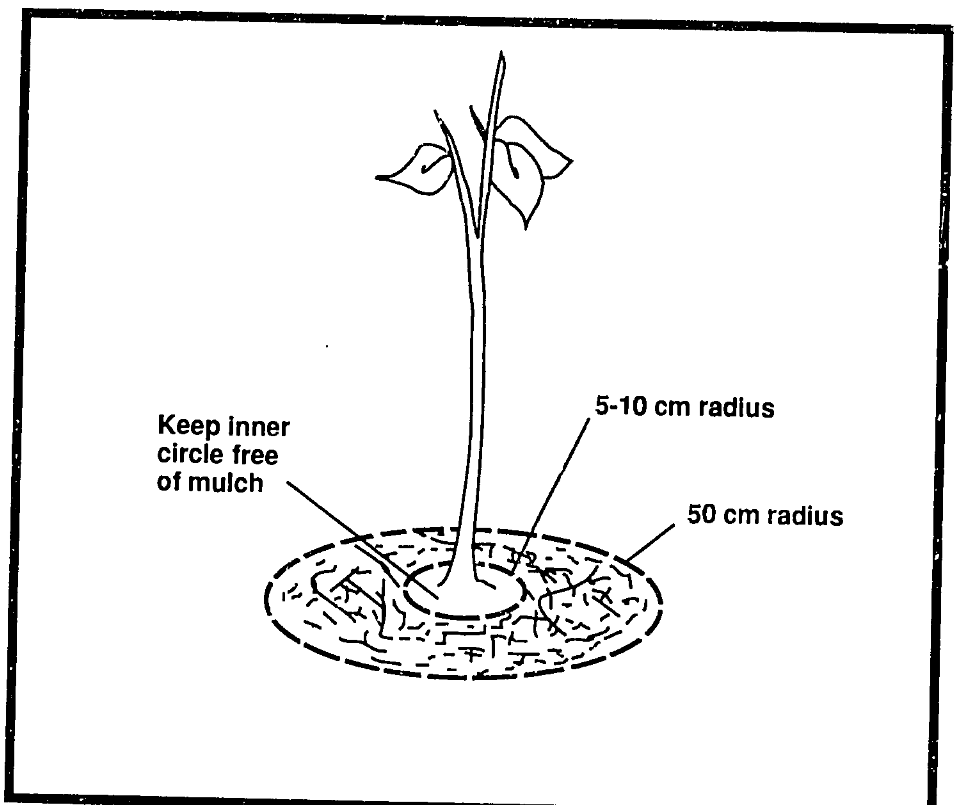

Figure 5.2. Mulch around seedling.

- o Avoid forming paths along the planting line where livestock and wildlife tend to follow and browse.
- o To control root competition, clean early in the dry season; to control crown competition, clean after the first flush of growth in the rainy season.
- o In arid zones and on droughty sites, use a micro-catchment to deliver extra water to each seedling. This will increase growth and survival. On extreme sites, space groups of trees closely, with wide intervals between groups and a large micro-catchment or contour trench serving each group.

Suitable subjects for investigation are implied by the preceding guidelines. For example, clean when the competition is half the tree height, equal to tree height, and double tree height. Or clear a circle with a radius of 25, 50, 100, or 200 cm.

The latter example illustrates an excellent model for exploration: double the first treatment to define the second, double the second treatment to define the third, and so on; include a minimum of four treatments. The economy of using four treatments discussed in section 2.4 applies to categories, such as species, and to points along a continuum, such as grams of fertilizer or weights of thinning.

5.2 Pruning and Lopping

Pruning is the "removal, close to or flush with the stem, of side branches (or roots), live or dead, and of multiple leaders...for the improvement of the tree or its timber...."[8] This improvement consists primarily of removing dead or non-productive branches (those with a negative photosynthetic balance) from the lower bole to accelerate volume growth or permit the laying on of knot-free timber (Figure 5.3).

The latter is the more common motive, since it increases the value of the wood, although not necessarily the price of the log. Secondary benefits to the landowner are improved access to the tree and the forest stand and, at certain stages of growth, reduced fire hazard, especially for conifers (Figure 5.4).

In all cases, prune the branch or leader as early as possible and as close to the bole as is practical, cutting into the stem phloem (bark) without touching the cambium layer. Early pruning greatly reduces time, cost, labor, and fire hazard. It also lessens the time before the knotty core is covered and clear wood is laid down.

If pruning is delayed until an enlarged collar has developed around the base of the branch (quite early with *Gmelina arborea*, for example), cut at the outer edge of the collar, not flush with the main stem (Figure 5.5). The large wound created by cutting a collar flush with the stem greatly increases the probability of insect or disease invasion of the stem and seldom lessens the period before clear wood is produced.

Pruning research is most often concerned with how early pruning can be carried out without unduly reducing tree growth and with quantifying the reduction, whether the researcher is concerned with wood quality or growth. Although a few scientists have subjectively selected unproductive branches, usually by sparse or lusterless leaves, most remove a percentage of the total height or of the live crown.

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8 *Terminology of forest science, technology practice and products*, FAO/IUFRO Multilingual Forestry Terminology Series, No. 1, edited by F.C. Ford-Robertson (Washington, D.C.: Society of American Foresters, 1971).

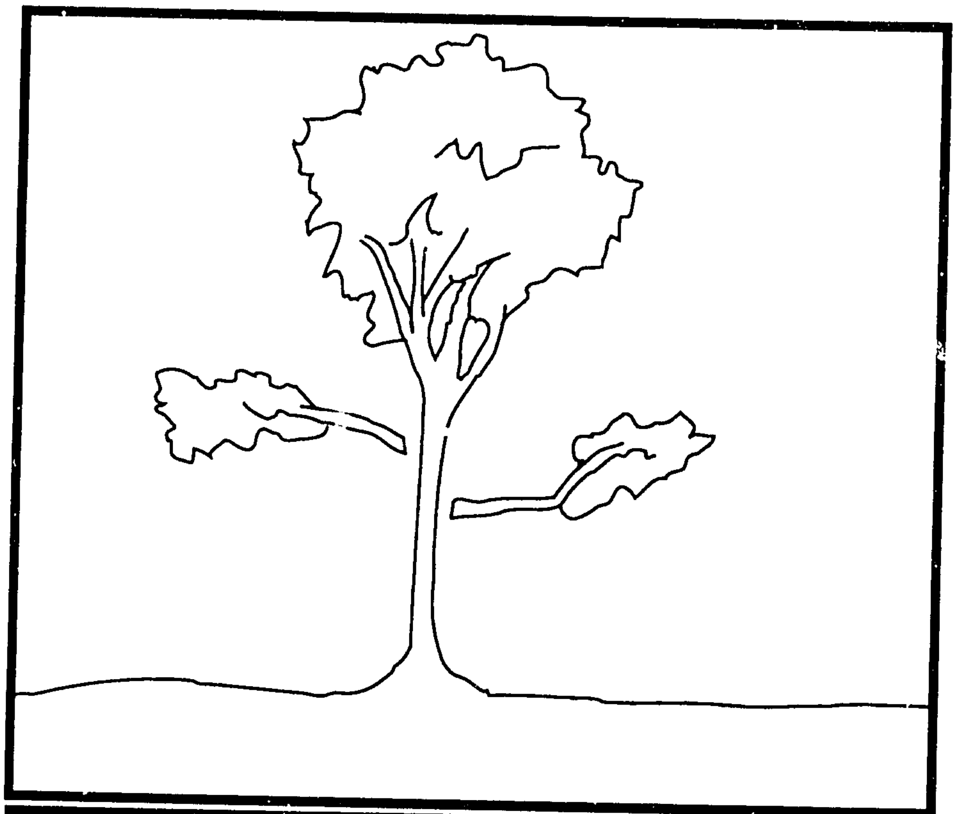

Figure 5.3. Pruning for knot-free timber.

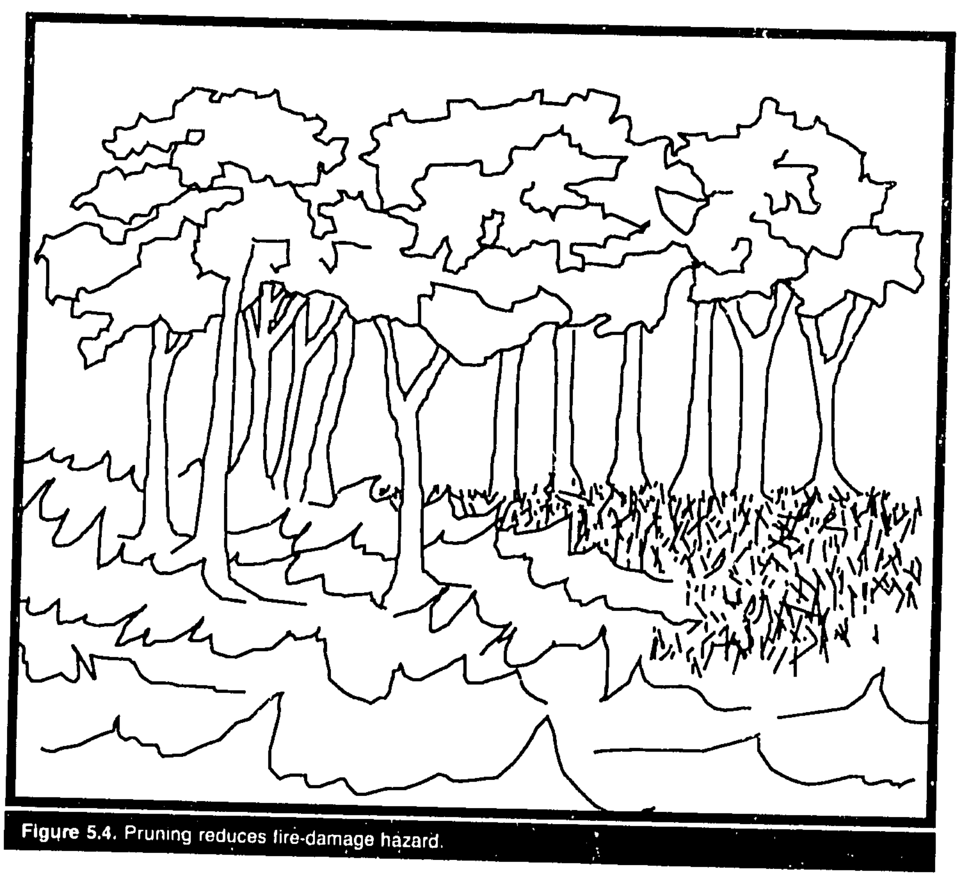

Figure 5.4. Pruning reduces fire-damage hazard.

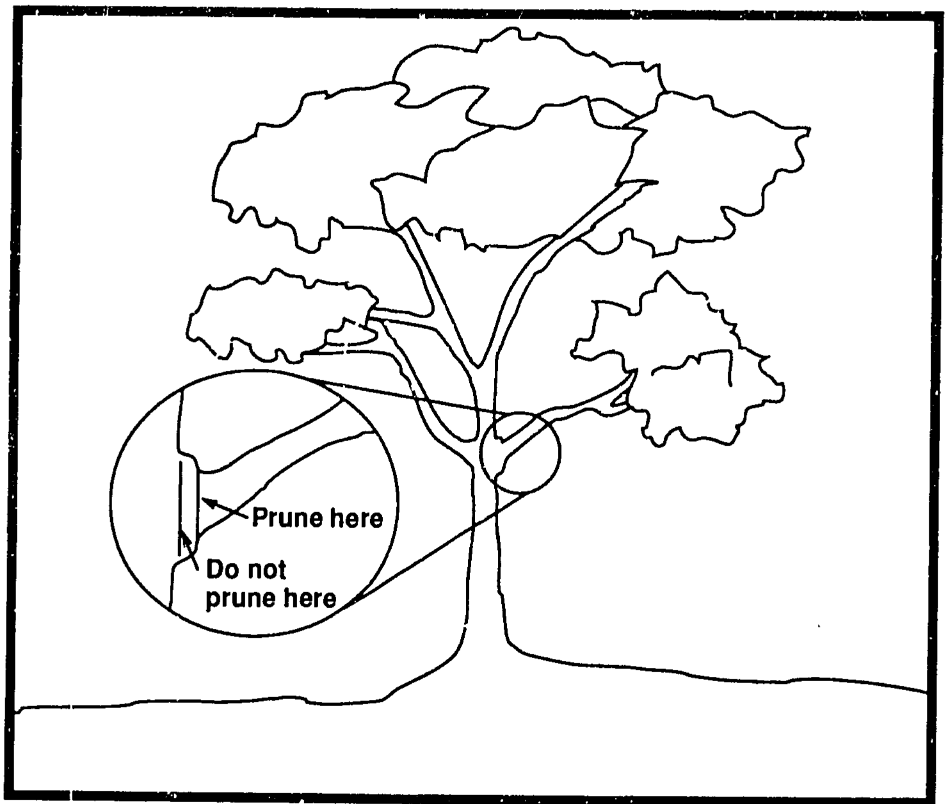

Figure 5.5. Pruning at branch collar.

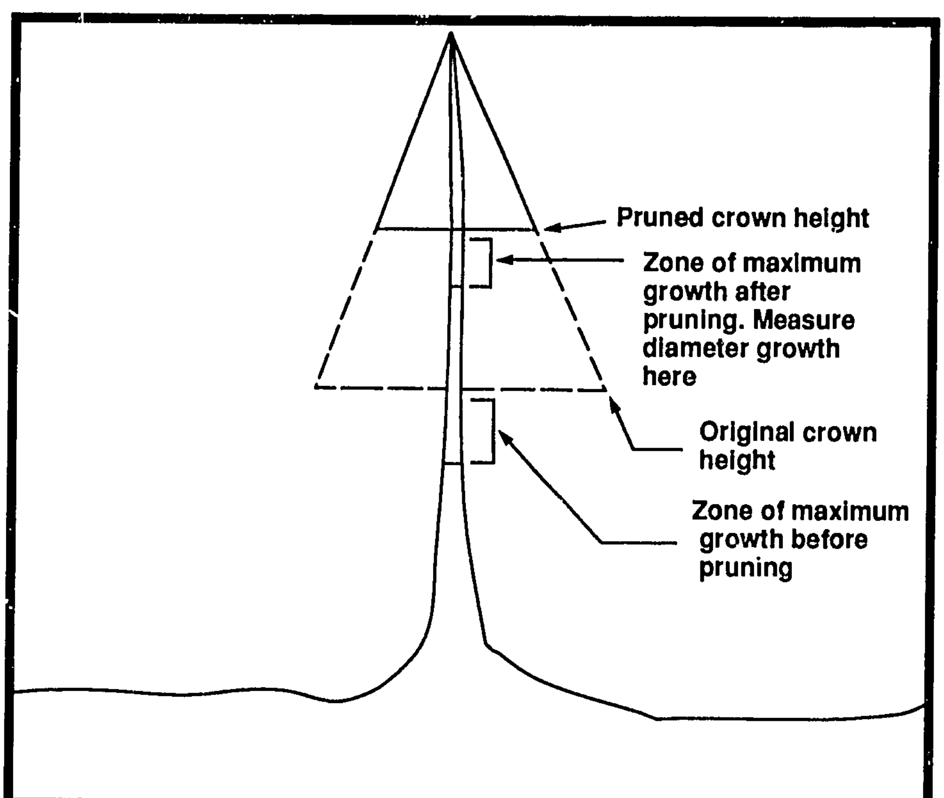

Figure 5.6. Zone for diameter measurement before and after pruning

Because live crown is strongly affected by competition, it provides only a shifting foundation for defining treatment. In a densely planted stand, trees may have a live crown of 25% or less of the total height. In such cases, removal of even 10% of the remaining crown may significantly reduce growth. On the other hand, an open-grown tree may have 90% or more live crown, and removal of 30 to 40% may not affect growth.

The commonly chosen base for pruning research is a percentage of total tree height, centered on a residual live crown of about 40% total tree height; that is, leaving perhaps 25, 35, 45, and 55% of tree height in live crown (Figure 5.6).[9]

Pruning of dead branches has no effect on tree growth rate, but does shorten the time before clear wood is produced. It may also reduce pest or pathogen infestation of the stem, and is usually cheaper than green pruning.

Agroforestry research may also be concerned with branch or forage production, normally preceded by pollarding. Such research is usually concerned with the number/percentage of branches to remove. Species like *Acacia mangium* and *Mimosa scabrella* have a low recovery rate if all green branches are removed simultaneously. Most species re-branch freely but allegedly recover more rapidly if a few branches are left after each pruning, on a rotating basis, so no branches become overgrown.[10]

In traditional forestry and forest utilization, *lopping* designates the removal of a branch from a standing or felled tree or its parts.[11] However, among farmers and agroforesters, lopping refers to the cutting of second- or lower-order branches or of first-order branches at an appreciable distance from the trunk of the tree (Figure 5.7). For bushes, lopping might be considered a heavy shearing.

Lopping is done next to houses and other buildings to control the crown size of large shade trees in restricted areas. However, the farmer's usual objective is to obtain forage or firewood without destroying the tree or simply to reduce the amount of shade cast by the tree. Species like *Albizia lebbek* and *Cassia siamea* tolerate lopping well on good sites and usually survive it even on poor sites, but the coniferous forests of the Himalayas demonstrate that many species suffer severely.

In practice, lopping for fodder or wood is primarily a reaction to archaic or inequitable laws, and is frequently associated with trespassing and theft on common or private lands. There is little other rationalization for climbing tall trees for minimal returns, which leave long, weak, and knotty stems highly susceptible to rot and breakage.

Research that demonstrates silvicultural advantages of lopping over pruning and pollarding would be desirable, as no such advantage is obvious.

When lopping or pruning, particularly large branches, avoid stripping off bark with the falling branch end, which can expose the live stem to invasion by disease organisms and insects. Instead, precede the cut that severs the branch with an undercut through the bark or through at least one fourth of the wood for a heavy branch (Figure 5.8).

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9 In the humid and subhumid trials of the MPTS Research Network in Asia, pruning is to 50% of tree height at 18 months of age.

10 Little hard data are available on whether this is true; the field merits research.

11 Ford-Robertson, *Terminology of forest science, technology practice and products*, 1971.

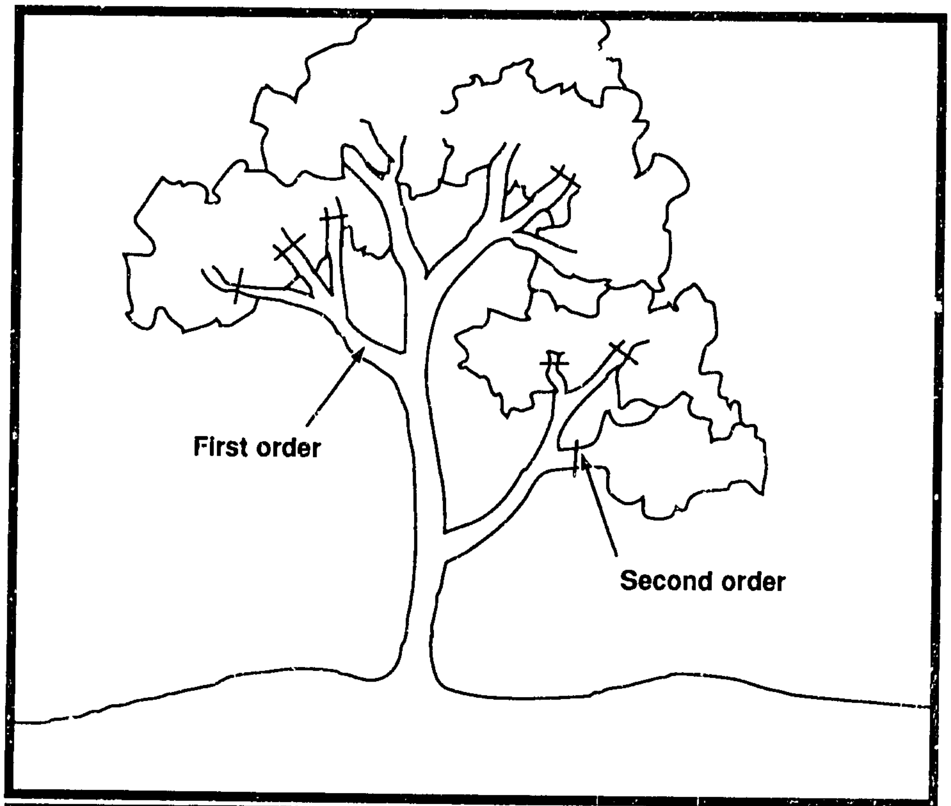

Figure 5.7. Branch lopping.

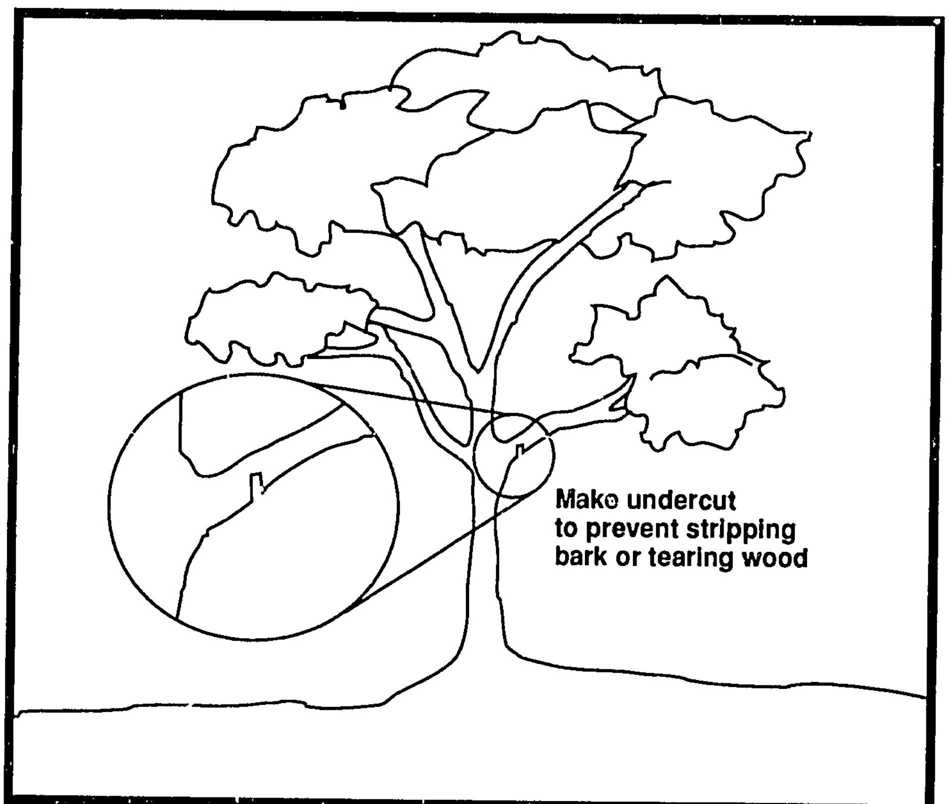

Figure 5.8. Pruning large branch.

5.3 Pollarding and Coppicing

The distinction between coppicing and pollarding is a somewhat vague difference in height. A pollard cut is normally above the reach of browsing animals.[12] This line is fairly clear for European cattle and sheep but is less so when camels, elephants, and giraffes are considered.

In tropical agroforestry, a more useful distinction is that coppicing is from a low stump and pollarding above a short, useful bole (Figure 5.9). Indeed, pollarding often leaves a bole of 2 m or more suitable for a fence post, vine support, or for commercial lumber.

Thus, *pollarding* is defined as cutting back the crown of a tree to produce a close head of shoots (Figure 5.10). Objectives may be to produce firewood, withes for basketry, small stakes and other small wood products, fodder, or any combination of slender wood and foliage. It is possible to obtain short logs from the basal stem. The crowns of some species produce highly figured and valuable sliced veneer.

Pollarding is also used to keep growing tips of branches above the reach of browsing animals (as on live fence posts) (Figure 5.11) and to raise seasonal shade to a level above the crops shaded, such as coffee and cacao. For these crops, annual pollarding can provide more light during the rainy season but permit cooling shade during the cloudless, dry season.

For many species, the high stump from pollarding produces more foliage and branchwood on short cutting cycles than does coppicing from a low stump.

In the humid and subhumid trials of the MPTS Research Network in Asia, one treatment is pollarding at 2 m height when the trees are 24 months old.

As mentioned in section 5.2, leaving at least one branch when pollarding is thought to improve development of roots and new branches for some species.

In alleycropping, pollarding/coppicing of two closely spaced rows of trees produces approximately double the wood and foliage of one row, but competes with the intercrop only slightly more than one row.

Better documented guidelines:

- Taller stumps produce more new branches and foliage.
- Lower stumps are slower to initiate crown competition with interplanted crops.
- A higher crown base permits more light to reach the intercrop, other conditions being equal.
- A longer cycle between cuts produces more net production of wood (there may be a limit to this statement, but it does not appear to have been established for any species or management system).

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12 Ibid.

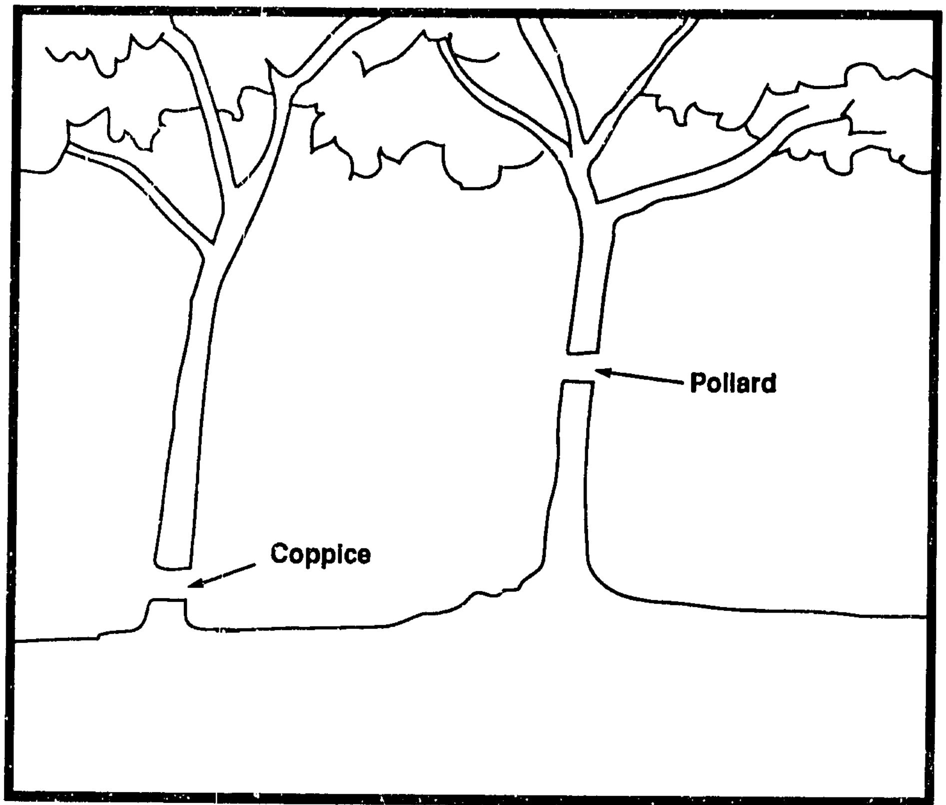

Figure 5.9. Coppice versus pollard cuts.

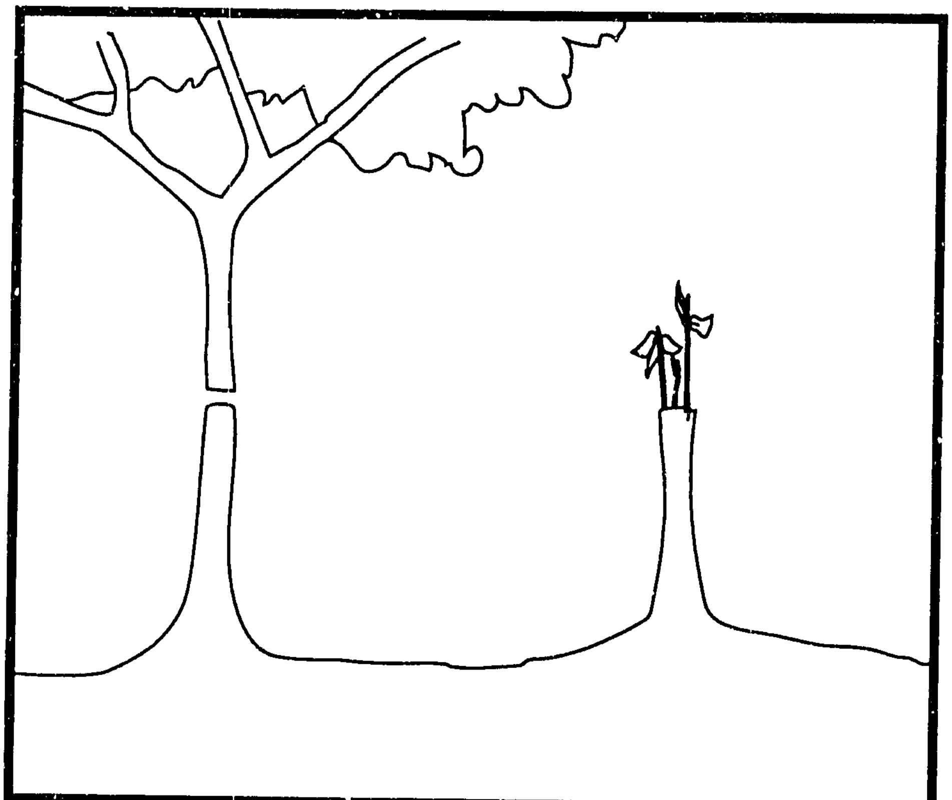

Figure 5.10. Pollarding tree for sprouts originating well aboveground

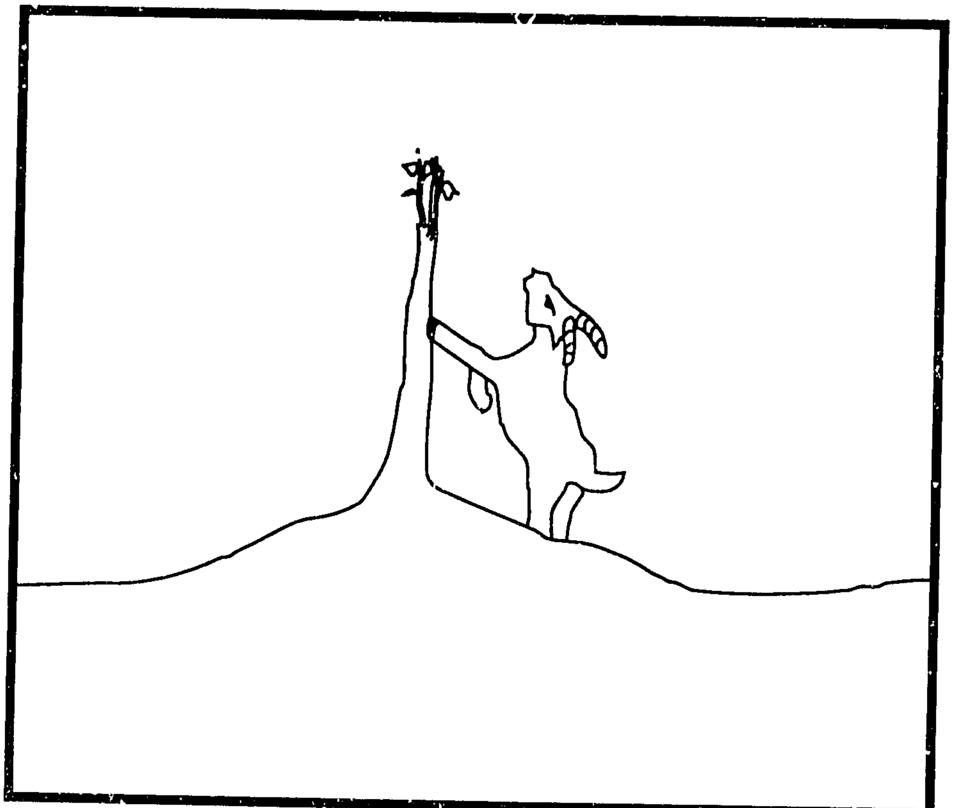

Figure 5.11. Pollarding protects sprouts from most browsing animals

- A shortened cutting cycle, within limits that vary with species and site, increases foliage production. Thirty days is about the minimum cycle to permit survival of any tree with complete pollarding or coppicing.

- Hedgerow trees in alleycropping offer the best combination of minimum competition and maximum shelter to the intercrop if coppiced or pollarded when the crop has two to four true leaves and again when direct shade is cast on the crop daily between 10:00 and 14:00 hours (10:00 a.m. to 2:00 p.m.).

- Intercrops are less affected by tree crown shading if continuous tree rows run north/south rather than east/west. The difference is less critical than timing of cut.

- Pollarding or coppicing may be done manually or mechanically, but direct browsing by livestock is not an equivalent substitute for cutting; trees are damaged and continuing yield is reduced by browsing.

5.4 Thinning and Stand Improvement

Thinning is defined as selective felling in an immature stand to accelerate diameter increment and improve the average form of the trees that remain. Stand improvement is the removal, including girdling and poisoning, of any unwanted trees or other vegetation.[13] Although research on thinning has been more inconclusive than on any other aspect of silviculture, a few rules are clear:

- A given genotype on a given site has an inherent potential for biomass production.
- Yield for any given set of conditions tends to be related to stand density in a curvilinear way (Figure 5.12).
- Within a fairly broad range of density, thinning permits concentrating growth on fewer trees without sacrificing total yield.
- Outside those limits, total yield is reduced because the site is not completely occupied (although individual trees grow quite rapidly) or because excessive competition between trees causes inefficient physiological functioning, at least during periods of weather stress. This often results in disease, insect attacks, and mortality.

The principal objective of thinning, therefore, is usually to maintain stocking rates within the range of maximum yield. If large trees are desired, stocking is kept near the lower end of the range. For many small items, stocking is maintained near the upper end of the range (Figure 5.13).

The several, classical types of thinning selected according to the quality of the stem form desired are:[14]

- **High Thinning**: Leaves the most promising stems, with due regard for even distribution over the stand and removing trees of any canopy class (Figure 5.14).
- **Low Thinning**: Favors dominants evenly distributed over the stand by removing non-dominant trees.
- **Selection Thinning**: Promotes trees with straight, cylindrical form by removing branchy and large, dominant stems.

In practice, field people tend to remove the same inferior trees from a given stand, regardless of the type of thinning planned. After two or three thinnings, the results are commonly indistinguishable as to type.

Most thinning in the tropics of high- and variable-value trees, such as teak or mahogany, is crop-tree release: the best trees are selected, and one or more of the principal competitors are removed beside each. The select crop trees may never comprise the entire stand, and there is not necessarily any effort to upgrade the quality of the non-crop trees (Figure 5.15).

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13 Ibid.

14 Ibid.

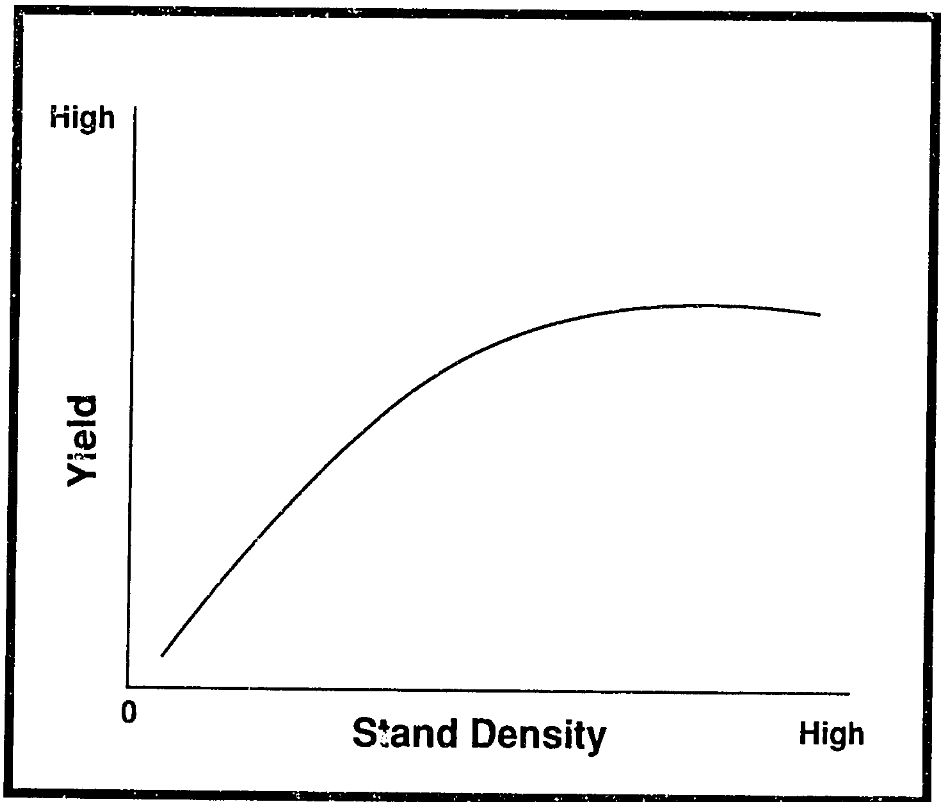

Figure 5.12. Curvilinear relationship of yield to stand density.

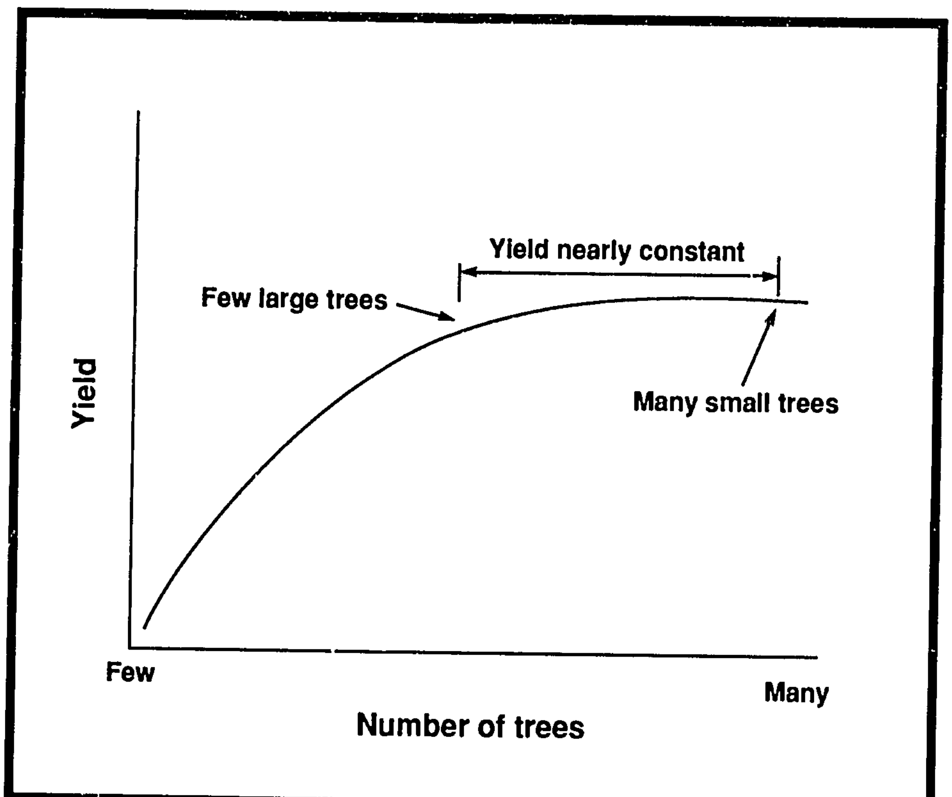

Figure 5.13. Maintaining yield for varied products

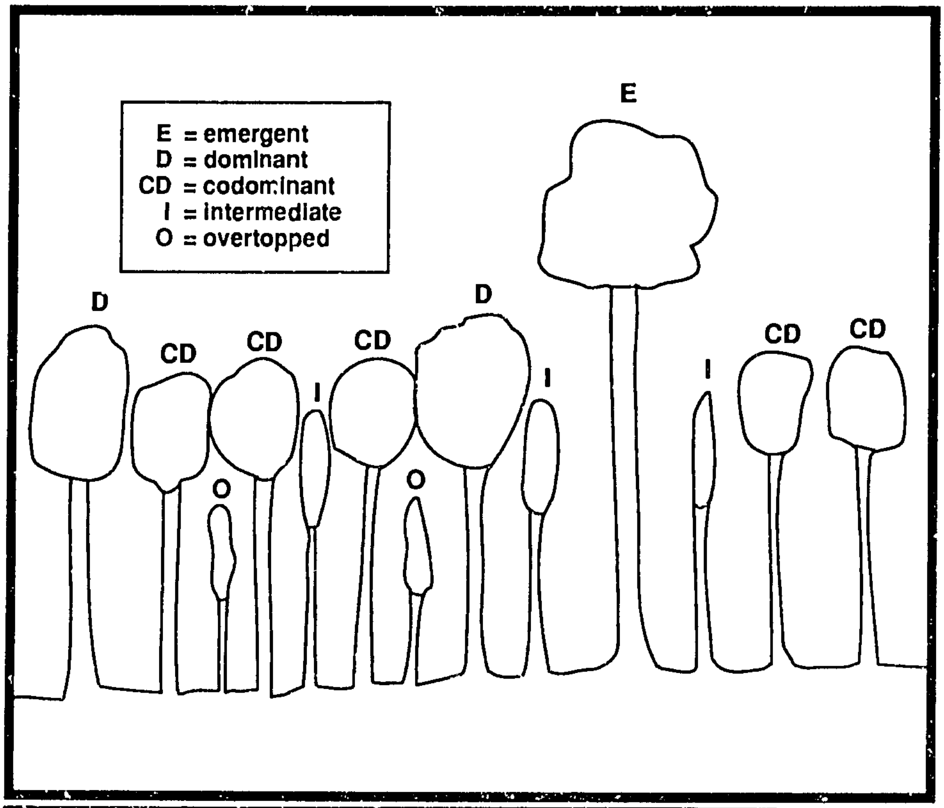

Figure 5.14. Tree canopy classes.

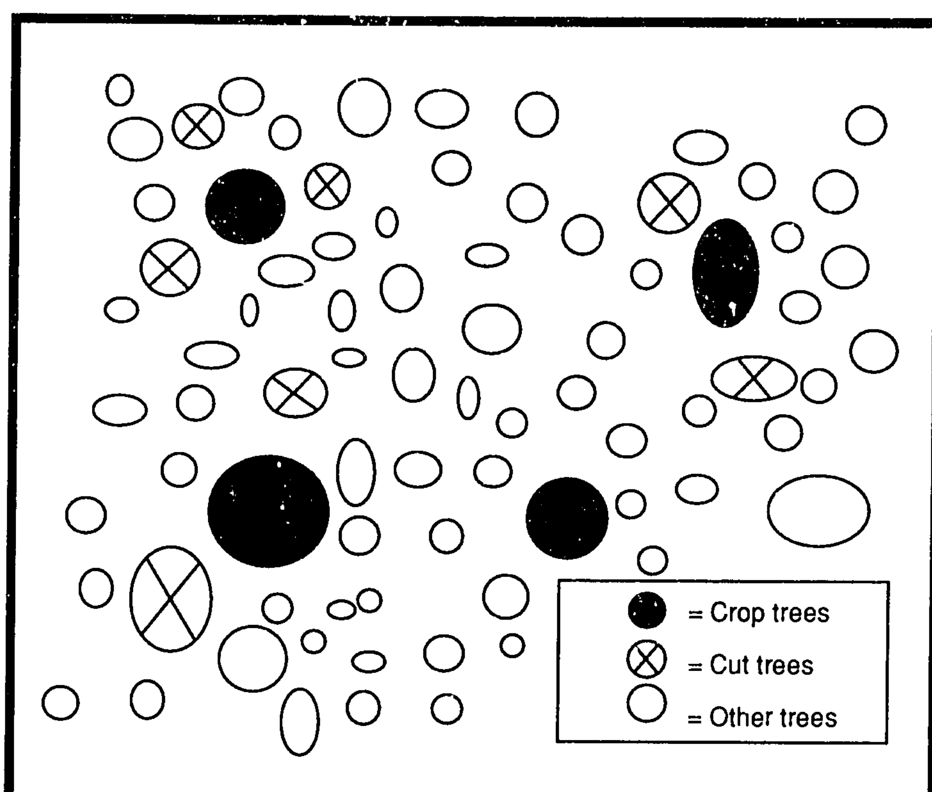

Figure 5.15. Crop-tree thinning

In plantations of relatively low- and uniform-value crops, such as pine or eucalyptus, a reverse form of stand thinning is commonly practiced: the poorest trees are selected and removed over the stand as a whole. The entire stand constitutes the crop and is upgraded at each thinning.

Investigation of the two systems is also somewhat different. *Weight* of crop-tree release can be simply expressed as removing the strongest 0, 1, 2, or 4 competitors (or some similar array) adjacent to a crop tree. Response is measured on an individual crop-tree basis.

Weight of stand thinning can be expressed per hectare as a number or percentage of stems/ha removed, basal area/ha removed, or volume/ha removed. Percentage of stems is the most commonly used expression because of its simplicity and practicality. Response is measured on a stand/ha basis.

- o Light thinning promotes about the same initial response from the residual trees as does heavy thinning.

- o Heavy thinning causes a more prolonged response of the residual stand than does light thinning.

An investigation of weight of stand thinning is almost as simple as that of crop-tree release: remove a fixed percentage of the least desirable trees, considering only a workable-size group of trees, then advance to consider another group.

Example: A tree marker looks at a compact group of nine trees that can be visually compared, evaluated and, in plantations, observed as a square of 3 x 3 trees (Figure 5.16). The weight of thinning can thus be any multiple of 11% (1/9). For a 22% thinning, the tree marker selects the two worst trees; for a 44% thinning, the worst four. The tree marker then repeats the process with the next group of nine. Besides providing a close control of weight, the system also ensures a reasonable distribution of the residual stand and that the best trees are preserved as residuals, according to the selection criteria.

If tree genotypes are essentially uniform, mechanical thinning is the simplest and most economical type of stand thinning; however, few stands are so similar genetically.

In natural stands, a simple system is *stick thinning*. Proceed through the woods carrying a stick of desired length. Wherever your stick touches two trees simultaneously, mark the inferior tree for removal (Figure 5.17). Spacing of residual trees averages about 1.5 times the stick length. Note that a stick thinning releases the whole stand.

A modern version is to use an angle gauge to determine stand basal area, then select the appropriate number of the poorest trees to reduce the residual basal area by the desired amount or to the desired level (Figure 5.18). This system is technically justifiable for research, but is cumbersome for routine field work.

Besides weight, thinning research can also be directed toward *cycle*, the time between cuts. The effects of a cycle are greatly affected by weight of thinning. A thinning weight of 20%, for example, is light on a cycle of 10 years between cuts but heavy on a cycle of six months between cuts. For a given weight, a longer cycle is more economical (higher yield per unit area and less maintenance of infrastructure), but a shorter cycle is better silviculturally (lighter traffic on the soil,

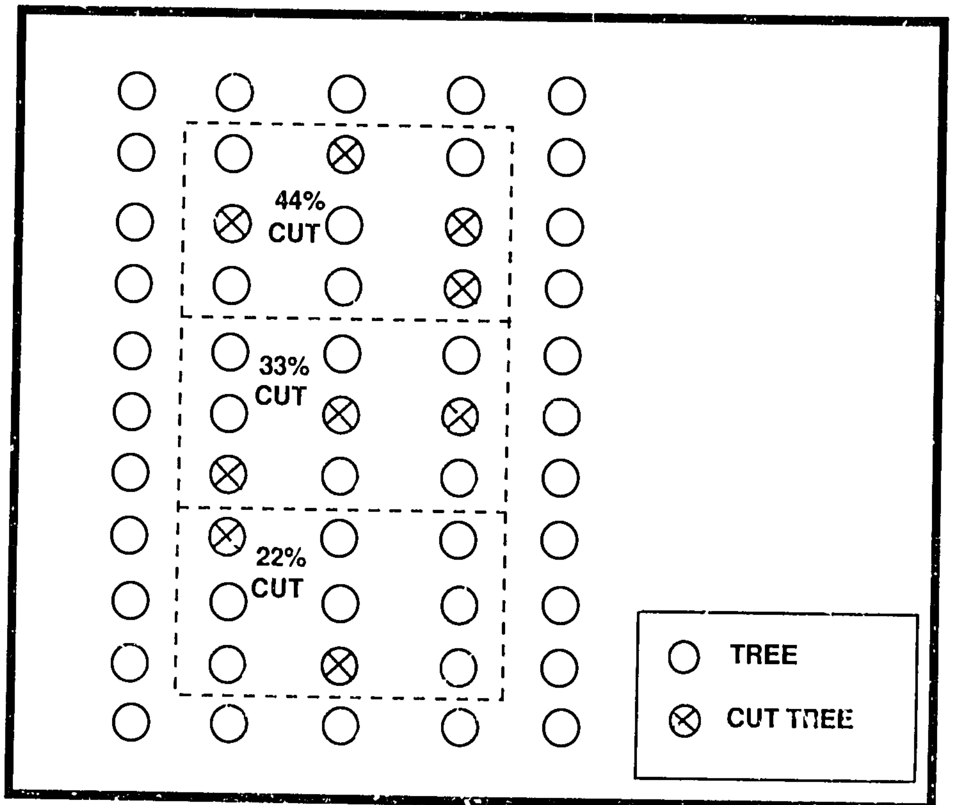

Figure 5.16. Control of thinning weight.

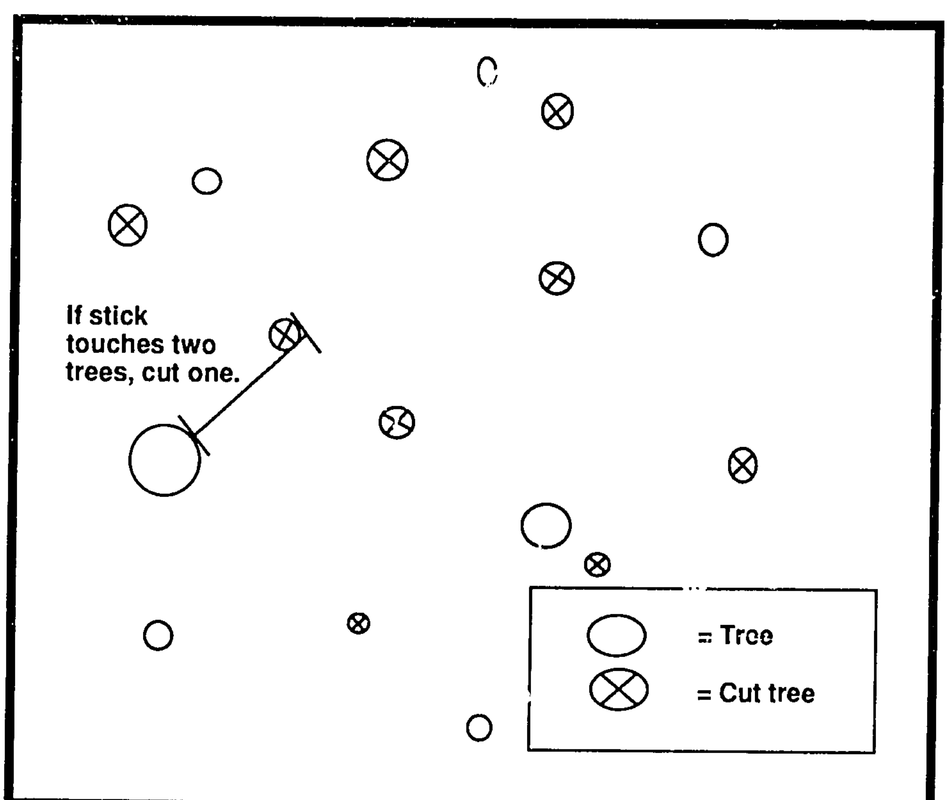

Figure 5.17. Stick thinning in natural forest.

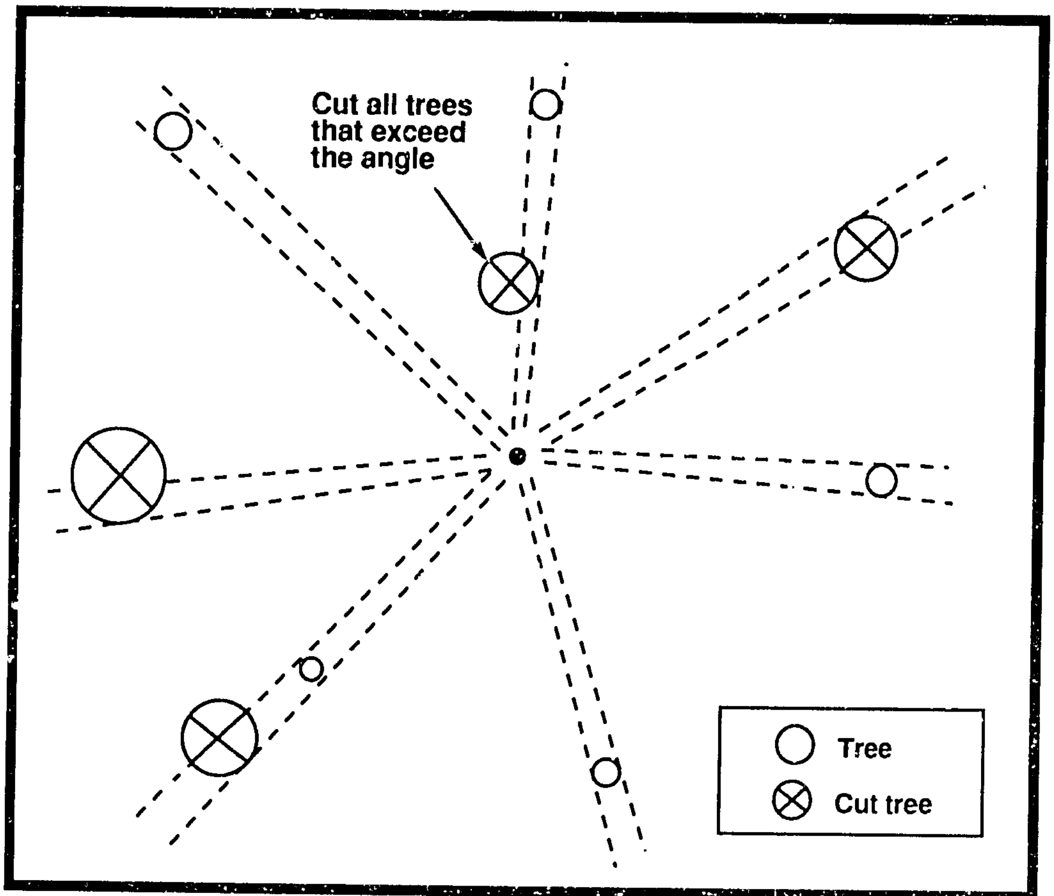

Figure 5.18. Angle-gauge tree selection for thinning.

less chance for erosion, and lower mortality). Quantifying such differences would establish a more rational base for future silvicultural decisions.

Intensity of thinning represents the interaction of weight and cycle. It is normally calculated by dividing weight by cycle length. If weight of thinning is 50% and the cycle is five years, the intensity equals 50 divided by 5 or 10% per year. The deceptiveness of such a measure becomes obvious if you take one of the values near its extreme. For example, a weight of 100% with a cycle of 10 years equals 100 divided by 10, also an intensity of 10%. Although a 50% thinning every five years is satisfactory in many tropical plantations, a 100% thinning on any cycle leaves nothing to grow.

It is suggested that thinning research not focus on the effects of intensity.

Determining which plants to remove for both thinning and stand improvement varies somewhat among practitioners, but general guidelines are as follows:

- o Trees harboring an infectious disease or insects dangerous to the remaining stand. This reduces risk to the residual trees.

- o Dead or dying trees with a present net value. This salvages trees that would otherwise be lost.

- o Any plant without a present or future value. This releases space, light, and nutrients for plants that do have such value. Note that "value" may refer to wood products, but may also refer to fruit, fiber, fodder, wildlife browse, or to a combination of products and services.

- o Plants that compete with superior trees. Deciding which to remove depends on the strength of competition and relative value of the crop and competing trees.

- o Trees inherently inferior because of species, form, or vigor. While such trees should be removed before the regeneration period begins, they often provide needed site protection during the vegetative phase of stand development.

In general, thinning similarly affects both long and short rotations of MPTS. However, intolerant species or those that coppice weakly usually survive and grow better as coppice following a clearcut or heavy thinning. They may die if thinned at a weight of 25 to 50% of the stand.

A special case is thinning among sprouts of the same stump. Abundant evidence shows that the remaining sprouts grow faster if all but two or three are removed. If only one young sprout is left on a large stump, it often seems unable to provide enough photosynthate to supply the entire root system, much of which dies. This is why scientists often recommend that you thin initially to three well-spaced sprouts, remove one when competition begins, and another when competition begins anew. This is generally sound advice for the production of large products.

Little data indicates under what conditions more biomass is produced by two or more sprouts or by only one. Research in this area is badly needed for important biomass species.

5.5 Harvest

Traditional forestry thinning and harvesting have quite different objectives. The purpose of thinning, as discussed in section 5.4, is to increase the quality or quantity growth of the remaining trees. Harvesting, however, means removing the biologically or financially mature trees to establish regeneration of the new crop.

Multipurpose trees may not ever be harvested in the traditional way. For example, *Leucaena* and *Gliricidia* species may be coppiced or pollarded annually for 50 years or more, as may other species used for coffee shade. Thus, they are harvested annually in the agricultural sense of the word, but not in the forestry sense. *Moringa oleifera* may be coppiced in beds more often than annually for the tender, edible leaves, as may hedgerow trees used for fodder or green manure in alleycropping.

On the other hand, *Gmelina* or *Tectona* species may have a crop-tree thinning with follow-up, repeated coppicing of the sprouts until a large sawlog or veneer log is available for harvest in the traditional sense.

General guidelines:

- o Most MPTS are mildly to strongly intolerant. Therefore, a true harvest cut to obtain regeneration is usually a clearcut for species that coppice well and a shelterwood cut for those that coppice poorly but develop well in even-aged stands.

- o If abundant, advanced regeneration is already established (fairly common under ungrazed *Leucaena*, for example), then the entire main canopy can be removed in a single cut. This is termed a one-cut shelterwood or, in some areas, the Malayan Uniform System when the harvest cut is followed by thinning/release of the understory and regeneration.

- o If advanced regeneration is not present, then a two- or even three-stage cut is made, usually removing 60 to 80% of the overstory basal area in the first cut and, after regeneration is obtained, the remainder in subsequent cut(s).

- o The regeneration is damaged less if still young when the overstory is completely removed.

- o If surrounded by trees, the minimum dimension of the harvested area should usually be the height of the larger, adjacent trees. If the harvested area is exposed to an open field or pasture on at least one side, there is no minimum dimension, although larger openings usually produce more and faster regeneration. All sections of the opening should receive direct sunlight during part of the day.

- o Moderate to tolerant species usually survive better when not exposed by clearcutting; however, they grow faster if they receive full sunlight at least part of the day or are lightly shaded with abundant sunflecks. Again, a shelterwood cut is usually ideal, although establishment is often successful in clearcut strips not wider than tree height and selection cuts about tree height in diameter.

- o Regardless of the type of harvest cutting, species other than those preferred commonly occur as often as those desired, or more so.

Cleaning and weeding are as important in naturally regenerated stands as in plantations.

6.0 Measurements

Remember:

- o Research requires precision and accuracy. Long-term, cooperative, and general research all require standard methodologies.
- o Methods should conform to well-established, global standards and terminology. To measure special products, try to follow the spirit of existing standards. Carefully document analytical methods, as well as measurement tools and techniques.
- o Mathematical modeling requires accurate measurements of meaningful environmental and organism characteristics adequate to test one or more hypotheses.
- o Science can and must provide consistent and accurate measurements.
- o Accurate measurements must be reproducible, especially in the cooperative science of a research network.

Precision. Precision refers to the exactness of measurement. Precision of measurement equals one-half the unit of measurement (see also statistical precision, section 2.4).

Accuracy. Accuracy refers to correctness of measurement. It is determined by two factors: consistency and reality. If repeated measurements of the same object vary, they cannot all be accurate. With a vernier caliper, it is possible to measure a tree dbh to 1/10 mm. But if the caliper is moved slightly, the new dbh measurement of the same tree will be different because of irregularities in stem roundness, bark thickness, and other variables. The precision is 1/10 mm divided by 2 = 1/20 mm, but all the readings are not the same so cannot all be accurate. In such a case, the precision is illusory.

The second factor is the relationship to reality. If you wish to measure dbh of a tree, breast height must be determined. This is often and reliably done with a stick cut to a length of 1.3 m. But if the base of the stick is sliced at an angle, the sharp point may slide through loose litter, sink into soft ground, sit exactly on hard ground, or even rest on a raised root or stone. In such a case, only the measurements done when the stick rests on hard ground can be accurate--and then only until the point wears down or breaks off.

Accidental or careless errors of measurement are not included in the discussion above of either accuracy or precision. Purely random errors tend to follow the rules of any random population. Positive and negative errors occur with equal frequency, and small errors occur more often than large ones. Thus, the errors *tend* to cancel out. For a plot of many trees, the mean may or may not be accurate despite a number of random errors. For an individual tree (the basic unit of genotype selection), errors invariably produce wrong answers.

Many errors, however, are not random in the technical sense. Foresters who fail to measure breast height location commonly estimate the height too high in the morning and gradually lower as they tire during the day. This means that their dbh measurements are too small in the morning and too large in the afternoon. These are not compensating errors. If a forester swings the angle gauge around himself as he revolves to view the whole plot instead of correctly walking around the angle gauge, the measured basal area is consistently too large.

Many errors are generated during recording. If two or more people are in the crew, one should measure the dimension of the tree and call out the measurement. The other should call out the same measurement and then record it. When both the measurer and the recorder can speak the same two languages, errors are reduced by the measurement being called out in one language and repeated in the second.

Regardless of precision, tests demonstrate that consistency is improved by recording to the *completed* unit, not to the nearest unit. For example, both 1.2 and 1.8 are recorded as 1.

You must have adequate space to record measurements. Of course, you should write clearly and carefully. The cost of illegible writing in too-small spaces, even if it means only one return field trip to clarify notes, greatly exceeds the benefits of saving paper.

Preventing errors at each stage of research is necessary, difficult, and ongoing. Even more costly, however, is the discovery and elimination of existing errors. Most techniques that prevent errors are cost-effective. For re-measurement, the resolution of incompatibilities in a series means time and labor, but one-time measurement errors are even worse. They may go undiscovered, and the whole study may yield erroneous conclusions.

6.1 Traditional Forestry Measurements

The traditional forestry measurements of height and diameter are used primarily to determine volume of bole or portions thereof.

6.1.1 Height. This is the vertical distance above a reference point. Some of the specific types of heights used in traditional forestry are:

- Total height (h). This is the height value most often measured and refers to the vertical distance from the average ground line (on relatively level ground) to the top of the tree. On a slope, the most common reference is to the ground line on the uphill side of the tree (Figure 6.1).

  Top of the tree refers to the uppermost portion of the main stem, without considering foliage or lateral branches. For some tropical trees with leaves a meter or more long, this distinction is relevant.

  The h of a leaning or crooked tree is measured vertically, not along the slope of the stem, and so is always less than the length of the bole. The reason is practical, not theoretical. You can easily determine the vertical h of a standing tree by simple trigonometry, but measuring actual length is more difficult and expensive (Figure 6.2).

- Commercial or merchantable height. Because this varies with time and place, you must always define it specifically, usually in terms of minimum acceptable diameter. If sawlogs are accepted to a minimum diameter of 25 cm, merchantable height equals the vertical distance from the ground line to a point on the bole with a diameter of 25 cm. This is sometimes abbreviated h25. This convention is not universally accepted, however, and should be defined when used.

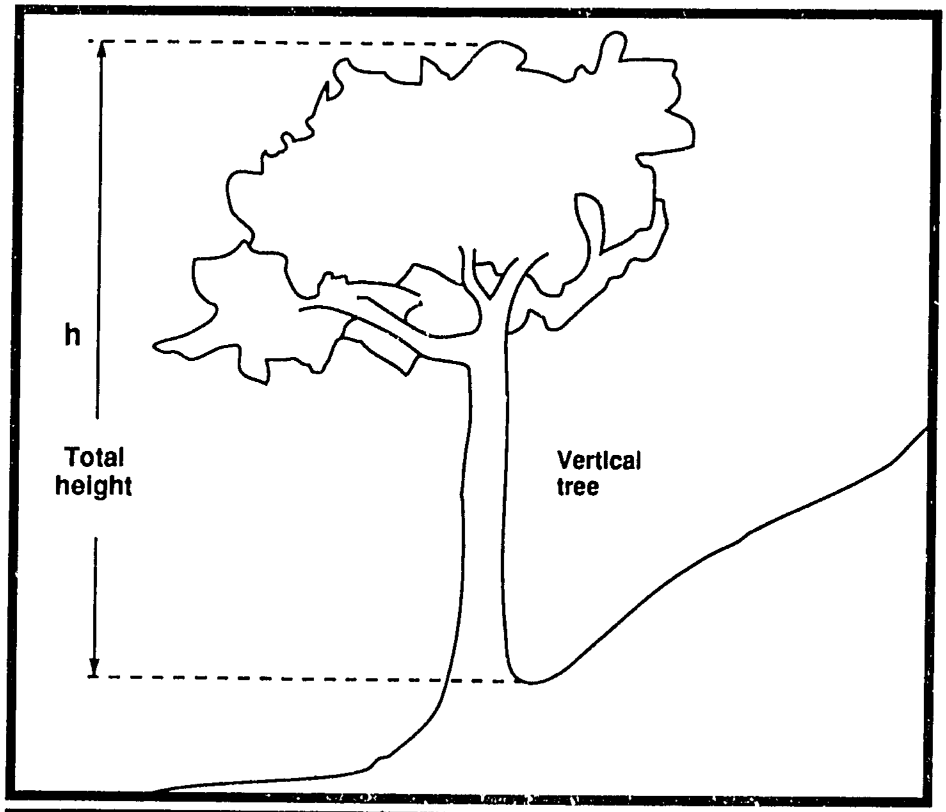

Figure 6.1. Ground line determination for measuring tree height

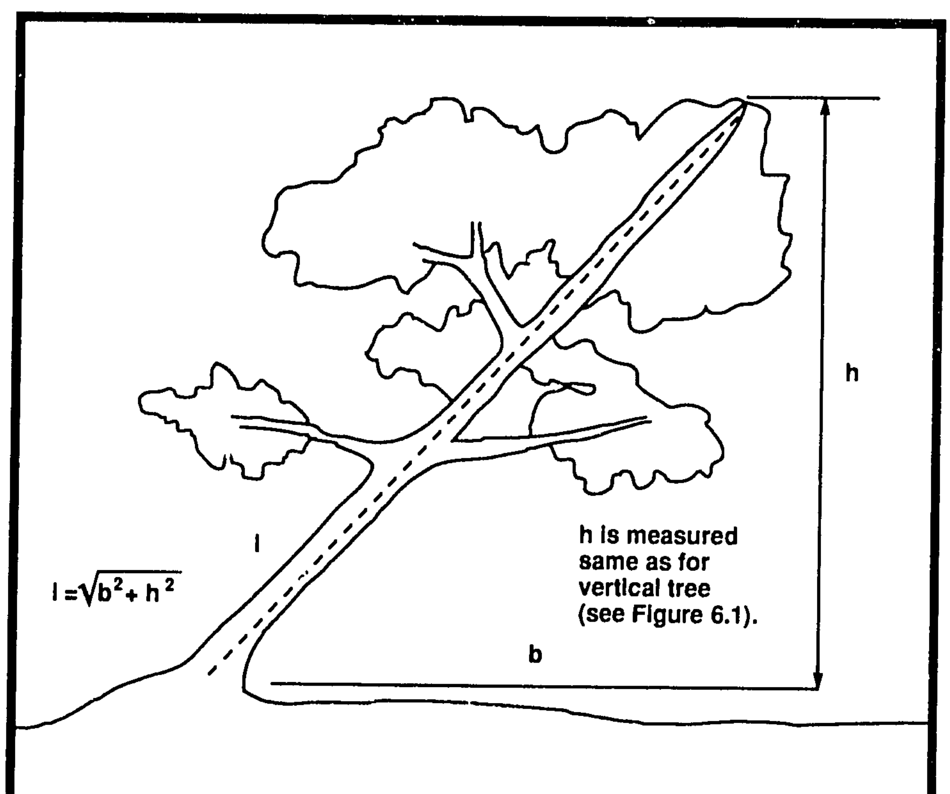

Figure 6.2. Measuring height (h) and length (l) of leaning tree

Because diameter inside bark (dib) is invisible from the ground, the diameter outside bark (dob) is usually measured or estimated for a standing tree. Again, this convention is not universally accepted, and you must define actual usage.

- o Crown height. This is the vertical height from ground to base of the live crown. Base of live crown is most often defined as the attachment point of the lowest branch of the continuous crown, without considering isolated or epicormic branches. Exact definition should be provided.

- o Crown length. This is the distance from the base of the crown to the uppermost point of the stem. Therefore, crown height plus crown length (as defined) must equal total tree height. If they do not, better definitions are needed (Figure 6.3).

- o Use a graduated pole, fixed or telescoping, to measure height up to a convenient level. For taller trees, use a hypsometer (to measure vertical angles) and a measured baseline.

- o Height is usually measured to the completed cm below 3 m, completed dm (tenth of a meter) from 3 m to about 15 m, and to completed meters above 15 m. These units are related to limits of accuracy more than utility. Even for accuracy, the precision is often false; nevertheless, they are the commonly accepted norms and should be adopted unless another unit is demonstrably superior.

6.1.2 Diameter of the Tree Stem. As stated in section 6.1, in traditional forestry, diameter is measured primarily as a step toward determining bole or log volume. The volume of a cylinder equals cross-sectional area times length, and the volume of a near-cylinder like a tree bole can be calculated as cross-sectional area times length times form factor (a correction for taper and irregularity).

If the tree were perfectly round, the cross-sectional area would simply be $r^2 \pi$ or $\left(\frac{d}{2}\right)^2 \times \pi$ Trees are usually not perfectly round, however. The diameter really needed is that which will give you the actual cross-sectional area (Figure 6.4).

This is the distance equal to the diameter of a circle with a cross-sectional area equal to that of the tree at the point of measurement. It is approximated when the same trees are measured repeatedly over time (in most research) by measuring circumference and dividing by pi (3.14159) or, more commonly, measuring circumference using a tape calibrated in units of equivalent diameter. A 1-cm unit on the tape is actually 3.14159 cm long. Since a circle has the largest possible cross-sectional area for a given circumference, a diameter based on circumference is always biased upwards unless the tree is perfectly round and the bark smooth. Such a tree is uncommon.

Diameter is often determined by two caliper measurements taken at right angles to each other, the mean calculated arithmetically from them and taken as the actual diameter (Figure 6.5). A related, third type of measurement is a single d measurement made anywhere if the tree looks round and at the midpoint between the widest and narrowest portions if asymmetry is obvious. Caliper measurements may be either too large or small with reference to the true mean, and tend to balance out. Their mean is usually closer to the true mean d than is a d estimated from girth measurements, of which errors are always too large. Because caliper measurements may fall anywhere on the tree circumference, they are not practicably reproducible or well-adapted to repeated measurements of the same trees.

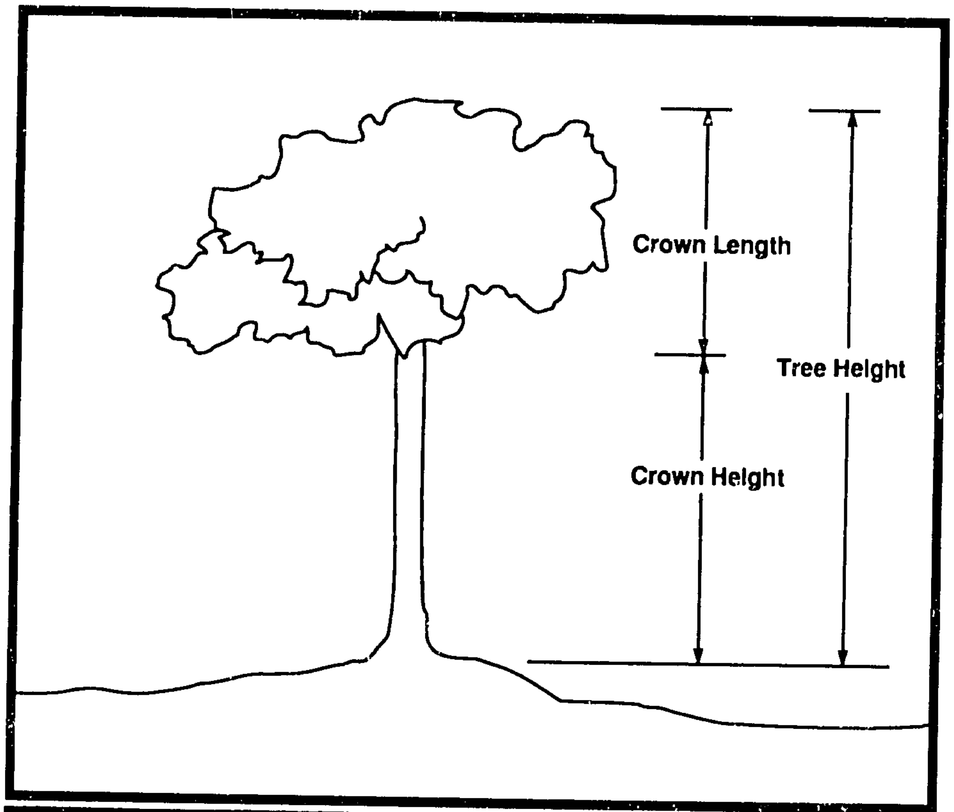

Figure 6.3. Crown height and length

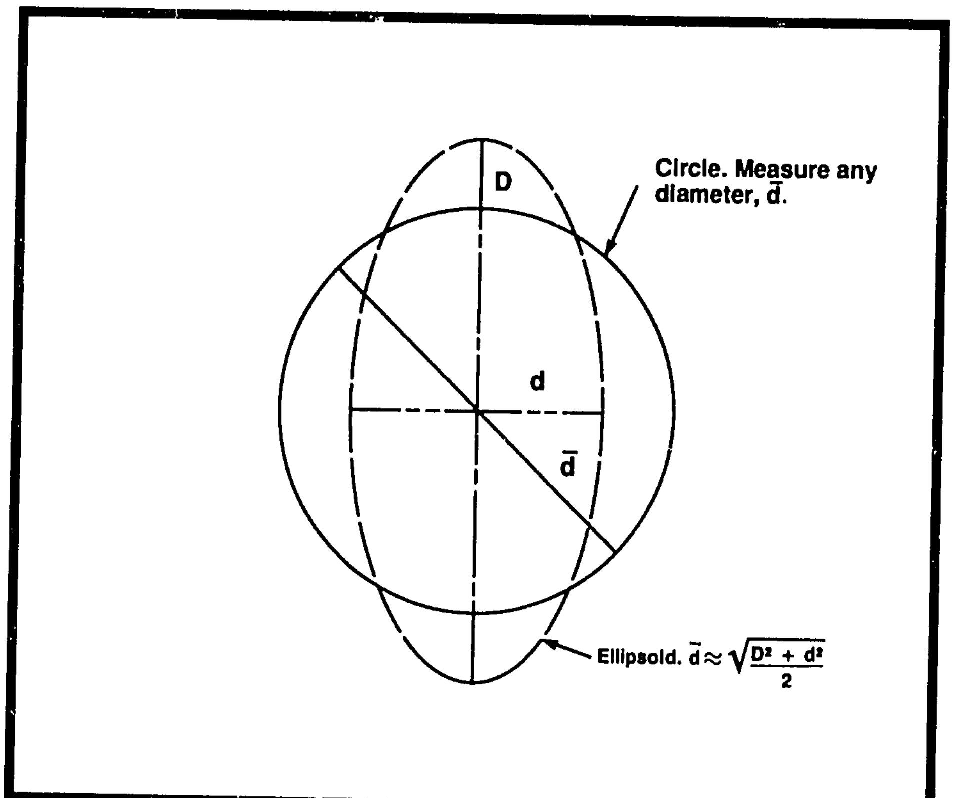

Figure 6.4. Tree diameter measurement

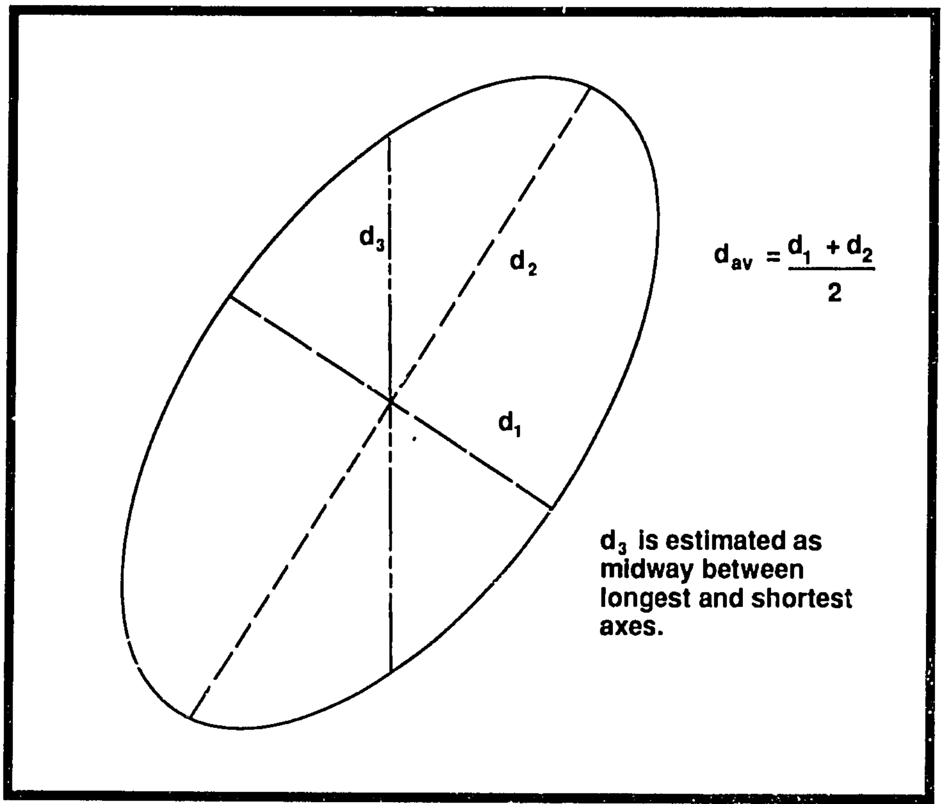

Figure 6.5. Caliper measurement of diameter.

Tape measurements of circumference are more consistent, while caliper measurements are more often accurate.

In traditional forestry, the standard point of measuring diameter is breast height. In the increasingly global metric world, that equals 1.3 m above the ground line, average or uphill side as specified. In those countries still using the English system of units, breast height is 1.37 m (4.5 ft). Diameter at breast height (dbh) usually includes bark. For clarity, it is sometimes designated dbhob (dbh outside bark) or dbhib (dbh inside bark).

In the nursery, diameter is often measured at the root collar (drc). This may be from 5 to 100 mm above the actual ground line. Because of changing obstructions and inequalities of ground surface, 50 mm is preferred as a standard. But the point you use should be consistent and specified. You may use various calipers to measure but a cutout, homemade gauge can be faster and cheaper (Figure 6.6).

For tree measurement related to use of the bole, basal d or d at stump height is commonly at 30 cm aboveground. Again, your actual usage should be consistent and specified.

Similarly, all recorded measurements should be as accurate as possible. For example, dbh of a live tree 1 m tall is 0, and should not be recorded as missing, although you need not record it. A tree 1.4 m tall has a dbh > 0 and should never be recorded as 0.

If you are recording dbh for commercial size trees on a research plot, you should also record it for smaller trees on the plot. If this is not done, the mean dbh is biased upwards, and

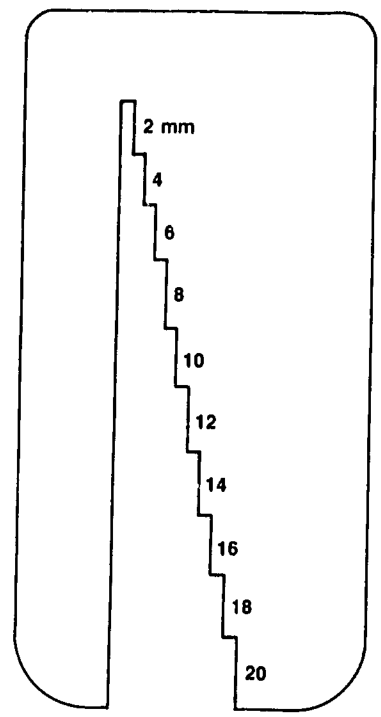

Figure 6.6. Nursery diameter gauge.

varying degrees of distortion will continue until dbh of all trees is included. Interpretation of results during the transition period is difficult or misleading.

For measurements of logs and shorter sections of a tree stem, various combinations of d with length are used, the intensity varying directly with the value of the product and inversely with the cost of labor. The most common are d at the top and base of the individual log, ib if the terminal cuts have been made, and ob if the stem is intact. Inside bark measurements are customarily made with a straight rule, and outside bark with a caliper or, rarely, a tape. In this case, a tape would be used for ease of carrying, not for consistent measurements.

Beyond this basic combination, you can make any desired number of measurements at whatever points are of concern. Usually, the more measurements you make, the more precise and accurate is the volume calculated. In all cases, the basic problem of an asymmetrical stem remains, both in cross-section and in taper. You should clearly record exact procedures.

If a management treatment, such as thinning or pruning, will affect the form of the stem, begin stem measurements at the time of treatment, before any effects occur. Measurements on all treatments should be the same. Pruning increases the relative diameter growth of the upper bole in relation to dbh, with greatest percentage growth at the base of the live crown. If you prune to heights of 4, 6, and 8 m, for example, maximum effect on bole d growth will be at about 3.7, 5.7, and 7.7 m, respectively. You should measure dob at each height for all treatments (Figure 6.7).

Diameter of the crown (dk) is also influenced by thinning and spacing, as well as pruning, species, site quality, and age. It is perhaps the best indicator of competition, and is often measured to evaluate competition.

The crown is usually measured using a non-elastic tape, which is stretched along an axis from one edge of the crown to its opposite edge, passing through the geographical center. You can consistently locate the edge of a crown 5 to 20 m above ground by standing with your shoulders parallel to the tape and your nose positioned exactly below the crown edge. Consistency is nearly impossible if you stand with your shoulders perpendicular to the tape (Figure 6.8).

If the crown is regular in shape, you may measure along any two axes perpendicular to each other. If the crown shape is irregular, you usually measure the longest and shortest axes, being sure to pass through the geographical center of the crown.

6.1.3 Multiple Stems. These stems are treated individually when separate at breast height. For commercially sound but biologically questionable reasons, each stem is usually recorded as a separate tree. (Section 6.2 provides greater detail.)

If the several stems are treated as a single tree, you calculate the equivalent dbh by taking the square root of the sum of the diameter squared of each individual stem (see section 6.1.2). You then use this equivalent dbh to determine basal area and volume. Volume determined from the equivalent dbh is less reliable since volume also depends on h, which usually varies with each stem.

6.1.4 Specific Gravity. This is the basic density (oven-dry weight of wood as related to the weight of an equal volume of water). You can obtain it reliably only by destructive sampling, permanently removing a tree or tree portion from the field trial.

The least destructive and least accurate method is to withdraw one bark-to-pith increment core with a hollow borer. Specific gravity varies with age from the pith within the tree bole, so you must adjust the sample for age, or at least position. Do this arithmetically by dividing the core from pith to cambium into sections or annual rings, if possible. Calculate the percentage of the total cross-sectional area of the stem associated with that length of the core, and weight the specific gravity by the amount of stem volume represented to derive a weighted mean specific gravity. The utility of such a calculation is questionable. The same considerations apply when you use two or more cores from the same vertical position in the stem.

Specific gravity also varies with tree height, so you must duplicate the same procedure at additional points up the tree if you desire greater accuracy for the whole stem.

Commonly, if one core is not sufficiently informative, delay analysis until the tree is felled, at which time you take a complete cross-section or a pie-shaped portion of a cross-section at breast height. For more detailed information, take similar samples at the stump and at the top of every log.

Calculating specific gravity is complicated by variations in the wood's moisture content. Maximum volume occurs only when the wood is fully saturated. Therefore, you must determine wood volume at saturation, usually by immersion, but you can determine the weight of actual wood fibers only when all water has been removed.

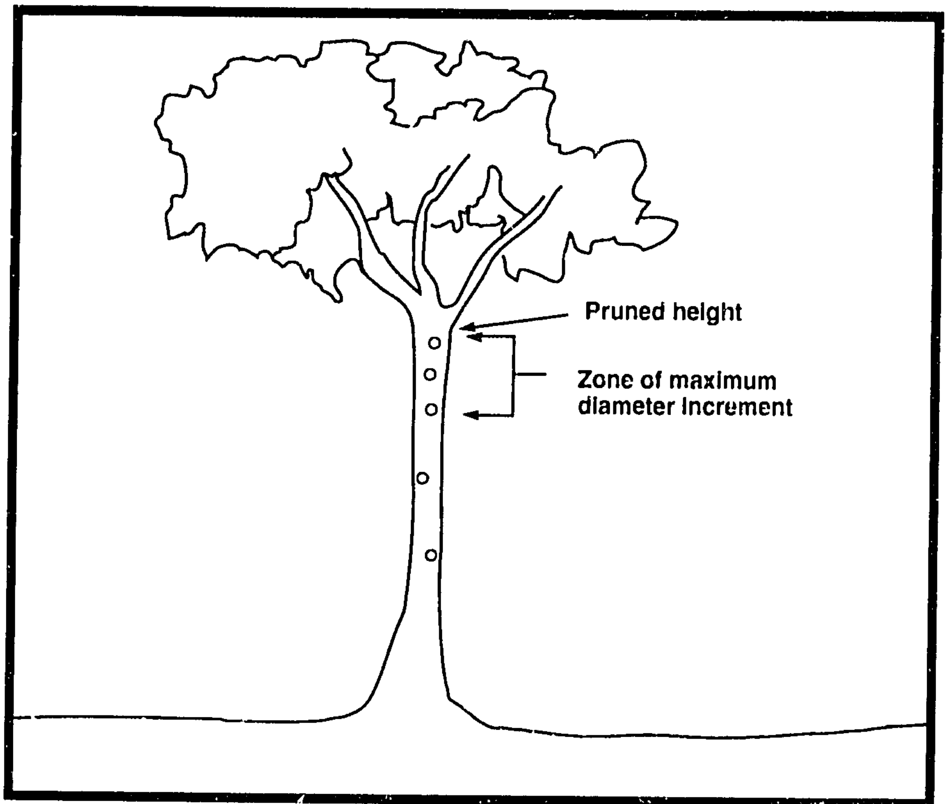

Figure 6.7. Zone for measuring pruning effects.

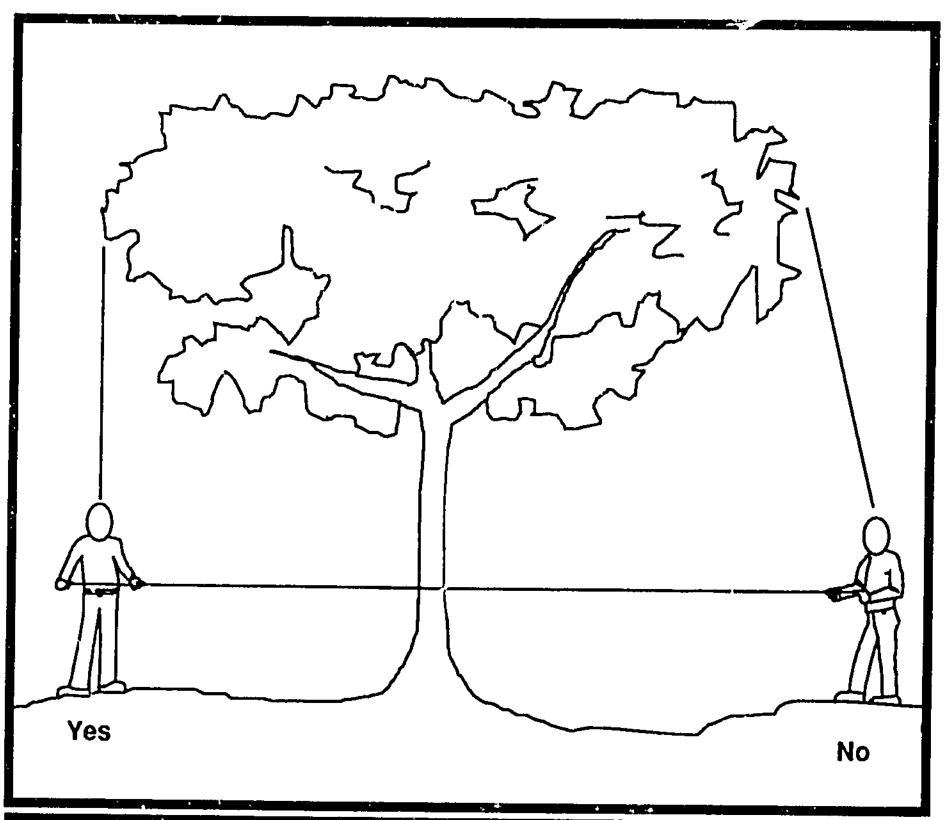

Figure 6.8. Measuring crown diameter.

Therefore, use the following procedure:

1) determine the volume of wet, never-dried wood,

2) dry it at 60 to 80 °C until a constant weight is achieved,

3) determine the weight, and

4) divide the weight in grams by the original volume in cubic centimeters. The resulting decimal is the specific gravity.

6.2 Non-traditional Measurements

As yet, there are no widely accepted procedures for measuring multipurpose tree species (MPTS) and their products. However, a consistent and standardized methodology **must** be adopted for valid comparisons to be drawn between experiments, even by the same scientist.

Even today, many foresters around the world use a breast height of 4.5 ft (1.37 m) while others use 1.3 m. Neither is demonstrably better, but they differ by an extent that varies with species, age, site, and past treatments. The only way to know to what extent they differ is to measure the same trees both ways. Since this is hardly ever done, data are never quite comparable.

Similarly, there is no proof that a basal diameter measured at 30 cm height is superior or inferior to measurement at 50 cm. But for comparability between years, plots, and experiments, only one height can be used. Standardized measurement methods must be adopted.

6.2.1 Total Height. Measure the same as in traditional forestry for the same reasons.

Determine height for the main stem only. If you measure length, measure all other stems from the point of attachment at the main stem to the growing tip of the subsidiary stem or to another specified point.

6.2.2 Stem Length. Because many MPTS are leaning trees, particularly in the early years, it is useful to measure total stem length, from the ground line to the top of the measured stem, equivalent to the height if the tree were erect (Figure 6.9). You should not confuse total length with total height. A sucker or branch approximately vertical often assumes apical dominance and becomes higher than the original leader, while stem length is still shorter (Figure 6.10). No matter how the figures are manipulated, records become difficult to interpret or are misleading if the distinction between length and height is not maintained for leaning trees.

6.2.3 Diameter. Measure the same as traditional measurements. Because many MPTS are multi-stemmed and often thorny, the accessibility of breast height may be difficult. For such species, measuring the d only at the base (db), preferably at 30 cm, is adequate. If the species is expected to attain industrial size and value, measuring the dbh is important enough to merit necessary pruning for access. Basal measurement (if made) of future sawtimber trees should also be at 30 cm above the ground.

Individually measure and record multiple stems if they are distinct at the height of measurement. For species with industrial potential, this is breast height. For species without industrial potential, this is below the actual height of measurement, either breast height or basal diameter height.

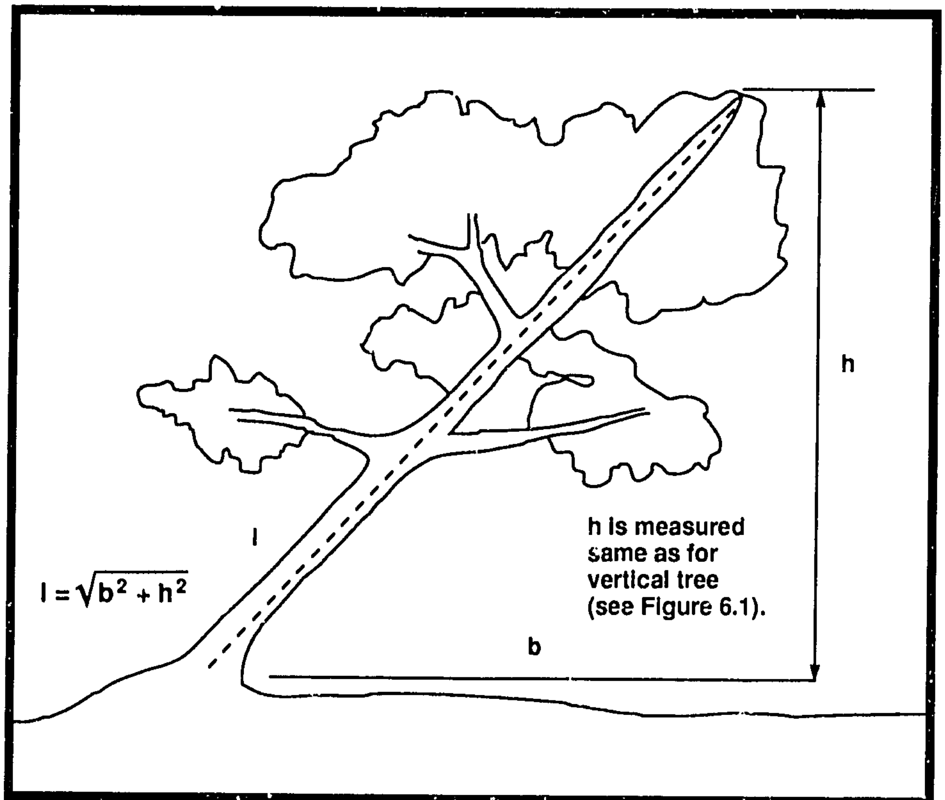

Figure 6.9. Measuring height (h) and length (l) of leaning tree.

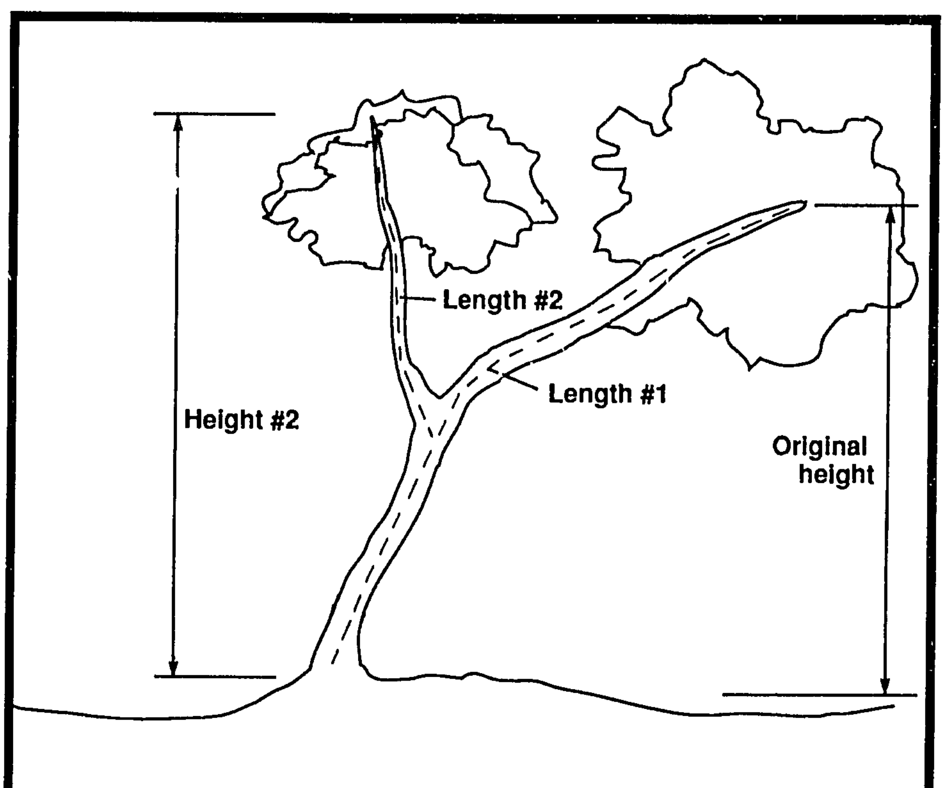

Figure 6.10. Measuring heights and lengths with old and new leaders

To determine the combined diameter for all stems of a multi-stemmed tree, the equivalent diameter equals the square root of the sum of the squares of the individual stem diameters; that is, $d_t = \text{sq rt} (d_1^2 + d_2^2 + ... + d_n^2)$

Measure length, as well as diameter, for each of the multiple stems, however chosen, until the length:diameter relationship has been confirmed as equal to the height:diameter ratio of the main stem, or a separate relationship is established for the auxiliary stems.

6.2.4 Wood Volume. Because of the irregular form, wood volume for MPTS is more difficult and expensive to determine than for sawtimber and other large products.

Volume determination depends largely on size of product. In the past, volume of small wood products has usually been from gross measurements of stacked products (Figure 6.11). However, actual wood content of stacked products varies so much that stacked volumes are of little utility for research. For limited quantities of small pieces, displacement of liquid is the most accurate, and frequently the cheapest, method (Figure 6.12).

For large pieces, measurement of length and one or more diameters, as in traditional forestry, appears the most promising method.

For large quantities of any size, economy requires sampling, using the same basic requirements for any type of population sampling, accompanied by mathematical modeling.

In any sampling of wood, divide the total into stem and branches. As indicated above, stems are defined as separating from the main bole below a selected point of reference. Common usage for the point of reference for trees that grow to industrial size is breast height. For smaller trees, a suggested reference point is 30 cm above the ground line. For any reference height, a supplementary, recommended criterion is that lateral stem diameter exceed 50% of the diameter of the main stem at the height of measurement. Any smaller material is classified as a branch. Define procedures used.

Some products have specific size classifications for acceptability or several classifications of different values. Fence posts, house poles, and vegetable stakes are examples. Such products are not marketed by weight or volume, but by piece, and they are counted rather than measured.

Products like firewood and pulpwood chips are frequently marketed by weight. Determine the weight of wood using portable weight scales for moderate or small quantities or by transporting large quantities to industrial platform scales, if available.

The principal complication in determining dry weight of wood is, of course, the fluctuating amount of water it contains. In a live tree, moisture content (based on dry weight) varies with species and season from about 50% to at least 200%.

For small quantities of wood, regardless of size, determine the wet weight, which drops rapidly in a tree just felled but with branches and foliage intact, by weighing all the wood. Then dry the wood to a constant weight, and reweigh to obtain dry weight. For large quantities, follow the same procedure, using a representative sample properly drawn. (Measuring well-selected, small samples from many trees is far more representative than measuring one entire tree.)

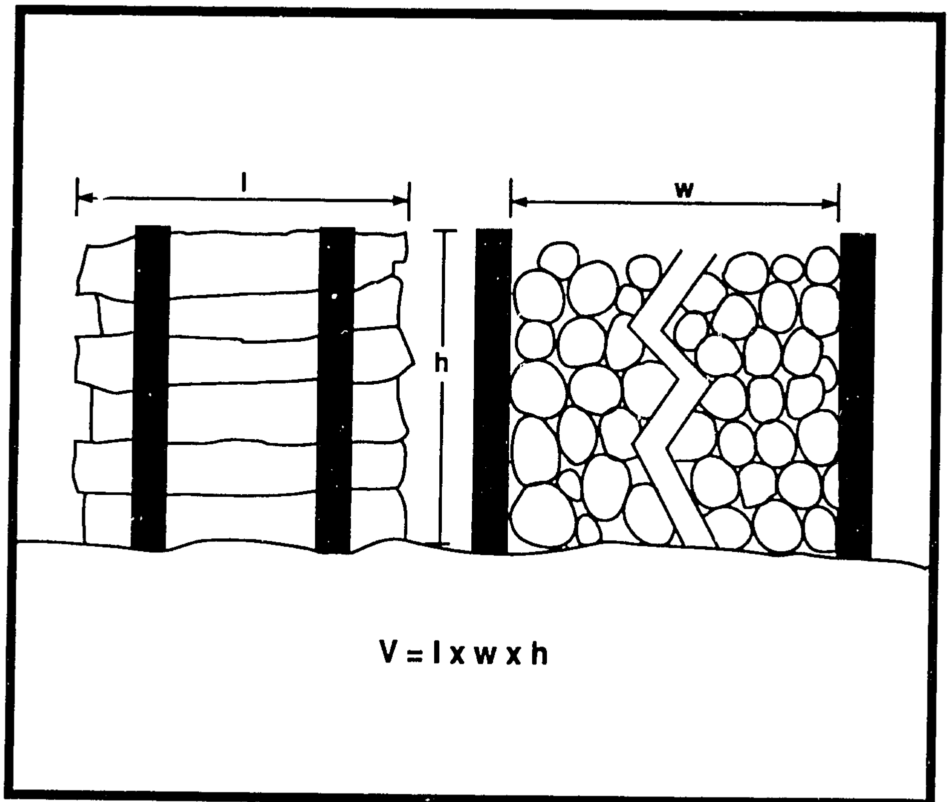

Figure 6.11. Measurement of stacked firewood volume.

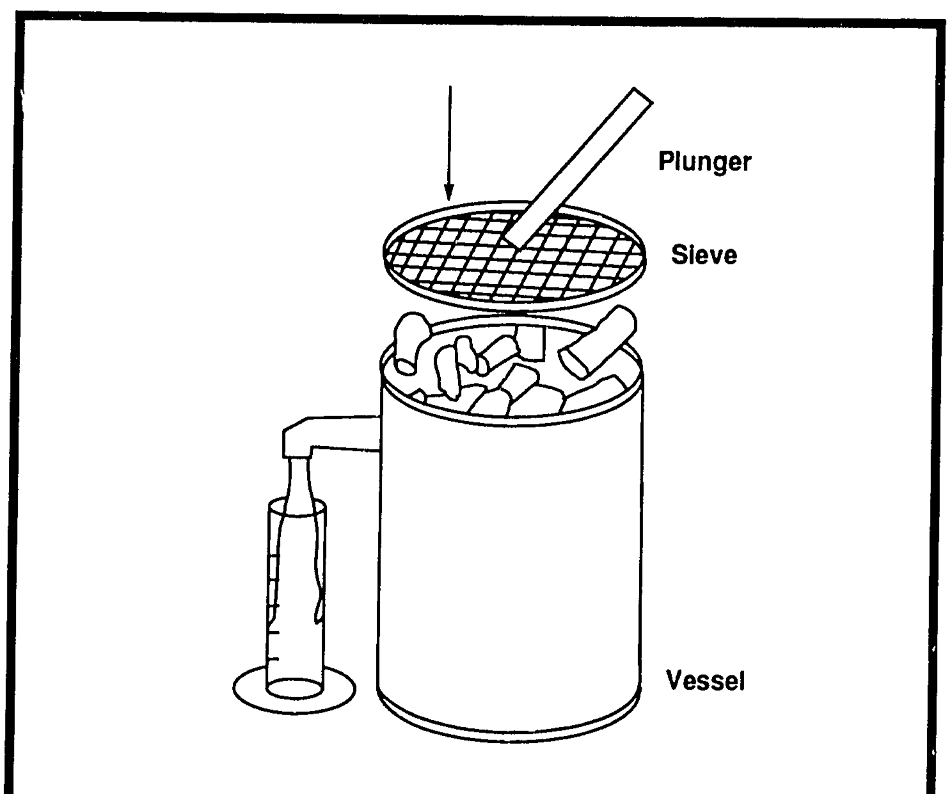

Figure 6.12. Displacement measurement of small pieces.

You can mathematically derive total dry weight from total volume and average specific gravity. Specific gravity varies with age and height in the tree, as discussed earlier. It also varies with side of a leaning tree and vertical position in branches, so your samples to determine specific gravity must come from throughout the usable, woody portion of the tree, preferably as disks containing complete cross-sections at the sampling point. If "dry" refers to any condition except oven-dry, you must include the qualifier and specification. For example, air-dry at 12% MC.

6.2.5 Extractives. Distribution of extractives within a tree is not reported adequately to permit a stratified sampling system. You should sample all tissues containing the extractive of interest by an unbiased, systematic scheme or a random one. Analyses of each sampling location within the tree offer you the opportunity to determine internal distribution but are more expensive than a few analyses from a bulked sample.

You should report by date in an appropriate metric unit the resins and gums extracted from the standing tree. Although yield/tree is preferable, yield/plot is acceptable. Using bulked yield per block or other non-treatment combination of plots as the basic unit for reporting is not informative research.

6.2.6 Fodder. This includes foliage and, in many species, bark and succulent twigs. For bushes or small trees, you may remove all foliage and succulent branches < 2 cm diameter (or other specified limit) for fodder, and weigh fresh and dry. For large trees, economy requires that you weigh only samples. Because foliage structure and content vary with age and position, your samples must also be drawn from systematically or randomly chosen positions throughout the crown.

Any sampling scheme that draws representative samples of leaves by age, sun versus shade, and by position in crown is satisfactory. The easiest is probably to use all leaves and succulent twigs of each chosen branch (Figure 6.13). For laboratory analysis of fodder nutrient content, a subsample of the bulked material is adequate after thoroughly mixing the original sampling, dividing in half, re-mixing, re-dividing, and repeating until your desired sample size is obtained.

6.2.7 Intercrop Yield. You should also report intercrop yield appropriately, using an adequately-defined metric unit. If yield is to be related to tree proximity, then stratify sample measurements by distance from tree, preferably from rectangular plots with the long axis perpendicular to a straight line connecting plot center to the nearest tree (Figure 6.14).

For meaningful interpretation, your crop sampling **must** include crops in the same field from throughout the complete range of interactions with the trees. The significant information is not normally whether crops next to a tree are affected, but how overall yield from the entire crop-and-tree system is affected.

For well-rounded results, you should consider use of tree and crop residues. If animals are included in the system, they should be included in your results (see section 6.2.8, below).

Supplementary information may be critical to interpretation. This includes exact cropping and harvesting dates, rainfall amount and distribution, species and variety of crop, and cultural methods and inputs.

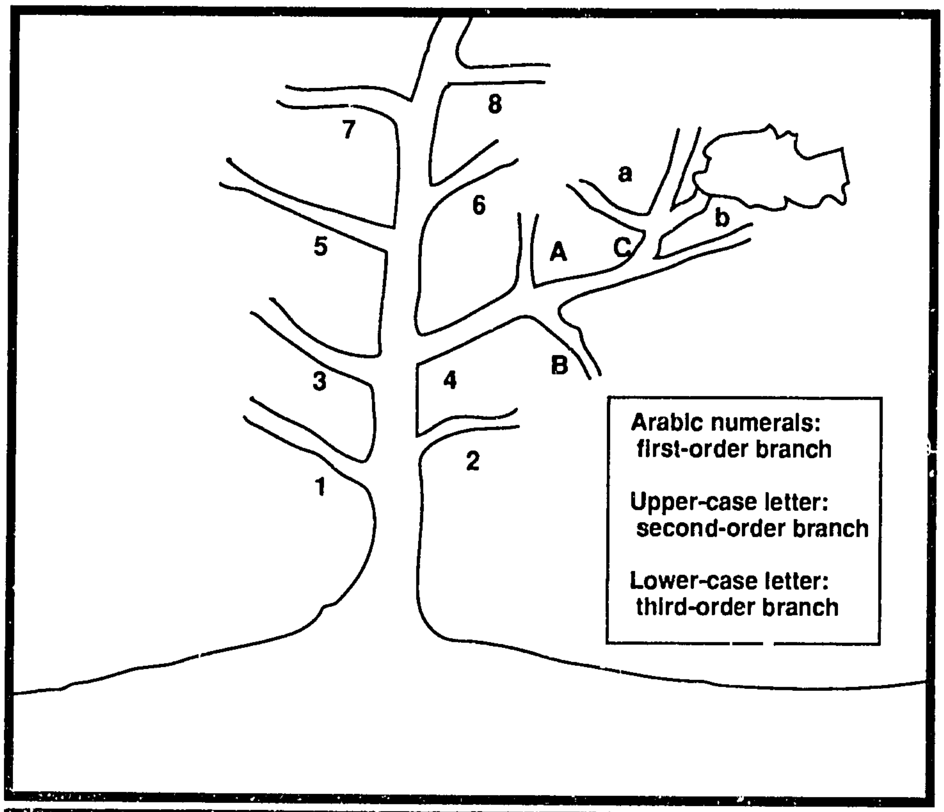

Figure 6.13. Selecting fodder samples from large tree.

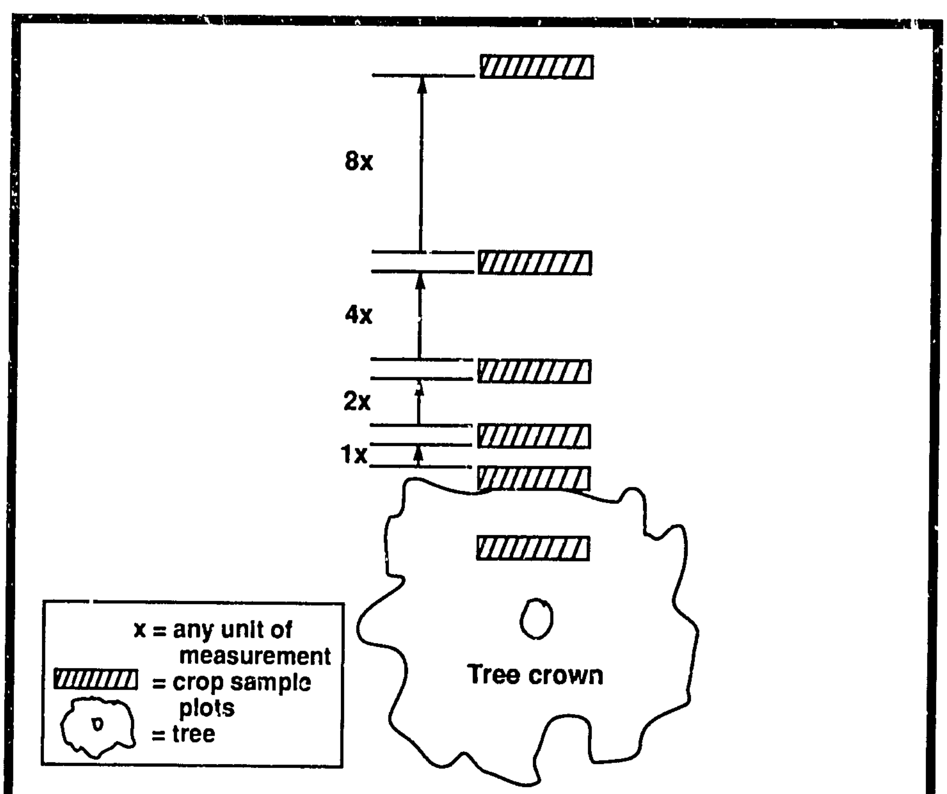

Figure 6.14. Sampling intercrop yield (vertical view)

6.2.8 Animal Production. Animal production is a composite measurement calculated from 1) reproduction rate, litter size, and birth weight of offspring; 2) weight gains and/or milk yields measured in grams or kilograms; and 3) survival. Smallholders rarely weigh their animals, but researchers can easily weigh sheep and goats with a hanging balance. Cattle and buffalo weights are difficult to measure directly without heavy and expensive equipment.

Common substitutes for the desired measurements are:

- o estimating age from dentition
- o estimating rate of reproduction and mortality from herd structure and farmer recall on herd entries and exits
- o estimating animal productivity from regular monthly visits

The substitutes are obviously less precise and are difficult to relate to nutrition and pasture conditions during a specific, short period.

Differences between bloodlines and general farm management cause large between-farm variations. Number of animals per farm may also be low, reducing potential replication of observations.

Supplementing grass and crop residues with nitrogen-rich fodder through a single dry-season can contribute substantially to weight gain; animal-units supported; reduced mortality; and improved reproductive rate, age at selling, and age at first calving. It is expected that, in many cases, the magnitude of improvement will be apparent to experienced farmers.

As with crops, supplementary information on domestic animals is essential. This includes species, breed, age, care, health, lactation, and whether working. Results are more replicable in a cut-and-carry system than when animals are on pasture. Fodder yield is also higher and far more sustainable.

6.3 Re-measurements

When you re-measure any part of a tree, carry out the procedures exactly as before. Use the same measurement instrument, reference height, and precision. If personnel are the same, however, exchange duties if practicable; that is, the one who measured the tree previously should now record, and the one who previously recorded should now measure. This tends to reduce unconscious repetition of errors, particularly when measurements are frequent. As mentioned before, most efforts to reduce errors are cost-effective.

To reduce accidental errors, carry the previously recorded measurements to the plot at the time of re-measurement. If measurements are entered into a computer system, the record carried to the field should be the computer printout, not the original field notes. This provides a check of the original data entry, as well as of the actual measurement.

The measurer calls out the new number, the recorder checks it against the previous measurement and calls it out if compatible. If the new measurement is less than the previous one (negative growth) or unreasonably larger, the measurer is requested to measure again. The measurer should not be advised of the apparent problem until after the measurement is verified to avoid bias of the second reading. If the verified measurement is incompatible with the prior one, this problem should be noted and resolved in the office.

6.4 Modeling

A principal aim of most researchers is to prepare a mathematical model describing the actual relationship of an organism to its environment, including reliable prediction of how changes in the environment affect performance of the organism.

Because both environments and life processes are so complex, constructing a useful model is never easy. The first necessity is a computing and analysis system that can calculate several differing, dynamic relationships with ease and accuracy and can compare the utility and reliability of the various formulae derived. The ingenuity and sophistication of the systems vary, but all can be reduced to a simple procedure:

- o Measure and categorize the continuous and discrete characteristics of the environment and organisms.
- o Hypothesize one or more mathematical relationships.
- o Test the hypotheses against the available data.
- o Select the most promising hypotheses.
- o Measure a new sample of the original population, and repeat the above steps until the required accuracy and precision are attained.
- o Test the model on a new, similar population.

Two assumptions are incorporated into the procedure outlined. The first is consistent and accurate measurements with a realistic precision. The second is appropriate selection of key characteristics of the environment and organisms. This requires the combined knowledge of plant physiology, silviculture, mensuration, soils, climatology, and statistics. Sometimes one person has the required expertise; more often, especially as the complexity of each field increases, two, three, or more experts are needed.

Each person must recognize that genetic composition and environmental factors govern the internal processes and conditions that regulate growth and development.

To date, genetic composition is controlled by the selection of species, provenance, variety, cultivar, and genotype. Recent successes with gene identification and transfer offer hope for greater precision in controlling future genetic composition.

Modern sensors and recorders make it possible to be inundated with environmental data. Thus, it is important to select, test, and verify those environmental factors most closely related to the most meaningful plant characteristics and development.

Internal processes are fairly well-understood. You can estimate conditions with some reliability within the limits of field management.

The talent and art of modeling, therefore, lie in selecting the most promising species and provenance, the most revealing environmental factors, the management practices that most efficiently favor the desired internal conditions, and the mathematical expression that accurately and reliably predicts the probable interaction of entities and conditions.

7.0 Record Forms for the Information and Decision Support System

The Information and Decision Support System (IADSS), the software package that helps F/FRED Project cooperators manage information about multipurpose tree species (MPTS), consists of integrated and related databases. Its long-term objective is to provide easy and effective management of research data with global applications. The goal is to encourage adoption of standard methodologies that will improve the quality and comparability of worldwide research on MPTS and related uses.

The first version of IADSS was designed to record, modify, retrieve, and analyze the data generated by the humid and subhumid network trials established in 1987 by F/FRED Project cooperators.[15]

The specific objective of these trials is to characterize the effects of environment on growth and yield to estimate species and site interactions. A minimum data set was decided on for the humid and subhumid network trials by network cooperators at a meeting held in Kuala Lumpur, Malaysia in December 1986.

The forms described below were originally prepared for the network trial experiments, and dedicated compiled software was written for recording and analyzing them.[16]

At the request of the MPTS research cooperators, a general purpose form, Form X, was developed to record additional types of measurements.

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[15] The forms described in this chapter were taken from the *IADSS user's manual* (Version 1.1), MPTS Network Research Series Manual No. 1, published in 1988 by the F/FRED Global Research Unit in Maui, Hawaii. The manual provides complete instructions for using the IADSS software.

[16] Information enclosed in brackets indicates material was not included in the *IADSS user's manual* or the *Manual for multipurpose tree species research cooperators*, manuals 1 and 2, respectively, in the MPTS Network Research Series.

7.1 FORM A. Institution Information

ADD

ID: TH-01

Institution Name:	**Thailand Institute of Scientific and Technological Research (TISTR)**
Mailing Address:	**196 Phaholyothin Road** **Bangkhen** **Bangkok 10900**
Country:	**Thailand**
Telex:	**21392 TISTR TH** Cable: **TISTR, BANGKOK**
Telephone:	**66-2-5791121 x 30**

Enter information in form above. Press <Ctrl-W> to save.
[Esc] = Exit, [F1] = Help

ID: Five-character code. The first two characters indicate the cooperating institution. (The current list of codes by institution is given in section 8.2.) Any cooperating researcher not assigned a code should devise one and advise the Global Research Unit or the F/FRED Management Office. The two-character, institutional code is followed by a hyphen and a two-digit location code assigned by the country institution.

Institution Name: English-language name of the institution with which the principal investigator is affiliated. A specific department or division can be added for clarity. Acronyms should follow the complete spelling of names and should be enclosed in parentheses.

Mailing Address: Complete street address with information adequate to deliver packages and messages, as well as the post office box or other information needed to deliver regular mail; include intra-city zip or other codes if relevant.

Country: Full, unabbreviated name.

Telex: Full telex code, including numerical country code. (Note that telex and telephone country codes are different systems.)

Cable: Full commercial code, if available.

Telephone: Numerical country, city, and individual codes (separated by hyphens), and, if available, extension (preceded by the letter X). (Note that the telephone country code is not the same as the code used for telexes.)

7.2 FORM B. Cooperator Information

ID: **TH-01**

Principal Investigator Name:
Family: **Yantasath** First: **Kovith**
Other Researchers:
Siriphong Patanavibul, Suthijed Chandrasiri,
Winai Supatanakul, Piya Charlermklin

Institution and Address of Principal Investigator (if different from FORM A)
Institution Name:

Address:

Country:
Telex: Cable:
Telephone:

[S]earch, [A]dd, [M]odify, [D]elete
[Esc] = Exit, [F2] = Print

ID: Same as for Form A, a combination of institution code and location number.

Principal Investigator Name: The name of the individual responsible for the experiment, with family name in the left-hand blank. In the F/FRED network experiments, this refers to the person stipulated in the research agreement.

Other Researchers: Names of other scientists participating in the experiment.

Institution and Address of Principal Investigator: Institution and address of the principal investigator, if different from that given in Form A.

7.3 FORM C. Trial Site Information

ADD

ID: TH-01

Site Name: Chumphon
Site ID : CHUMP01

Elevation (m): -9
Latitude (deg): 10 (min): 58
Longitude (deg): 99 (min): 29

Aspect (degrees from North): 0
Direction (N,S): N
Direction (W,E): E

Trial Site Topography:
Slope Gradient (degrees): 0
Slope Position (U=upper, M=middle, L=lower):

General Topography:
Slope Gradient (degrees): 0
Length of Slope (1= <100m, 2= 100-500m, 3= >500m):

Enter information in form above. Press <Ctrl-W> to save.
[Esc] = Exit, [F1] = Help

ID: Same as for previous forms.

Site Name: Name of the site as it is commonly referred to by in-country researchers. The name can be used for only one location in that country.

Site ID: A unique code that consists of the first five letters of the site name plus two digits, a total of seven or fewer characters with any remaining spaces left blank.

Elevation: Site elevation above mean sea level, in meters.

Aspect: Direction toward which the topography of the experiment area faces, in azimuth degrees measured clockwise from due north: due east is 090, south 180, west 270, and north 360. Use a compass to determine the degrees. If the topography is level, use 0.

Latitude: Degrees, minutes, and direction from the equator.

Longitude: Degrees, minutes, and direction from the Greenwich meridian.

Trial Site Topography, Slope Gradient: Average slope (in degrees) of the trial site as a whole. If there is no slope, enter 0. [If there are considerable differences between replications or blocks, enter V for variable.]

Trial Site Topography, Slope Position: The slope on which the trial site lies is divided and classified into upper, middle, or lower thirds. If slope gradient was classified as 0, leave this space blank.

General Topography, Slope Gradient: Average slope (in degrees) of the area surrounding the experiment. If there is no slope, enter 0.

General Topography, Length of Slope: The codes for length of slope are 1 (less than 100 m), 2 (100-500 m), and 3 (more than 500 m). If slope gradient was classified as 0, leave this space blank.

ID: **TH-01**

Village Name: _
Village ID :

Land Ownership (public/private):

Proximity of nearest household (km):
Proximity of nearest village (km) :

Primary surrounding land use (crop/forest/pasture):
Grazing pattern adjacent to plot (tended/untended):

Plot observation by researchers/guards (daily/weekly/biweekly):

Plot Area Protection:	Fencing	(Yes/No):
	Guards	(Yes/No):
	Agreement	(Yes/No):

Enter information in the form above. Press <Ctrl-W> to save.
[Esc] = Exit

ID: Same as previous forms.

Village Name: Enter the name of the village used in the Village and Farm Forestry Database. If that village has not been selected, describe the village closest to the experiment site.

Village ID: The first seven letters of the village name. If the name has fewer than seven letters, leave the remaining spaces blank.

Land Ownership: *Public* means belonging to any unit of the government, at any level, including the reigning monarch. *Private* means belonging to any individual, family, or privately-owned business organization.

Proximity of Nearest Household: Distance [by trail or road] (in km) to the nearest occupied house. If the nearest occupied house is in a village, the distance to both the household and the village is the same.

Proximity of Nearest Village: Distance [by trail or road] (in km) to the nearest village.

Primary Surrounding Land Use: Principal use of the land that surrounds the experiment area at time of recording. [If land is currently unused, classify it by existing vegetation as either "forest" or "pasture."]

Grazing Pattern: [Classify grazing pattern as tended only if livestock movement is adequately controlled either by a person or a fence.]

Plot Observation: Frequency of observation visits to the experiment area. Answers should be accurate.

Plot Area Protection: Answers should be realistic. [A one-wire fence, weekly visit by a guard, or brief mention to a neighbor without even a verbal agreement clearly indicates a negative response.]

7.5 FORM E. Site Descriptor-Climate

ADD

ID: TH-01

Climate Station Name: Prachuap Khiri Khan
Climate Station ID : PRACHUA Years of Record: 35
Latitude (deg) : 10 (min): 58 Direction (N,S) : N
Longitude (deg): 99 (min): 29 Direction (E,W): E
Elevation (m): 0 Distance from Experiment Site (km): 120

Mo	MaxT(C)	MinT(C)	Precip(mm)	Mo	MaxT(C)	MinT(C)	Precip(mm)
Jan	29.7	19.2	47	Jul	32.2	24.2	88
Feb	30.8	20.9	56	Aug	31.8	24.2	103
Mar	32.0	22.3	50	Sep	32.0	23.9	94
Apr	33.4	23.9	40	Oct	30.9	23.2	222
May	33.3	24.6	121	Nov	30.0	22.2	194
Jun	32.3	24.5	96	Dec	29.6	20.4	35
				Mean			

Enter information in form above. Press <Ctrl-W> to save.
[Esc] = Exit, [F1] = Help.

ID: Same as previous forms.

Climate Station Name: The nearest or most useful climatological station with more than six years of records.

Climate Station ID: The first seven letters of the station name. If name has less than seven letters, leave the remaining spaces blank.

Years of Records: Number of years records have been kept at the named station.

Latitude: Degrees, minutes, and direction of station from the equator.

Longitude: Degrees, minutes, and direction of station from the Greenwich meridian.

Elevation: Elevation of the station (in m) above mean sea level.

Distance from Experiment Site: Straight-line distance (in km) of the climatological site from the experimental area.

Temperatures and Precipitation: If available, enter the long-term, monthly mean maximum and minimum temperatures.

If the monthly means for the station are not available, their calculation requires two steps. First, calculate the mean for each year. For each month of each year, sum the values (maximum or minimum temperature) for every day recorded. Divide the total of the temperatures by the number of days recorded, a maximum of 31. Repeat for all available or desired years (at least seven). Second, calculate the long-term mean. For each month, sum the values for all the years. Divide each total by the number of years of records for that month. This is the value to be entered in Form E. [If maximum and minimum temperatures are not available but daily averages are, leave the extremes blank and enter the averages directly, but use maximum and minimum if available.]

Obtain mean total monthly precipitation from the station or (as for temperature) by adding precipitation/month each year over the life of the station and dividing by the number of years of records.

The system calculates the annual mean temperatures and total precipitation.

Occurrence of frosts and dry months are other climatic characteristics often considered valuable indicators of site potential.

7.6 FORM F. Site Descriptors-Soil

MODIFY

ID: **TH-01**

Soil Pedon ID: 87FN875-4
Soil Classification (Family Level of Soil Taxonomy):
loamy-skeletal, siliceous, isohyperthermic Oxic Paleustult

Soil Order: **Ultisol**
Soil Moisture Regime . . . (by Soil Taxonomy) : **Ustic**
Soil Temperature Regime (by Soil Taxonomy): **Isohyperthermic**
Soil Parent-Material : **Colluvium from sandstone**
Soil Texture (Surface): **Fine sandy loam**
(Subsoil): **Clay**
Soil Drainage (Surface): **Well drained**
(Subsoil): **Well to somewhat poorly**
Soil Color (Surface): **Very dark grayish brown**
(Subsoil): **Yellowish red**
Special Problems (erosion, salinity, depth to impermeable layer):
Slight erosion and low salinity.

Enter information in form above. Press <Ctrl-W> to save.
[Esc] = Exit, [F1] = Help

ID: Same as previous forms.

Soil Pedon ID: Provided by the U.S. National Soils Survey Laboratory or equivalent; if not yet available, leave blank for later completion. This must be for the same site identified on Form C.

[A qualified soil scientist may provide the remaining soils information as available: family, texture, parent material, color, moisture and temperature regimes, drainage.]

7.7 FORM G. Experiment Site Preparation

ADD

Existing Vegetation (description of biomass):	ID: **TH-01**
Method of Clearing (sequence of operations):	
Residue (I=Incorporated, R=removed, B=burned): (% of surface free of residues after preparation): %	
Method of Soil Cultivation (sequence, depth and type of implements):	
Enter information in form above. Press <Ctrl-W> to save.	

[Esc] = Exit, [F1] = Help

ID: Same as previous forms.

Existing Vegetation: Describe the vegetation on the experiment site as it existed immediately before site preparation, including the dominant species and estimated overall density.

[Density is "complete" if the site was completely occupied by dense vegetation, "partial" if dense vegetation covered only part of the area, and "sparse" if vegetation was light or thinly distributed.]

If the area was devoted to crops, pasture, or tree plantations before clearing, indicate which species and the time so used, if available.

Method of Clearing: Describe the sequence of operations for removing existing vegetation from the experiment site. Describe any improvements to site drainage.

Residue: Enter either I (incorporated), R (removed), or B (burned) as appropriate, and estimate percentage of area free of all residues [except ashes.]

Method of Soil Cultivation: Describe all cultivation done after clearing the site for the experiment up to the time of planting.

7.8 FORM H. Experiment Description

ADD

ID: **TH-01**

Experiment Name: **1987 Humid/Sub-humid Zone Network Trial**

Objective:

To evaluate the F/FRED Project's priority species under three management regimes in multi-location trials.

Experiment Design:

A randomized complete block design with four replications. The treatment design is a 3*2*3 complete factorial with factors of species, genotypes, and cutting management.

Plot Area (m^2): **98.0**

Weather Station ID: **PRA11**

Distance from Weather Station (m): **-9**

Enter information in the form above. Press <Ctrl-W> to save.

[Esc] = Exit

ID: Same as previous forms.

Experiment Name: The name applied to the same experiment throughout the network, if applicable. For individual experiments, use a short, descriptive title not to exceed 40 characters, including spaces.

Objective: A brief description of the objectives of the experiment named in the previous blank. The system completes the name, objective, experiment design, and plot area for experiments with a network ID.

Experiment Design: Describe basic design and number of replications.

Plot Area: [For individual experiments, enter to the whole square m; for example, enter both 98.2 and 98.7 sq m as 99 sq m; this is done so that multiplication of the number of plots times the area/plot will always include a sufficient amount (never less than necessary) of land for the experimental area. Plot area extends beyond the exterior lines of trees by a distance equal to half the distance to the adjacent tree in the opposite direction (see Figure 7.1)].

Weather Station ID: (See Form L-1.) Contains the first three letters of the daily weather station name plus a 2-digit station number assigned by the principal investigator. [Instruments should be isolated from interfering objects; as a minimum, no object should enter the space defined by a cone of 90 degrees centered above the instruments (Figure 7.2)]

Distance from Weather Station: Straight-line distance in m from the station to the nearest point of the experimental area. Note: The weather station is part of the experiment installation where daily weather recording is done; do not confuse it with the climate station.

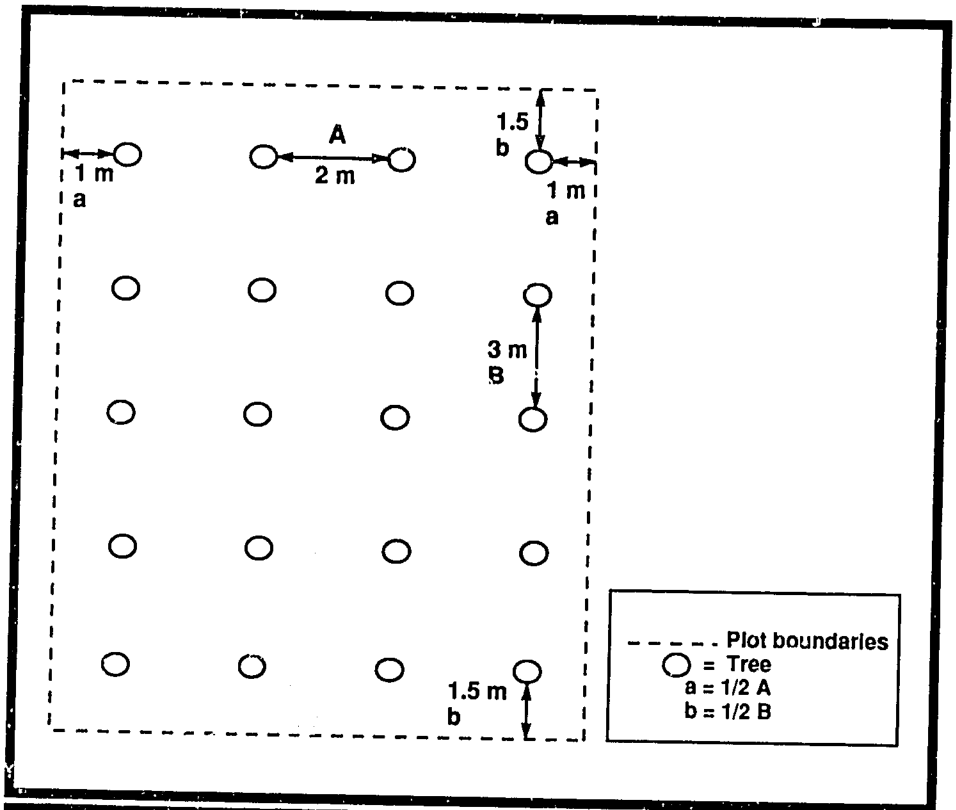

Figure 7.1. Plot layout.

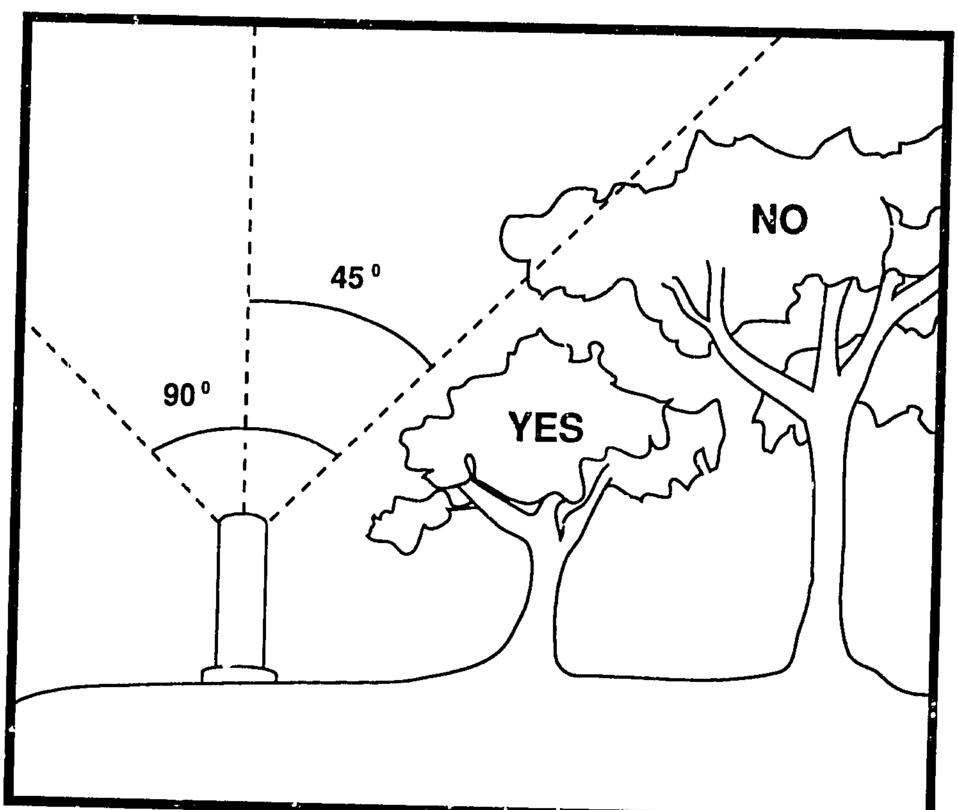

Figure 7.2. Space defined by placement of weather instrument, showing tree interference

7.9 FORM I-1. Treatment Factors and Levels

```
                                                                ID:   TH-01
Factor _A
              Name:       SPECIES
       Description:       MPTS species for humid environmental zone

     Level of Species          Description
     --------------------      ----------------------------------------
     ACACMA                    Acacia mangium
     ACACAU                    Acacia auriculiformis
     LEUCDI                    Leucaena diversifolia

[S]earch, [A]dd, [M]odify, [D]elete
[P]rev. record, [N]ext record, [PgUp]=Page Up, [PgDn]=Page Down
[E]sc = Exit, [F2] = Print
```

ID: Same as previous forms.

Factor: The system provides for up to 10 factors (lettered consecutively A through J). The various categories, as well as actual quantitative levels, are termed *levels* in this system; that is, species x, y, and z are levels, as are applications of 10, 30, and 40 g of chemical.

Name: The name of the treatment factor, such as species, provenance, or fertilization. Each factor has its own page of description (or screen when entering data into the software system). The name may not exceed eight characters and cannot contain a blank space; For example, Cutting Practice could be named CUT_PRAC, but never CUT PRAC.

Description: A brief description of the treatment factor named.

Level of Species and Description: Enter a code, **not to exceed eight characters**, for each level, followed by a clear description. For example, if Factor A is Species, levels and descriptions could be:

ACACAU	*Acacia auriculiformis*
ACACNI	*Acacia nilotica*
LEUCDI	*Leucaena diversifolia*

If Factor B is Cutting Practice, levels and descriptions could be:

CONTROL	No cutting at all
PNPH4	Prune 40% of total tree height
PNPH6	Prune 60% of total tree height

For network experiments, you only need to supply the factor. The system completes the remaining treatment and level information. At field locations, it is safer to enter all the appropriate information initially. Eight levels can be entered and shown on one page. Recommended six-character codes for species are listed in section 8.3.

7.10 FORM I-2. Treatment Combinations

ID: **TH-01**

Trt. No.	Factor_A	Factor_B	Factor_C	Factor_D	Factor_E
1	**ACACMA**	**MANG_QLD**	**CONTROL**		
2	**ACACMA**	**MANG_QLD**	**POLLARD**		
3	**ACACMA**	**MANG_QLD**	**PRUNING**		
4	**ACACMA**	**MANG_PNG**	**CONTROL**		
5	**ACACMA**	**MANG_PNG**	**POLLARD**		
6	**ACACMA**	**MANG_PNG**	**PRUNING**		
7	**ACACAU**	**AURI_QLD**	**CONTROL**		
8	**ACACAU**	**AURI_QLD**	**POLLARD**		
9	**ACACAU**	**AURI_QLD**	**PRUNING**		
10	**ACACAU**	**AURI_PNG**	**CONTROL**		
11	**ACACAU**	**AURI_PNG**	**POLLARD**		
12	**ACACAU**	**AURI_PNG**	**PRUNING**		

[S]earch, [A]dd, [M]odify, [D]elete
[PgUp]=Page Up, [PgDn]=Page Down
[Esc] = Exit, [F2] = Print

ID: Same as previous forms.

Treatment Number: A series of numbers assigned one to each treatment for all combinations of treatment factor and level. The numbers assigned must be consistent throughout records at each experiment location. Single-digit numbers are entered in the second, right-hand column of the two columns available.

Factors: These are usually entered in alphabetical order. You may enter levels in any desired order, but recording, analysis, and interpretation are facilitated if the order is logical.

In a factorial design, the total number of treatments is the product of the number of levels for Factor A times the number of levels for Factor B, etc.

7.11 FORM I-3. Experiment Layout

ID: **TH-01**

Plot No.	Trt. No.	Rep. No.	Plot No.	Trt. No.	Rep. No.	Plot No.	Trt. No.	Rep. No.
1	**17**	**1**	13	**10**	**1**	25	**2**	**2**
2	**3**	**1**	14	**1**	**1**	26	**12**	**2**
3	**9**	**1**	15	**18**	**1**	27	**10**	**2**
4	**7**	**1**	16	**5**	**1**	28	**4**	**2**
5	**12**	**1**	17	**11**	**1**	29	**14**	**2**
6	**16**	**1**	18	**2**	**1**	30	**1**	**2**
7	**4**	**1**	19	**15**	**2**	31	**5**	**2**
8	**15**	**1**	20	**17**	**2**	32	**18**	**2**
9	**8**	**1**	21	**7**	**2**	33	**6**	**2**
10	**13**	**1**	22	**8**	**2**	34	**11**	**2**
11	**6**	**1**	23	**13**	**2**	35	**9**	**2**
12	**14**	**1**	24	**16**	**2**	36	**3**	**2**

[S]earch, [A]dd, [M]odify, [D]elete
[PgUp] = Page Up, [PdDn] = Page Down
[Esc] = Exit

ID: Same as previous forms.

Plot, Treatment Numbers and Replication: Those you assign to the particular plot and replication are listed. The system does not provide listings for network experiments. Complete accuracy is **essential** to successful implementation of the experiment. Enter one-digit numbers in the right-hand column of the field.

7.12 FORM J. Experiment Planting

ADD

ID: TH-01

Planting Date (mm/dd/yy): _ / /

Tree Spacing (if constant for all plots)
Between Rows (m): -9.0 Within Row (m): -9.0

Control of competing vegetation at planting
(description and estimation of % control):

Preplant Amendments (fertilizer, herbicide or others):

Soil Moisture (1=dry, 2=damp, 3=moist, 4=wet, 5=very wet)
Condition At Planting: Condition After Planting:

Enter information in the form above. Press <Ctrl-W> to save.
[Esc] = Exit, [F1] = Help

ID: Same as previous forms.

Planting Date: [If more than one day is required], enter the month, day, and year when planting is completed. Enter 0 before single-digit values; for example, enter March as 03, not 3 (space) or (space) 3.

Tree Spacing: If the same nominal spacing is used for all plots, record distance between rows and between trees within rows in meters and tenths.

Control of Competing Vegetation: Describe methods of vegetation control used at the time of planting, including herbicides, tools, and estimated effectiveness.

Preplant Amendments: Describe as precisely as feasible any amendments to the soil at the time of planting, such as fertilizer, lime, organic matter, and irrigation water.

Soil Moisture: Evaluate the soil moisture at the time of planting and the general condition over the three months following planting.

1 = dry. [Soil frequently without available water in the rooting zone, causing some vegetation to stay wilted overnight. Continuous dry periods sometimes exceeding one week.]

2 = damp. [Water present in the rooting zone most of the time; wilting overnight rare; continuous dry periods probably less than one week.]

3 = moist. [Water in the rooting zone; no wilting overnight; no local spots of water logging.]

4 = wet. [Soil near field capacity most of the time; local spots flooded or saturated; runoff with each rain.]

5 = very wet. [Soil saturated or nearly so most of the time; waterlogged soil common; runoff or flooding with every rain; observable plant stress from oxygen or other deficiency related to excess water.]

7.13 FORM K. Tree Species

	ID: **TH-01**
Species ID: **1**	
Tree Species: Genus:	**Acacia**
Species:	**auriculiformis**
Sub-species:	
Seed Origin:	
Country:	**Australia**
State/Territory:	**Queensland**
Locality:	**Moorehead River**
Elevation (m):	**70**
Latitude (deg): **15** (min):	**20** Direction (N,S) : **S**
Longitude (deg): **143** (min):	**40** Direction (E,W):**E**
Seed Supplier: **CSIRO**	Lot Number: **15477**

[S]earch, [A]dd, [M]odify, [D]elete
[PgUp] = Page Up, [PgDn] = Page Down
[Esc] = Exit, [F2] = Print

ID: Same as previous forms.

Species ID: For network experiments, a number is provided for 24 species and 2 genera considered the most likely to be tested (see Table 7.1). For all other species, enter 0 and type in the species code (see section 8.3). The term *sub-species* is synonymous here with *variety*.

Table 7.1. Recommended network species and IADSS codes.

No.	Species	No.	Species
1	*Acacia auriculiformis*	14	*E. microtheca*
2	*A. mangium*	15	*Gliricidia sepium*
3	*A. senegal*	16	*Leucaena diversifolia*
4	*A. nilotica*	17	*L. leucocephala*
5	*Albizia falcataria (Paraserianthes falcataria)*	18	*Melia azedarach*
6	*A. lebbek*	19	*Morus alba*
7	*A. procera*	20	*Populus* spp.
8	*Alnus nepalensis*	21	*Prosopis cineraria*
9	*Artocarpus* spp.	22	*P. juliflora**
10	*Azadirachta indica*	23	*Robinia pseudoacacia*
11	*Calliandra calothyrsus*	24	*Sesbania bispinosa*
12	*Dalbergia sissoo*	25	*S. grandiflora*
13	*Eucalyptus camaldulensis*	26	*S. sesban*
		0	Other

* [includes the *P. juliflora/pallida* complex.]

7.14 FORM L-1. Weather Station Information

ADD

```
Weather Station ID:    PRA11                                        ID:  TH-01
     Weather Station Name:  Prachuap Khiri Khan
     Responsible Institution;
                    Name:  Thailand Institute of Scientific and
                           Technological Research (TISTR)
                 Address:  196 Phaholyothin Road
                           Bangkhen, Bangkok  10900
                           Thailand

Observation Time (hh):  9

Start Date of Collecting Data (mm/dd/yy):  / /

Elevation (m):  0
Latitude  (deg):  10  (min):  58      Direction (N,S) :  N
Longitude (deg):  99  (min):  29      Direction (E,W):   E
--------------------------------------------------------------------
Enter information in form above.  Press <Ctrl-W> to save.
[Esc] = Exit,  [F1] = Help
```

ID: Same as previous forms.

Weather Station ID: Five characters consisting of the first three letters of the commonly used name of the weather station and a two-digit designation [assigned by the principal investigator].

Weather Station Name: Commonly used name in full.

Responsible Institution: Complete name, followed by acronym in parenthesis, and address.

Observation Time: The hour of the day, using the 24-hour system, when weather observations are usually made; 09:00 is preferred because, at this time, the air temperature most closely approximates the mean of maximum and minimum. However, it is more important that observations are made at the same time every day than it is to observe the 09:00 or other particular time.

Start Date of Collecting Data: The month, day, and year when observations began at this station, preferably not later than the date of planting.

Elevation and position are recorded as for site (if at the site) or as for the climatological station (if that station also provides weather data).

7.15 FORM L-2. Daily Weather Measurements

ID: **TH-01**

Year: Month:

Day	MaxT (C)	MinT (C)	Precip (mm)	Humidity (%)	Day	MaxT (C)	MinT (C)	Precip (mm)	Humidity (%)
1					11				
2					12				
3					13				
4					14				
5					15				
6					16				
7					17				
8					18				
9					19				
10					20*				

[S]earch, [A]dd, [M]odify, [D]elete

[Esc] = Exit

*Page 2 provides space for recording observations through 31 days.

ID: Same as previous forms.

Enter maximum and minimum temperature, precipitation, and humidity for each day of each month, beginning by the time of planting. The system calculates total precipitation and temperature means at the end of the month. Be sure to control evaporation of rainwater before taking readings. The funnel-shaped entry common to most rain gauges is adequate for daily readings, but a thin film of kerosene (paraffin) may be needed if you cannot record rainfall daily.

7.16 FORM M-1. Preplant Soil Measurements

ADD

Date (mm/dd/yy): _ / /   ID: **TH-01**

Layer Upper	(cm) Lower	ph (H20)	ph (KCl)	N (%)	P (ppm)	K (ppm)	OM (%)
-9	**-9**	**-9.0**	**-9.0**	**-9.00**	**-9.00**	**-9.00**	**-9.00**
-9	**-9**	**-9.0**	**-9.0**	**-9.00**	**-9.00**	**-9.00**	**-9.00**
-9	**-9**	**-9.0**	**-9.0**	**-9.00**	**-9.00**	**-9.00**	**-9.00**
-9	**-9**	**-9.0**	**-9.0**	**-9.00**	**-9.00**	**-9.00**	**-9.00**
-9	**-9**	**-9.0**	**-9.0**	**-9.00**	**-9.00**	**-9.00**	**-9.00**
-9	**-9**	**-9.0**	**-9.0**	**-9.00**	**-9.00**	**-9.00**	**-9.00**
-9	**-9**	**-9.0**	**-9.0**	**-9.00**	**-9.00**	**-9.00**	**-9.00**

Enter information in the form above. Press <Ctrl-W> to save.
[Esc] = Exit

Layer: Depth from soil surface to upper and lower boundaries (in whole cm). Sample for each layer is a composite for all replications. For network experiments, observations are pH (H_2O-based), nitrogen (%), phosphorus (ppm), potassium (ppm), and organic matter (%) for each layer. (Analytical methods to be used will be distributed to cooperators.)

Bulk density, cation exchange capacity, and color (plus salinity where relevant) are other soil characteristics often considered as valuable predictors of site quality.

If economy is less critical, analysis of soils of each treatment (or even each plot) before planting increases the possibility of recognizing changes that result from the treatments applied.

7.17 FORM M-2. Soil Measurements

ADD

Date (mm/dd/yy): _ / /   Age (months):   ID: TH-01
Plot(s)   :

Plot	Date (mm/dd/yy)	Age (mo)	Layer (cm) Upper	Lower	--- pH --- (H20)	(KCl)	N (%)	P (ppm)	K (ppm)	OM (%)
			-9	-9	-9.0	-9.0	-9.00	-9.00	-9.00	-9.00
			-9	-9	-9.0	-9.0	-9.00	-9.00	-9.00	-9.00
			-9	-9	-9.0	-9.0	-9.00	-9.00	-9.00	-9.00
			-9	-9	-9.0	-9.0	-9.00	-9.00	-9.00	-9.00
			-9	-9	-9.0	-9.0	-9.00	-9.00	-9.00	-9.00
			-9	-9	-9.0	-9.0	-9.00	-9.00	-9.00	-9.00
			-9	-9	-9.0	-9.0	-9.00	-9.00	-9.00	-9.00

Enter information in the form above. Press <Ctrl-W> to save.
[Esc] = Exit

For the humid and subhumid network, soil in each plot of two of the replications are sampled annually, at 12, 24, and 36 months. Core samples are bulked by treatments. Two sets of samples are taken by soil layer: 1) 0-15 cm and 2) 15-30 cm. A complete experiment has 36 composite soil samples for analysis at each annual soil sampling; that is, a composite sample from an upper and a lower horizon from each of the 18 treatments.

Information is equivalent to Form M-1, with the addition of the age of the trees in months at the time measurements were made and the plots sampled.

7.18 FORM N. Tree Measurements (by tree)

ADD

ID: TH-01

Date (mm/dd/yy): 01/01/88 Age (months): 6 Plot: 12

Survival (live/total): 47/47 (95%) Trees measured: 9

Tree	Height (m)	Basal(10cm) ----Diameter (cm)----	DBH(1.3m)
	-9.0	-9.0	-9.0
	-9.0	-9.0	-9.0
	-9.0	-9.0	-9.0
	-9.0	-9.0	-9.0
	-9.0	-9.0	-9.0
	-9.0	-9.0	-9.0
	-9.0	-9.0	-9.0
	-9.0	-9.0	-9.0
	-9.0	-9.0	-9.0

Tree	Height (m)	Basal(10cm) ----Diameter (cm)----	DBH(1.3m)
Mean:	99.0	99.0	99.0

Enter information in the form above. Press <Ctrl-W> to save.

[Esc] = Exit

The essence of research is well-planned, careful, and accurate measurements (see section 6.0). You can discover accidental errors by comparing the previous and present measurements of a selected dimension of the same tree. Your original measurements should be taken and recorded carefully, of course, because there is no previous measurement to indicate an accidental error.

You should record second and later measurements on a printed copy of the previous measurements. Do this only after comparing the new and old measurements (see section 6.3).

Age: Age from the date of planting to the date of measurement (to the nearest month).

Plot: Each plot at an experimental location has a unique, identification number. Replications are identified on form I-3, but blocks are not identified as such nor is a plot number necessarily identified with a planting block.

Survival: For the humid and subhumid network, the number of live trees equals the number of trees now alive plus those cut alive for biomass determination. (Trees cut while alive for biomass determination are assumed to be live throughout the measurement period.)

The total number of trees equals the number of trees scheduled to be planted or the number actually planted, whichever is less. Replants for initial mortality are not included. For the humid and subhumid network, the total number of trees per plot is 49. The system calculates the survival percentage at the time of measurement.

Other researchers may prefer to use total number of trees planted on the plot. In such cases, total number of trees includes initial mortality. Survival percentage equals number of live trees at any time, divided by the total number of trees planted.

Trees Measured: Number of trees measured at this date used to calculate mean values. In the humid and subhumid network, the central nine trees (3 x 3) are measured at ages 6, 12, 18, and 24 months. In case of mortality among those trees, the nearest adjacent tree in the surrounding row is substituted through the 24-month measurement, thus maintaining nine measurements until age two years. Thereafter, mortality is not replaced.

Other researchers may prefer not to replace trees that die, particularly if they begin with larger plots. Measuring at least eight trees per plot until the end of your experiment is desirable.

Tree Number: Identification of each specific tree for which measurements or observations are recorded. This ID number must remain constant throughout the life of the plot; if a tree dies, retire the number and never apply it to another tree on that plot. The numbering system should be the same for all experiments in a network.

In the Asian MPTS networks, numbering begins in the northwest corner of the plot and proceeds eastward in the first row; the first tree in the second row is directly under the first tree of the first row. (This is sometimes called the typewriter system.) (See Figure 7.3.)

Other researchers, particularly those using large plots, may prefer to save on-plot travel time by beginning with the first tree in each row directly under the last tree in the preceding row (snake fashion). (See Figure 7.3.)

Height (h): Total tree height is the vertical distance from the ground line to the apical bud of the main stem; leaves and lateral branches are not considered. On appreciable slopes, measure from the ground line on the uphill side of the tree. Use a graduated pole to measure to the completed dm. If the tree exceeds the height for which a graduated pole can be used (about 8-12 m), replace it with a hypsometer and read to the completed meter.

In the humid and subhumid network, the total length of leaning or misshapen trees is substituted for total height (Figure 7.4).

Most researchers prefer the height as a standard. If total length is desired, it is recorded separately from vertical height.[17]

TYPEWRITER
Small Plots

1	2	3	4	5
6	7	8	9	10
11	12	13	14	15
16	17			

SNAKE
Large Plots

1	2	3	4	5	6	7	8	9
18	17	16	15	14	13	12	11	10
19	20	21	22	23	24	25	26	27
					31	30	29	28

Figure 7.3. Systems for numbering trees on a plot.

[17] In the *IADSS user's manual* (Version 1.1), recording **both** h and l requires using IADSS Form X.

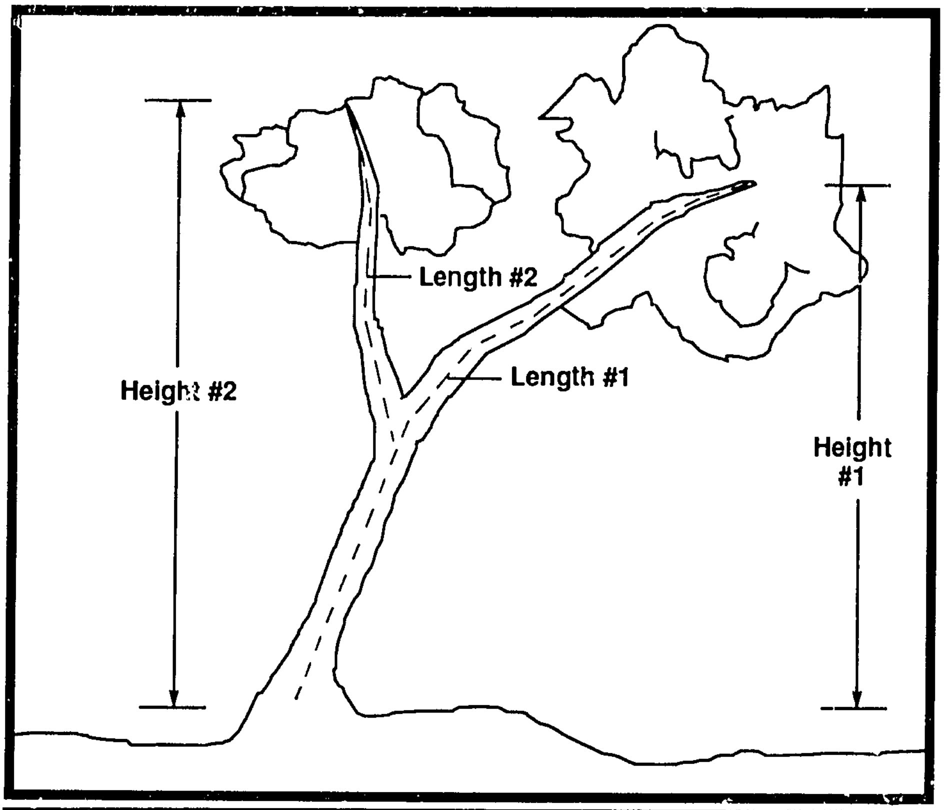

Figure 7.4. Height and length of misshapen tree

Diameter at the Base (db): You usually measure basal diameter at nominal stump height; thus, measure db at 30 cm above ground line to the completed mm, using a caliper if db is < 50 mm and a tape if > 50 mm.

In the humid and subhumid network, db is measured at 10 cm. Count as separate stems those that originate below 10 cm above the ground line and that have a dbh at least 70% the dbh of the main stem. Calculate the equivalent db of the tree by taking the square root of the sum of the db's squared of each stem.

Other researchers may prefer to treat each stem separately, recording both db and length from its connection with the main stem to the uppermost bud. Scientists do not yet agree as to whether lateral stems that are not measured should be removed.

Diameter at Breast High (dbh): Dbh is measured at 1.3 m above ground line. If there is a knot or other abnormality at that height, measure at a nearby point that most closely approximates what the correct measurement would have been (this is usually above 1.3 m). You usually measure breast height on each tree with a scaled stick; mark any other point used with paint or some other means of identification for future reference.

In the humid and subhumid network, multiple stems are counted as all stems that originate below 50 cm above ground and that have a dbh at least 70% that of the main stem. The equivalent dbh is the square root of the sum of the dbh's squared of all stems.

Most researchers prefer to classify separately all stems that originate below the point of measurement (in this case, 1.3 m), not only those that originate below 50 cm.

7.19 FORM N. Tree Measurements (by plot)

ADD

ID: TH-01

Plot	Date (mm/dd/yy)	Age (mo)	--Survival-- live/total(%)	Height (m)	Basal(10cm) ---Diameter	DBH(1.3m) (cm)---	Trees measured
_	01/01/88	12	/	-9.0	-9.0	-9.0	-9
	01/01/88	12	/	-9.0	-9.0	-9.0	-9

Enter information in form above. Press <Ctrl-W> to save.
[Esc] = Exit

ID: Same as previous forms.

Date: Same as previous forms.

You can fill in the plot forms directly without including tree measurement forms; however, if tree measurement forms are completed, the system always prepares the plot forms. Information is the same as for tree forms, except that mean values are used.

Plot mean diameter values for the humid and subhumid network are arithmetic means, which are the easiest to calculate and are what you actually see on the plot. Geometric means are more linearly related to tree volumes and weights, so are used when volume or weight is an essential part of tree/plot analysis.

7.20 FORM O. Foliage Biomass Measurements (by tree)

ADD

Date (mm/dd/yy): **01/01/88** Age (months): **6** ID: **TH-01** Plot: **24** Trees measured: **2**

	Foliage Weight			
Tree	TWW (g)	SWW (g)	SDW (g)	TDW (g)
-	-9	-9	-9	999
	-9	-9	-9	999
Mean:				99.9 (kg)

Enter information in form above. Press <Ctrl-W> to save and to generate TDW and mean values.

[Esc] = Exit

ID: Same as previous forms.

Date: Same as previous forms.

Age: Age is in months from planting to measurement.

Tree: Tree number is a permanent designation. In the humid/subhumid network, trees for destructive sampling are selected at random from the outside (buffer) row, but adjacent trees cannot be removed (Figure 7.5). That is, trees randomly selected must be all even-numbered or all odd-numbered. If two separated trees do not remain in the outside buffer row, tree(s) may be selected from the interior buffer row immediately surrounding the central nine measurement trees.

Trees Measured: For each tree harvested for biomass measurement, follow Form N (Tree) instructions for h, dbh, and db.

TWW: Total Wet Weight of foliage is foliage fresh weight. See Form P (Tree) for information on separating parts of the tree. In the humid and subhumid network, the leaves and petioles are separated from all twigs, branches, flowers, and fruit.

If one of your objectives is to determine fodder weight, include succulent bark and twigs (less than 2 cm diameter) and edible fruits and flowers as fodder by bulking with foliage. For greater detail, weigh the foliage and succulent branches separately and then combine them as a total weight for fodder.

Weigh separately all foliage, branches, and wood in that order (unless the tree is unmanageably large) immediately upon felling. Weigh all components of one tree before felling the next to avoid mixing samples inadvertently and to ensure freshness of materials.

SWW: Obtain Sample Wet Weight by taking a representative sample (if necessary) of each class of material, bulking by combining individual samples into a large composite sample, and mixing thoroughly and partitioning. Repeat until the desired quantity remains. This is often 500-1,000 g,

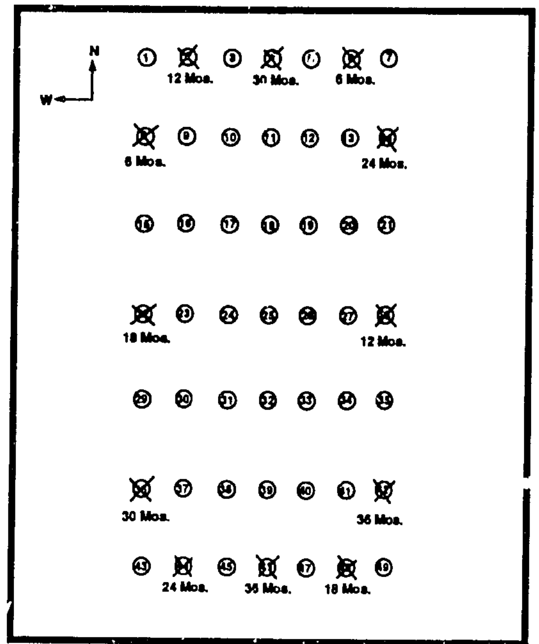

Figure 7.5: Example of Sampling for biomass trees

depending on total and individual leaf weight. Place in a labeled, sealed plastic bag, and send to a laboratory for weighing and analysis. At the lab, re-weigh the sample upon arrival.

For trees too large to handle all foliage conveniently, follow this procedure: Before removing any foliage, select a random sample of first-order branches (preferably 10-15 branches). Next, randomly select one sample second-order branch from each first order branch. Then, select one random branch from each lower order in turn until you reach a twig with green leaves (Figure 7.6). Bulk all green leaves of the final selections into a composite sample.

SDW: Obtain Sample Dry Weight by drying at 60-80 °C until weight is constant, and then re-weighing.

TDW: Total Dry Weight = TWW x SDW/SWW.

N, P, K: Determine the amount of nitrogen, phosphorous, and potassium in the laboratory from the bulked dry material from each desired category for consideration. Record the techniques used.

You may record additional types of measurements on IADSS Forms X-1 and X-2.

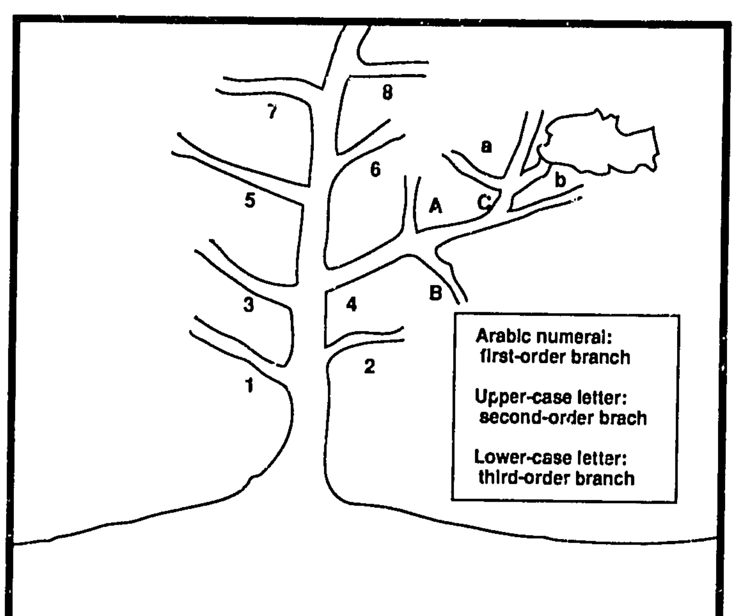

Figure 7.6. Sampling foliage

7.21 FORM O. Foliage Biomass Measurements (by plot)

ADD

ID: TH-01

Plot	Date (mm/dd/yy)	Age (mo)	Foliage Dry Wt and Nutrients: Dry Wt (kg/tree)	N (% of Dry Wt)	P (% of Dry Wt)	K (% of Dry Wt)	Trees Measured
-	**01/01/88**	**12**	**-9.0**	**-9.0**	**-9.0**	**-9.0**	**-9**
	01/01/88	**12**	**-9.0**	**-9.0**	**-9.0-**	**-9.0**	**-9**

Enter information in form above. Press <Ctrl-W> to save.
[Esc] = Exit

Information is the same as for Form O (by tree), except plot number is recorded instead of tree number, and plot mean values recorded instead of tree values. The system calculates plot values automatically if tree values are provided. Decisions on bulking sample materials will depend on treatments, facilities, and funds available.

The following information applies to the humid and subhumid network trials:

Foliage Nutrient Analysis: Foliar nutrient analysis will be done on samples from every biomass harvest. All samples will be bulked for a genotype, a total of six samples every six months.

Foliage Dry Weight: Foliage will be bulked from the two biomass trees per treatment. This will result in one sample from each plot, 72 samples from a complete experiment with four blocks. These samples will be labelled, weighed at harvest, and dried for sample dry weight.

Wood Sample Dry Weight: Four disks of approximately 10 cm length will be cut from each tree at the base of the stem, middle of the stem, top of the stem, and at the midpoint of a major branch. These will be bulked from the two biomass trees per treatment. This will result in one sample of eight disks from each plot, 72 samples from a complete experiment with four blocks. These samples will be labeled, weighed at harvest, and dried for sample dry weight.

7.22 FORM P. Wood Biomass Measurements (by tree)

ADD

Date (mm/dd/yy):	06/15/87			Age (months): 6		ID:	TH-01	
						Plot:	16	
						Trees measured:	2	
	Stems				Branches and Twigs			
Tree	TWW (kg)	SWW (g)	SDW (g)	TDW (kg)	TWW (g)	SWW (g)	SDW (g)	TDW (g)
–	-9.00	-9	-9	99.9	-9	-9	-9	9999
	-9.00	-9	-9	99.9	-9	-9	-9	9999
Mean:				99.9 (kg)				9.99 (kg)

re-[M]odify, any other key to continue

[Esc] = Exit

See comments for Form O (by tree).

Date: Refers to the date that trees are felled and fresh weight measurements of wood are taken.

Age: Age (to the nearest month) when fresh weight measurements of wood are taken, from time of planting.

Plot: Number of the specific plot being sampled.

Trees Measured: For the humid and subhumid network trials, two randomly selected trees (both even-numbered or odd-numbered) at each time of measurement. For the arid network trials, this means four randomly selected trees from each thinning.

Measurements are the same as for foliage biomass, but divided into wood from stems and wood from branches.

Trees will be cut at 10 cm above ground line, then partitioned into stems, branches, and foliage. Top of all stems is assumed where dob exceeds 2 cm. All other woody material is considered branches.

TWW: Total Wet (fresh) Weight. Determine with scale and record in kg and tenths (or up to three significant digits for small samples) as soon as convenient after felling. Because foliage and branches lose percentage of water faster, weigh foliage before branches and branches before stems. Do not sever individual branches from the tree until all foliage has been weighed; do not subdivide stems until all branches are weighed. All weighing, sampling, and bagging of one tree should be completed before you fell the next tree.

SWW: Sample Wet Weight. Determine from a representative sample of stem or branch wood. For branches, cut a disk from the mid-length point of one randomly selected branch. For stems, slice a disk at the base, tip, and midpoint from each stem up to five stems (Figure 7.7). If there are more than three stems per tree, sample only the three largest. Place samples (without bark) in a sealed and labeled plastic bag and send to laboratory.

SDW: Sample Dry Weight. Obtain by weighing the fresh sample upon arrival at the laboratory, drying the sample at 60-80 °C until weight is constant, and re-weighing.

TDW: Total Dry Weight = TWW x (SDW/SWW).

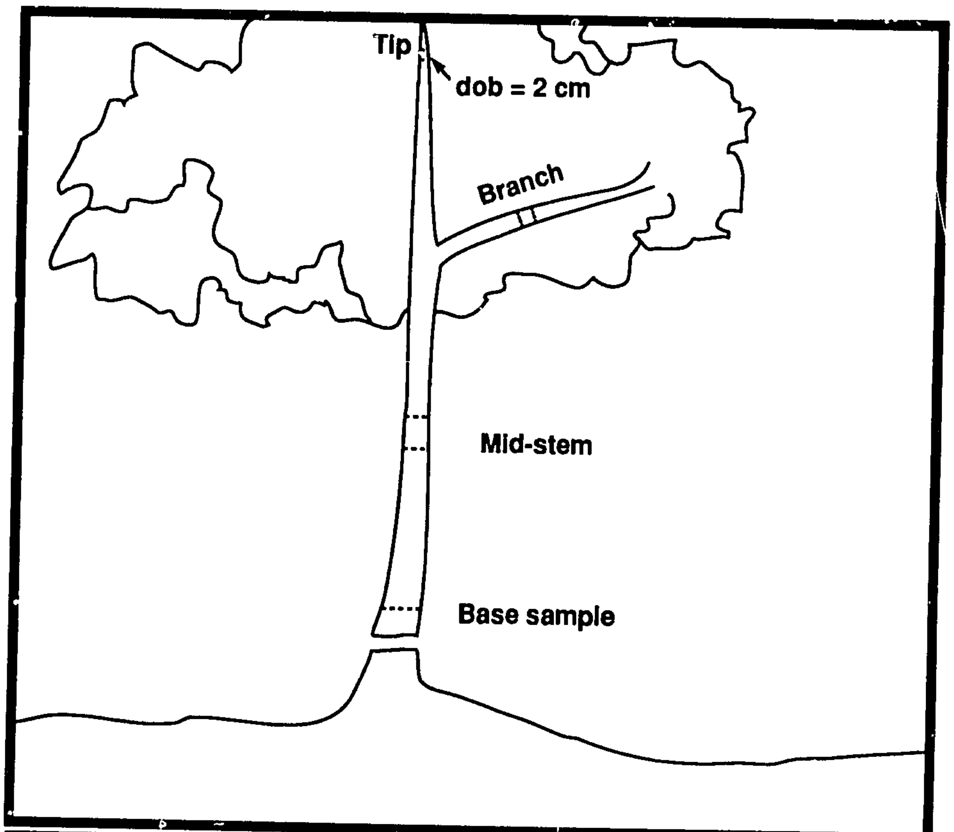

Figure 7.7. Sample disk locations to determine specific gravity.

7.23 FORM P. Wood Biomass Measurements (by plot)

ADD

ID: TH-01

Plot	Date (mm/dd/yy)	Age (mo)	------Wood Dry Wt (kg/tree)---- Stems	Branches/Twigs	Specific Gravity	Trees Measured
-	12/01/87	6	-9.0	-9.00	-9.00	-9
-	12/01/87	6	-9.0	-9.00	-9.00	-9

Enter information in form above. Press <Ctrl-W> to save.

[Esc] = Exit

Plot wood biomass is recorded similarly to tree wood biomass, except the order differs and only dry weight/plot is recorded. If you record tree data, the system calculates plot values, except for specific gravity.

Specific Gravity (sp gr): This equals oven-dry weight of the wood (without bark) divided by the wet displacement volume, expressed as a decimal. If the dry wood weighs 60 g and the wet volume is 100 cc, then sp gr = 60/100 = 0.60.

Although the humid and subhumid network procedure does not provide for measuring and recording the sp gr of each tree, such information can improve future tree research and biotechnological regeneration.

If the tree and samples are small enough, you can use the entire sample to determine sp gr (basic density). To do so, determine the wet volume by displacement before drying (Figure 7.8). Submerge the wood in a filled vessel, then measure the liquid that overflows. The wood must be completely immersed, but the plunger must not displace any water.

If samples are too large or if no suitable vessel is available to measure overflow, weight displacement is equally valid. Place a vessel containing sufficient water to cover the wood samples and with substantial freeboard on a scale and weigh. Place the wood sample in the water and, with a plunger, force all samples under water. While exerting sufficient force to hold the samples under, re-weigh (Figure 7.9). The weight of the vessel with water and submerged wood minus the weight of the vessel with water only (in g) equals the volume of wood (in cc). Calculation of sp gr is the same as above.

For representative weight of a tree, you must include samples of representative weight from each part of the tree. Sp gr at the base is usually heavier than from the midpoint, which is heavier than at the tip of the stem. All must be included in the same proportions as the wood represented. Thus, you must not discard or partition large samples unless all samples are partitioned in the same way.

A worthwhile subsidiary study would be to maintain separate records of sp gr by tree and by position in tree to analyze the variation with position, size, age, etc. This could help simplify future sampling without losing accuracy.

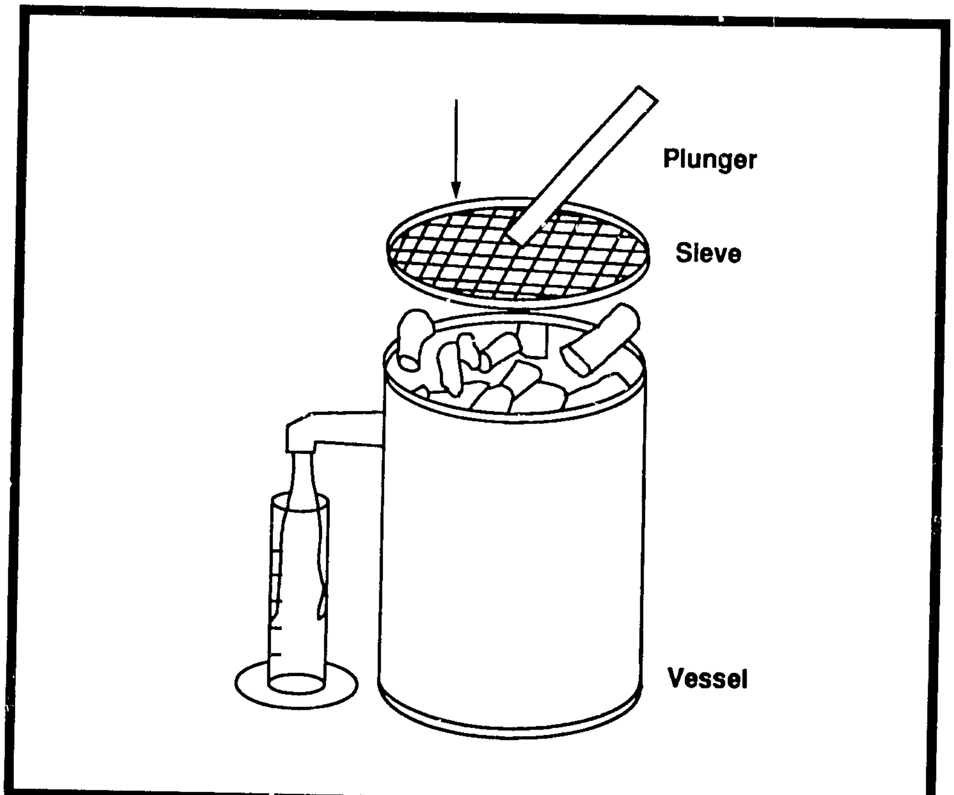

Figure 7.8. Measuring volume of small, fresh pieces.

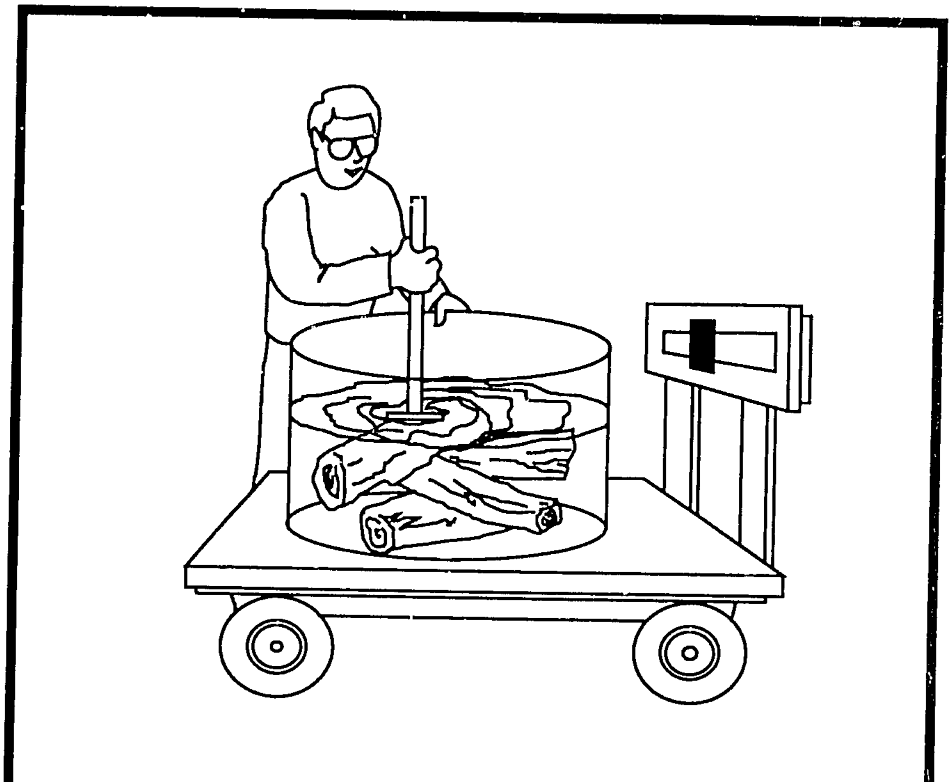

Figure 7.9. Displacement measurement of large, fresh pieces

7.24 FORM Q. Tree Litter Measurements

ADD

ID: TH-01

Date (mm/dd/yy): _ / /   Age (months):

Plot(s)   :

Plot	Date (mm/dd/yy)	Age (mo)	Layer Upper	(mm) Lower	Dry WT (kg/trees)	OM (%)	------Nutrients (%)------ N	P	K
			-9	-9	-9	-9	-9.00	-9.00	-9.00
			-9	-9	-9	-9	-9.00	-9.00	-9.00

Enter information in form above. Press <Ctrl-W> to save.

[Esc] = Exit

Litter measurements have been dropped from the 1987 humid and subhumid network trials. Use the present IADSS forms as follows:

Enter the plot, date, and age as for previous forms.

Layer: This refers to the organic material lying on top of the mineral soil. [Virtually all litter deposits include a layer (at least part of the year) in which the original material is practically unmodified and is recognizable as to origin. In some cases, a second layer (sometimes called fermented) is made up of partially modified materials, such as leaves, twigs, woody and animal matter, and is recognizable only as to general origin. A third, almost universal layer (at least part of the year) is amorphous and broken down to such an extent that the original form cannot be distinguished.]

Record the distance (in mm) from the litter/atmosphere boundary to the upper and the lower boundaries of each layer. This is measured along one or two sides of a 1 x 1 m square, located at random between the trees of the interior 3 x 3 rows. To measure, move adjacent litter.

Dry Weight: Remove each layer of litter from the square meter, dry by heating to 60-80 °C until weight is constant, and weigh (one sample square from each of two plots/treatment).

OM, N, P, K: Analyze each dry litter sample for organic matter, nitrogen, phosphorous, and potassium. Obtain the sample by bulk-mixing material from each treatment and then partitioning to reduce to desired sample size.

More commonly, litter fall is collected in sieve-bottomed square or round traps with material removed, weighed, and analyzed periodically.

Amorphous material is usually sampled separately with small samples collected periodically from randomly selected locations.

Litter degradation is usually measured by placing known quantities of fresh litter in open-mesh bags on the ground, then re-weighing periodically. None of the systems yield precisely the same results as undisturbed nature. But because their results are reproducible, treatments can be compared.

7.25 FORM R. Tree Phenology Observation

Genotype: **ACAC_PNG** ID: **TH-01**

Flowering

Date (mm/dd/yy) of flower bud appearance (50% of trees): **06/14/87**

Flower bud abundance (L=light, M=medium, H=heavy): **M**

Date (mm/dd/yy) of open flower appearance (50% of trees): **08/06/87**

Open flower abundance (L=light, M=medium, H=heavy): **L**

Fruiting

Date (mm/dd/yy) of fruit appearance

(50% of trees > 1 cm length of fruit): **11/01/87**

Date (mm/dd/yy) of mature fruit appearance (50% of trees): **01/13/88**

[S]earch, [A]dd, [M]odify, [D]elete
[PgUp]=Page Up, [PgDn] =Page Down
[Esc] = Exit, [F2] = Print

The humid and subhumid network trials are measured every six months. This form is designed to record briefly an annual summary of observations by genotype for the experiment as a whole, without considering treatment effects.

ID: Same as previous forms.

Genotype: Record the species, variety, and/or provenance.

Flowering: For control plots only, record date when 50% of the trees of the particular species at the particular site have flower buds and whether bud abundance is L = light (few locations that could have flower buds do), M = medium (many locations do have buds, but many more could), or H = heavy (buds are present at most of the locations that could have them).

For control plots only, record date when 50% of the trees have open blossoms. Terms *light*, *medium*, and *heavy* are defined as above.

Fruiting: For control plots only, record date when 50% of the trees have fruit > 1 cm long. No provision is made for fruits < 1 cm long. Also report when 50% of the trees have mature fruit.

For other studies in tree improvement or seed production, additional phenological observations are desirable. You should record them at least monthly, preferably weekly. These include tree diameter and height, leaf buds, leaf flushes, flower flushes, leaf fall, and fruit fall.

7.26 FORM S. Tree Damage Observations

ADD

ID: **TH-01**

Date (mm/dd/yy)	General Health (1=Good,2,3,4)	Comments (Include Plot No, Cause,...)	Damage (%)

This form is a log of dated summary evaluations with brief comments. Record date of observation as on previous forms. Code general health as follows: 1 = trees are growing well with no evidence of environmental limitations; 2 = leaves are discolored or shoot growth is limited, but overall health is good (describe the problem briefly); 3 = growth is limited, but there are some healthy leaves (indicate % of leaf or stem abnormality and cause of problem); and 4 = no growth or no healthy leaves (note cause and % damage).

You may use chemical spray to control insect damage up to 12 months after field planting. Treatment after 12 months is unlikely to be cost-effective in the long run.

7.27 FORM T. Irrigation

ADD

ID: **TH-01**

Date (mm/dd/yy)	Amount (mm)	Method
01/55/88	**200**	**Sprinkler system**

Enter information in form above. Press <Ctrl-W> to save.

[Esc] = Exit, [F1] = Help

This is a log of irrigation operations, with date of application, amount, and method. Uniform application is assumed.

If irrigation is a variable, you will need additional and more detailed information.

7.28 FORM U. Log of Experiment Operations

ADD

ID: TH-01

Date (mm/dd/yy)	Management Operation	Remark
01/01/87	**clearing**	**clearing of plots started today**

Enter information in form above. Press <Ctrl-W> to save.
[Esc] = Exit, [F1] = Help

This is a summary log of operations. Recorded are date, management operation, and remarks. Like phenology, damage, and irrigation, this information is not integrated into the analysis system at this time.

The system searches for specific dates or a range of dates, but does not search for a management operation or remark. You can do this only by scrolling through the records. Complete the form at every visit and after every silvicultural operation.

7.29 FORM X-1. General Measurements Definition

ADD

Date (mm/dd/yy): **05/06/88** ID: **TH-01**

	Measurements 1	2	3	4	5	6
NAME	**HT1**	**BASAL1**	**DBH1**	**SRV**		
UNIT	**(m)**	**(cm)**	**(cm)**	**(%)**		
PLOT VALUE	**AVERAGE**	**GEO.MEAN**	**GEO.MEAN**	**AVERAGE**	**AVERAGE**	**AVERAGE**

Enter information in form above. Press <Ctrl-W> to save.
[Esc] = Exit, [F1] = Help

This is the form available for describing, measuring, and analyzing measurements not provided for in the specific network experiments. You may enter up to six different measurements by name, unit, and plot value. The names **must not** be the same as those used on other form fields, which are listed below:

PSURVIV	WT	STEM
HT	N	BRANCH
BASAL	P	GRAVITY
DBH	K	

You are permitted eight characters, so you may slightly modify the same information. For example, you could designate DBH as DBH1, or any descriptive name of not more than eight characters.

Plot Value. This indicates how the individual measurements will be summarized for plot values: Average = arithmetic mean; Geo. Mean = geometric mean.

7.30 FORM X-2. General Measurements (by tree)

ADD

ID: **TH-01**

Date (mm/dd/yy): **01/01/88** Age (months): **12** Plot: **23**
No. of trees: **2**

Tree	HT1 (m)	BASAL1 (cm)	DBH1 (cm)	SRV (%)		
-	**-9**	**-9**	**-9**	**-9**	**-9.000**	**-9.000**
Mean	**9**	**9**	**9**	**9**	**9.000**	**9.000**

re-[M]odify, any other key to save.

[Esc] = Exit, [F1] = Help

Enter the ID, date, and age as for other forms.

Enter measurements for appropriate characteristics at the wish of the observer.

The system calculates means as specified in Form X-1 (arithmetic or geometric).

7.31 FORM X-2. General Measurements (by plot)

ADD

ID: **TH-01**

Date (mm/dd/yy): **6/18/88** Age (months): **18**

Plot Age	HT1 (m)	BASAL1 (cm)	DBH1 (cm)	SRV (%)		
_	**-9**	**-9**	**-9**	**-9**	**-9.000**	**-9.000**
	-9	**-9**	**-9**	**-9**	**-9.000**	**-9.000**

Enter information in form above. Press <Ctrl-W> to save.

[Esc] = Exit, [F1] = Help

The system provides plot summaries based on measurements as defined on Form X-1 and recorded on Form X-2 (by tree), or you can enter plot information manually without using Form X-2 (by tree).

Values listed are date, age in months since planting , plot, and arithmetic or geometric mean of the variables measured.

7.32 Research Summary Database

The use of the IADSS data management system assumes treatment results will be summarized in a form that can be readily communicated to other networks and used within their data management systems. Similarly, the treatment summaries from other networks should be usable in IADSS.

To obtain this mutually beneficial result, agreement by concerned networks will be required in selecting and formatting summary information. No general agreement has yet been reached.

A preliminary set of agreements has been prepared, based on current usage in the TREDAT (CSIRO), MIRA (CATIE), and IADSS (F/FRED) systems. Copies of the tentative baseline format will be sent to concerned personnel for consideration and modification. Anyone wishing to participate in the review and improvement may obtain a draft copy from:

K.G. MacDicken
F/FRED Coordinating Unit
c/o Kasetsart University
Faculty of Forestry
P.O. Box 1038
Bangkok 10903, Thailand

Foster B. Cady
F/FRED Global Research Unit
University of Hawaii
P.O. Box 186
Paia, Hawaii 96779
USA

C.B. Briscoe
F/FRED Management Office
Winrock International
1611 N. Kent St., Suite 600
Arlington, Virginia 22209
USA

8.0 IADSS Codes

Codes should be:

- o Brief -- to avoid incomplete forms
- o Descriptive -- to aid memory and reduce errors
- o Unique -- to distinguish clearly each code and its referent from all others

The codes found in this chapter are intended to comply with the above criteria. You may use alternate codes if they also comply with the basic criteria but not after the codes have been incorporated into network data. Please review the codes used in this manual and express your preferences by writing to the F/FRED Global Research Unit:

F/FRED Global Research Unit
University of Hawaii
P.O. Box 186
1010 Holomua Road
Paia, Hawaii 96779 USA

telephone (808) 579-8481
telex NifTAL 7430315 (ITT)
dialcom 41: tcn374

You may also write to the F/FRED Management Office:

F/FRED Management Office
Winrock International
1611 N. Kent St., Suite 600
Arlington, Virginia 22209 USA

telephone(703) 525-9430
telex 248589 WIDC
dialcom 41: tcn408

8.1. Country Codes

Codes are listed for countries expected to grow multipurpose trees under tropical or subtropical conditions.[18] While local spellings of country names would be desirable in some cases, they could prevent effective communication. Use the international codes from the above-referenced publication when you add any country now omitted. Country codes and country names are listed together in alphabetical order.

AF (Afghanistan)
Afghanistan (AF)
AG (Antigua)
Algeria (DZ)
American Samoa (AS)
Angola (AO)
Antigua (AG)
AO (Angola)
AR (Argentina)
Argentina (AR)
AS (American Samoa)
AU (Australia)
Australia (AU)

Bahrain (BH)
Bangladesh (BD)
Barbados (BB)
BB (Barbados)
BD (Bangladesh)
Belize (BZ)
Benin (BJ)
BH (Bahrain)
Bhutan (BT)
BI (Burundi)
BJ (Benin)
BN (Brunei)
BO (Bolivia)
Bolivia (BO)
Botswana (BW)
BR (Brazil)
Brazil (BR)
British Virgin Islands (VG)
Brunei (BN)
BT (Bhutan)
BU (Burma)
Burkina Faso (HV)
Burma (BU)
Burundi (BI)
BW (Botswana)
BZ (Belize)

CA (Canada)
Cameroon (CM)
Canada (CA)
Cape Verde (CV)
Cayman Islands (KY)
CC (Cocos)
Central African Republic (CF)
CF (Central African Republic)
CG (Congo)
Chad (TD)
Chile (CL)
China (CN)
Christmas Islands (CX)
CI (Ivory Coast)
CK (Cook Islands)
CL (Chile)
CM (Cameroon)
CN (China)
CO (Colombia)
Cocos (CC)
Colombia (CO)
Comoros (KM)
Congo (CG)
Cook Islands (CK)
Costa Rica (CR)
CR (Costa Rica)
CU (Cuba)
Cuba (CU)
CV (Cape Verde)
CX (Christmas Islands)

DE (Germany)
DJ (Djibouti)
Djibouti (DJ)
DM (Dominica)
DO (Dominican Republic)
Dominica (DM)
Dominican Republic (DO)
DZ (Algeria)

East Timor (TP)
EC (Ecuador)
Ecuador (EC)
EG (Egypt)
Egypt (EG)
El Salvador (SV)
Equatorial Guinea (GQ)
ES (Spain)
ET (Ethiopia)
Ethiopia (ET)

Faeroe Islands (FO)
Fiji (FJ)
FJ (Fiji)
FO (Faeroe Islands)
FR (France)
France (FR)
French Guiana (GF)
French Polynesia (PF)

GA (Gabon)
Gabon (GA)
Gambia (GM)
GD (Grenada)
Germany (DE)
GF (French Guiana)
GH (Ghana)
Ghana (GH)
GM (Gambia)
GN (Guinea)
GP (Guadeloupe)
GQ (Equatorial Guinea)
Grenada (GD)
GT (Guatemala)
GU (Guam)
Guadeloupe (GP)
Guam (GU)
Guatemala (GT)
Guinea (GN)
Guinea-Bissau (GW)
Guyana (GY)

---

[18] The codes and names are taken from the *ISO standards handbook no. 1*, 2nd ed., ISO 3166-1981 (E/F) (France: UNESCO, 1982).

GW (Guinea-Bissau)
GY (Guyana)

Haiti (HT)
HK (Hong Kong)
HN (Honduras)
Honduras (HN)
Hong Kong (HK)
HT (Haiti)
HV (Burkina Faso)

ID (Indonesia)
IL (Israel)
IN (India)
India (IN)
Indonesia (ID)
IQ (Iraq)
IR (Iran)
Iran (IR)
Iraq (IQ)
Israel (IL)
Ivory Coast (CI)

Jamaica (JM)
Japan (JP)
JM (Jamaica)
JO (Jordan)
Jordan (JO)
JP (Japan)

Kampuchea (KH)
KE (Kenya)
Kenya (KE)
KH (Kampuchea)
KI (Kiribati)
Kiribati (KI)
KM (Comoros)
KN (St. Christo./Nevis)
Korea (KR)
KR (Korea)
Kuwait (KW)
KW (Kuwait)
KY (Cayman Islands)

LA (Laos)
Laos (LA)
LB (Lebanon)
LC (St. Lucia)
Lebanon (LB)
Lesotho (LS)
Liberia (LR)
Libya (LY)
LK (Sri Lanka)
LR (Liberia)
LS (Lesotho)
LY (Libya)

MA (Morocco)
Macau (MO)
Madagascar (MG)
Malawi (MW)
Malaysia (MY)
Maldives (MV)
Mali (ML)
Martinique (MQ)
Mauritania (MR)
Mauritius (MU)
Mexico (MX)
MG (Madagascar)
MI (Midway)
Micron. Fed. State (MN)
Midway (MI)
ML (Mali)
MN (Micron. Fed. State)
MO (Macau)
Morocco (MA)
Mozambique (MZ)
MQ (Martinique)
MR (Mauritania)
MU (Mauritius)
MV (Maldives)
MW (Malawi)
MX (Mexico)
MY (Malaysia)
MZ (Mozambique)

Nauru (NR)
NC (New Caledonia)
NE (Niger)
Nepal (NP)
New Caledonia (NC)
New Zealand (NZ)
NG (Nigeria)
NI (Nicaragua)
Nicaragua (NI)
Niger (NE)
Nigeria (NG)
NP (Nepal)
NR (Nauru)
NZ (New Zealand)

PA (Panama)
Pacific Islands (PC)
Pakistan (PK)
Panama (PA)
Papua New Guinea (PG)
Paraguay (PY)
PC (Pacific Islands)
PE (Peru)
Peru (PE)
PF (French Polynesia)
PG (Papua New Guinea)
PH (Philippines)
Philippines (PH)
PK (Pakistan)
Portugal (PT)
PR (Puerto Rico)
PT (Portugal)
Puerto Rico (PR)
PY (Paraguay)

QA (Qatar)
Qatar (QA)

Reunion (RI)
RI (Reunion)
RW (Rwanda)
Rwanda (RW)

St. Christo./Nevis (KN)
St. Lucia (LC)
St. Martin (SM)
St. Vincent/Gren. (VC)
Samoa (WS)
SB (Solomon Islands)
SC (Seychelles)
SD (Sudan)
Senegal (SN)
Seychelles (SC)
SG (Singapore)
SL (Sierra Leone)
SM (St. Martin)
SN (Senegal)
SO (Somalia)
Solomon Islands (SB)
Somalia (SO)
South Africa (ZA)
Spain (ES)
SR (Suriname)
Sri Lanka (LK)
Sudan (SD)
Suriname (SR)
SV (El Salvador)
Swaziland (SZ)
SZ (Swaziland)

Taiwan (TW)
Tanzania (TZ)
TD (Chad)
TG (Togo)
TH (Thailand)
Thailand (TH)
TK (Tokelau)
TN (Tunisia)
TO (Tonga)
Togo (TG)
Tokelau (TK)
Tonga (TO)
TP (East Timor)
Trinidad/Tobago (TT)
TT (Trinidad/Tobago)
Tunisia (TN)
TV (Tuvalu)
Tuvalu (TV)
TW (Taiwan)
TZ (Tanzania)

Uganda (UG)
United States (US)
Uruguay (UY)
US (United States)
US Virgin Islands (VI)
UY (Uruguay)

Vanuatu/N. Hebr. (VU)
VC (St. Vincent/Gren.)
VE (Venezuela)
Venezuela (VE)
VG (British Virgin Islands)
VI (US Virgin Islands)
Vietnam (VN)
VN (Vietnam)
VU (Vanuatu/N. Hebr.)

Wake Island (WK)
Western Samoa (WS)
WK (Wake Island)
WS (Samoa)
WS (Western Samoa)

YE (Yemen)
Yemen (YE)

ZA (South Africa)
Zaire (ZR)
Zambia (ZM)
Zimbabwe (ZW)
ZM (Zambia)
ZR (Zaire)
ZW (Zimbabwe)

8.2 Network Trials Institution Codes

Humid and Subhumid Zones

Principal Investigator	Institution	Institution Code
Kamis Awang	Universiti Pertanian Malaysia (UPM) Serdang 43400, Selangor, Malaysia	MP
Suree Bhumibhamon	Kasetsart University Bangkok 10900, Thailand	TK
Boonchoob Boontawee	Royal Forest Department Bangkok 10900, Thailand	TS
Enrique Crizaldo	Ecosystems Research and Development Bureau (ERDB) Laguna 3720, Philippines	FF
Muhammad Hafeez	Punjab Forestry Research Institute P.O. Box 1513 Nishatabad, Faisalabad, Pakistan	PK
Ta-Wei Hu	Chinese Cultural University Hwa Kang, Yang Ming Shan Taipei, Taiwan (ROC)	CH
Mohd. Lokmal B. Hj. Ngah	Forest Research Institute Malaysia (FRIM) P.O. Box 201, Kepong 52109 Kuala Lumpur, Malaysia	MF
Fuh-Juinn Pan	Taiwan Forestry Research Institute (TFRI) Botanical Garden, 53 Nan-Hai Road Taipei, Taiwan (ROC)	CF
Siriphong Pattanavibul	Thailand Institute of Scientific and Technology Research (TISTR) 196 Phaholyothin Road Bangkok 10900, Thailand	TH
Romeo S. Raros	Visayas State College of Agriculture (ViSCA) Pasay City, Philippines	PV
K.M. Siddiqui/Shams-ur-Rehman	Pakistan Forest Institute Peshawar, NWFP, Pakistan	PF
Komar Soemarna	Forest Research and Development Center (FRDC) P.O. Box 66 Bogor, Indonesia	IF

Arid and Semiarid Zones

Principal Investigator	Institution	Institution Code
Rafiq Ahmed	University of Karachi Karachi 32, Pakistan	UK
Ghulam Akbar	Pakistan Agricultural Research Council (PARC) 20, G-5/1; P.O. Box 1031 Islamabad, Pakistan	PA
Raziuddin Ansari	Atomic Energy Agricultural Research Centre Tando Jam, Pakistan	AE
A.N. Chaturvedi	TATA Energy Research Institute 90, Jor Bagh New Delhi 110 003, India	TA
K.R. Dahal/F. Thapa	Institute of Agriculture and Animal Sciences Central Campus, Rampur, Chitwan, Nepal	NS
Muhammad Hafeez	Punjab Forestry Research Institute P.O. Box 1513 Nishatabad, Faisalabad, Pakistan	PK
N.G. Hegde	Bharatiya Agro-Industries Foundation (BAIF) Kamdhenu, Senapati Bapat Rd. Pune 411 016, India	BA
Noor Mohammad	National Agricultural Research Centre Islamabad, Pakistan	NA
Chin Ong	ICRISAT Patancheru P.O. Andhra Pradesh 502 324, India	IC
R.K. Rao	Indian Forest Service M.J. Road, Nampalli Hyderabad 500 001, India	IF
J.S. Rawat	Madurai Kamaraj University Madurai 625 021, Tamil Nadu, India	MK

Principal Investigator	Institution	Institution Code
J.N. Rayamajhi	Institute of Forestry Pokhara, Nepal	NI
Eka Raj Sharma	Forestry Department H.M. Government of Nepal Babar Mahal Kathmandu, Nepal	NF
K.M. Siddiqui/Shams-ur-Rehman	Pakistan Forest Institute Peshawar, NWFP, Pakistan	PF
N.D. Weerawardhana	Community Forestry Project Passara Rd. Badulla, Sri Lanka	SL

8.3 Species Codes

Species codes usually consist of the first four letters of the genus plus the first two letters of the species. For example, you would code *Pinus caribaea* as PINUs CAribaea or PINUCA. Varieties follow the species code, using the first two letters. For example, *Pinus caribaea* variety *hondurensis* would be coded PINUCAHO.

To maintain the uniqueness of codes, another letter may be substituted for the fourth, sixth, or eighth letter where necessary. Such codes are indicated by an asterisk (*). Keep the code and actual name in the same alphabetical order, if possible.

The species listed below are those commonly used or likely to be used in the near future. As you add other species, please advise the F/FRED Project.

Code	Genus	Species	Family
ABELES	*Abelmoschus*	*esculentus*	*Malvaceae*
ACACAL	*Acacia*	*albida* = FAIDAL	
ACACAE	*Acacia*	*aneura*	*Mimosaceae*
ACACAM	*Acacia*	*ampliceps*	*Mimosaceas*
ACACAN	*Acacia*	*angustissima*	*Mimosaceae*
ACACAR	*Acacia*	*arabica* = ACACNI	
ACACAS*	*Acacia*	*aulacocarpa*	*Mimosaceae*
ACACAU	*Acacia*	*auriculiformis*	*Mimosaceae*
ACACCE	*Acacia*	*centralis*	*Mimosaceae*
ACACCI	*Acacia*	*cincinnata*	*Mimosaceae*
ACACCO	*Acacia*	*confusa*	*Mimosaceae*
ACACCR	*Acacia*	*crassicarpa*	*Mimosaceae*
ACACCY	*Acacia*	*cyanophylla*	*Mimosaceae*
ACACDA*	*Acacia*	*dealbata*	*Mimosaceae*
ACACDD*	*Acacia*	*deanii*	*Mimosaceae*
ACACDE	*Acacia*	*decurrens*	*Mimosaceae*
ACACDI	*Acacia*	*dificilis*	*Mimosaceae*
ACACFE	*Acacia*	*ferruginea*	*Mimosaceae*
ACACFI	*Acacia*	*filicifolia*	*Mimosaceae*
ACACHO	*Acacia*	*holosericea*	*Mimosaceae*
ACACLC*	*Acacia*	*leptocarpa*	*Mimosaceae*
ACACLE	*Acacia*	*leucophloea*	*Mimosaceae*
ACACMA	*Acacia*	*mangium*	*Mimosaceae*
ACACME	*Acacia*	*mearnsii*	*Mimosaceae*
ACACMF*	*Acacia*	*melanophloia*	*Mimosaceae*
ACACML*	*Acacia*	*melanoxylon*	*Mimosaceae*
ACACMO	*Acacia*	*modesta*	*Mimosaceae*
ACACNI	*Acacia*	*nilotica*	*Mimosaceae*
ACACOR	*Acacia*	*oraria*	*Mimosaceae*
ACACPA	*Acacia*	*paramattensis*	*Mimosaceae*
ACACPE	*Acacia*	*pennatula*	*Mimosaceae*
ACACPL	*Acacia*	*planiformis*	*Mimosaceae*
ACACPN*	*Acacia*	*polybotrya*	*Mimosaceae*
ACACPO	*Acacia*	*polystachya*	*Mimosaceae*
ACACRO	*Acacia*	*rothii*	*Mimosaceae*
ACACSA	*Acacia*	*saligna*	*Mimosaceae*

Code	Genus	Species	Family
ACACSE	*Acacia*	*senegal*	*Mimosaceae*
ACACSL*	*Acacia*	*seyal*	*Mimosaceae*
ACACST	*Acacia*	*stenophylla*	*Mimosaceae*
ACACSZ*	*Acacia*	*sylvestris*	*Mimosaceae*
ACACTO	*Acacia*	*tortilis*	*Mimosaceae*
ACACTU	*Acacia*	*tumida*	*Mimosaceae*
ACACVC*	*Acacia*	*victoriae*	*Mimosaceae*
ACACVI	*Acacia*	*villosa*	*Mimosaceae*
ACROFR	*Acrocarpus*	*fraxinifolius*	*Caesalpiniace*
ADANDI	*Adansonia*	*digitata*	*Bombacaceae*
AGATDA	*Agathis*	*dammara*	*Araucariaceae*
AGAVSI	*Agave*	*sisal*	*Agavaceae*
AILAAL	*Ailanthus*	*altissima*	*Simaroubaceae*
AILAGL	*Ailanthus*	*glandulosa*	*Simaroubaceae*
ALBIAD	*Albizia*	*adinocephala*	*Mimosaceae*
ALBIAM	*Albizia*	*amara*	*Mimosaceae*
ALBIFA	*Albizia*	*falcataria* = PARAFA	
ALBIGU	*Albizia*	*guachapele*	*Mimosaceae*
ALBILE	*Albizia*	*lebbek*	*Mimosaceae*
ALBILO	*Albizia*	*longipedata*	*Mimosaceae*
ALBIPR	*Albizia*	*procera*	*Mimosaceae*
ALBILP*	*Albizia*	*lophantha*	*Mimosaceae*
ALBISA	*Albizia*	*saman*	*Mimosaceae*
ALLIAS	*Allium*	*ascalonicum*	*Amaryllidaceae*
ALLISA	*Allium*	*sativa*	*Amaryllidacea*
ALLODE	*Allocasuarina*	*decaisneana*	*Casuarinaceae*
ALOCSP	*Alocasia*	spp.	*Araceae*
ALNUAC	*Alnus*	*acuminata*	*Betulaceae*
ALNUGL	*Alnus*	*glutinosa*	*Betulaceae*
ALNUNE	*Alnus*	*nepalensis*	*Betulaceae*
ALTIEX	*Altingia*	*excelsa*	
AMARSP	*Amaranthus*	spp.	*Amaranthaceae*
AMOMCA	*Amomum*	*cardamomum*	*Zingiberaceae*
AMORFR	*Amorpha*	*fruticosa*	*Leguminosae*
ANACOC	*Anacardium*	*occidentale*	*Anacardiaceae*
ANANCO	*Ananas*	*comosus*	*Bromeliaceae*
ANNOMU	*Annona*	*muricata*	*Annonaceae*
ANNOSQ	*Annona*	*squamosa*	*Annonaceae*
ARACHY	*Arachis*	*hypogeae*	*Leguminosae*
ARTOAL	*Artocarpus*	*altilis*	*Moraceae*
ARTOHE	*Artocarpus*	*heterophyllus*	*Moraceae*
ARTOIN	*Artocarpus*	*integrifolia*	*Moraceae*
ASPAOF	*Asparagus*	*officinalis*	*Liliaceae*
AVERBI	*Averrhoa*	*biiimbi*	*Oxalidaceae*
AVERCA	*Averrhoa*	*carambola*	*Oxalidaceae*
AVICAL	*Avicennia*	*alba*	*Avicenniaceae*
AVICIN	*Avicennia*	*intermedia*	*Avicenniaceae*

Code	Genus	Species	Family
AVICMA	*Avicennia*	*marina*	*Avicenniaceae*
AVICOF	*Avicennia*	*officinalis*	*Avicenniaceae*
AZADIN	*Azadirachta*	*indica*	*Meliaceae*
BALAAE	*Balanites*	*aegyptica*	
BAMBAR	*Bambusa*	*arundinacea*	*Gramineae*
BARRAS	*Barringtonia*	*asiatica*	
BAUHVA	*Bauhinia*	*variegata*	*Leguminosae*
BIXAOR	*Bixa*	*orellana*	*Bixaceae*
BOMBQU	*Bombacopsis*	*quinatum*	*Bombacaceae*
BOMXCE*	*Bombax*	*ceiba*	*Bombacaceae*
BORAAE	*Borassus*	*aethiopium*	*Palmaceae*
BRACBR	*Brachiaria*	*brizantha*	*Poaceae*
BRACHU	*Brachiaria*	*humidicola*	*Poaceae*
BRASJU	*Brassica*	*juncea*	*Cruciferae*
BROUPA	*Broussonetia*	*papyrifera*	*Moraceae*
BUTEFR	*Butea*	*frondosa*	*Papilionaceae*
BUTEMO	*Butea*	*monosperma*	*Papilionaceae*
BUTYPA	*Butyrospermum*	*paradoxum*	
CAESBO	*Caesalpinia*	*bonducella*	*Caesalpiniaceae*
CAESER	*Caesalpinia*	*eriostachys*	*Caesalpiniaceae*
CAESSA	*Caesalpinia*	*sappan*	*Caesalpiniaceae*
CAESVE	*Caesalpinia*	*velutina*	*Caesalpiniaceae*
CAJACA	*Cajanus*	*cajan*	*Leguminosae*
CALLCA	*Calliandra*	*calothyrsus*	*Mimosaceae*
CALLHO	*Calliandra*	*houstoniana*	*Mimosaceae*
CALOPR	*Calotropis*	*procera*	*Asclepiadaceae*
CAMESI	*Camellia*	*sinensis*	*Theaceae*
CANAOD	*Cananga*	*odorata*	*Anonaceae*
CANLEN*	*Canavalia*	*ensiformis*	*Leguminosae*
CANMCO*	*Canarium*	*ccmune*	*Burseraceae*
CANNED*	*Canna*	*edulis*	*Cannaceae*
CAPPAP	*Capparis*	*aphylla*	*Capparidaceae*
CAPSAN	*Capsicum*	*anuum*	*Solanaceae*
CAPSFR	*Capsicum*	*frutescens*	*Solanaceae*
CARIPA	*Carica*	*papaya*	*Caricaceae*
CARSCA*	*Carissa*	*carandas*	*Apocynaceae*
CARSSP*	*Carissa*	*spinarum*	*Apocynaceae*
CASSFI	*Cassia*	*fistula*	*Caesalpiniaceae*
CASSGR	*Cassia*	*grandis*	*Caesalpiniaceae*
CASSSI	*Cassia*	*siamea*	*Caesalpiniaceae*
CASSSP	*Cassia*	*spectablis*	*Caesalpiniaceae*
CASUCU	*Casaurina*	*cunninghamiana*	*Casuarinaceae*
CASUDE	*Casuarina*	*decaisneana* = ALLODE	
CASUEQ	*Casuarina*	*equisetifolia*	*Casuarinaceae*
CASUGL	*Casuarina*	*glauca*	*Casuarinaceae*
CASUJU	*Casuarina*	*junghuniana*	*Casuarinaceae*
CATABI	*Catalpa*	*bignonioides*	*Bignoniaceae*

Code	Genus	Species	Family
CATALO	*Catalpa*	*longissima*	*Bignoniaceae*
CEDROD	*Cedrela*	*odorata*	*Meliaceae*
CEDRTO	*Cedrela*	*toona* = TOONCI	
CEIBPE	*Ceiba*	*pentandra*	*Bombacaceae*
CELTAU	*Celtis*	*australis*	*Ulmaceae*
CENTPU	*Centrosema*	*pubescens*	*Leguminosae*
CHAMPA	*Chamaecytisus*	*palmensis*	
CHAMPR	*Chamaecytisus*	*proliferus*	
CHLOGA	*Chloris*	*gayana*	
CHOEAX	*Choerospondias*	*axillaris*	*Anacardiaceae*
CHROOD	*Chromolaena*	*odorata*	
CHRYCA	*Chrysophyllum*	*cainito*	*Sapotaceae*
CICEAR	*Cicer*	*arientinum*	*Leguminosae*
CINNVE	*Cinnamomum*	*verum*	*Lauraceae*
CITRAU	*Citrus*	*aurantifolia*	*Rutaceae*
CITRRE	*Citrus*	*reticulata*	*Rutaceae*
CITRSI	*Citrus*	*sinensis*	*Rutaceae*
COCCUV	*Coccoloba*	*uvifera*	*Polygonaceae*
COCONU	*Cocos*	*nucifera*	*Palmaceae*
COFFAR	*Coffea*	*arabica*	*Rubiaceae*
COFFCA	*Coffea*	*canephora*	*Rubiaceae*
COFFRO	*Coffea*	*robusta*	*Rubiaceae*
COLOES	*Colocasia*	*esculenta*	*Araceae*
COLUAR	*Colubrina*	*arborescens*	*Rhamnaceae*
COLUFE	*Colubrina*	*ferruginosa*	*Rhamnaceae*
CONOLA	*Conocarpus*	*lancifolius*	*Combretaceae*
CORAED*	*Cordeauxia*	*edulis*	*Caesalpiniaceae*
CORDAL	*Cordia*	*alliodora*	*Boraginaceae*
CORDDE	*Cordia*	*dentata*	*Boraginaceae*
CORDSE	*Cordia*	*sebestena*	*Boraginaceae*
CRESAL	*Crescentia*	*alata*	*Bignoniaceae*
CROTSP	*Crotalaria*	spp.	*Leguminosae*
CUCUSA	*Cucumis*	*sativus*	*Cucurbitaceae*
CUPRLU	*Cupressus*	*lusitanica*	*Cupressaceae*
CYBIDO	*Cybistax*	*donnell*-smithii	*Bignoniaceae*
CYMBCI	*Cymbopogon*	*citratus*	*Gramineae*
CYMBFL	*Cymboponon*	*flexuosa*	*Gramineae*
CYMBNA	*Cymbopogon*	*nardus*	*Gramineae*
DACRED	*Dacryodes*	*edulis*	*Burseracea*
DALBLA	*Dalbergia*	*latifolia*	*Faboideaceae*
DALBME	*Dalbergia*	*melanoxylon*	*Faboideaceae*
DALBRE	*Dalbergia*	*retusa*	*Faboideaceae*
DALBSI	*Dalbergia*	*sissoo*	*Faboideaceae*
DENDHA	*Dendrocalamus*	*hamiltonii*	*Gramineae*
DENDLO	*Dendrocalamus*	*longispathis*	*Gramineae*
DENDST	*Dendrocalamus*	*strictus*	*Gramineae*
DERRIN	*Derris*	*indica*	
DESMTR	*Desmodium*	*triflorum*	*Leguminosae*

Code	Genus	Species	Family
DETAMI	Detarium	*microcarpum*	
DIOCSP*	*Dioscorea*	spp.	*Dioscoreaceae*
DIOSKA	*Diospyros*	*kaki*	*Ebenaceae*
DODOVI	*Dodonea*	*viscosa*	*Sapindaceae*
DURIZI	*Durio*	*zibethinus*	*Bombacaceae*
ELAEGU	*Elaeis*	*guineensis*	*Palmaceae*
ELEAAN	*Eleagnus*	*angustifolia*	*Eleagnaceae*
ERYTBE	*Erythrina*	*berteroana*	*Fabaceae*
ERYTFU	*Erythrina*	*fusca*	*Fabaceae*
ERYTIN	*Erythrina*	*indica*	*Fabaceae*
ERYTOR	*Erythrina*	*orientalis*	*Fabaceae*
ERYTPO	*Erythrina*	*poeppigiana*	*Fabaceae*
EUCAAL	*Eucalyptus*	*alba*	*Myrtaceae*
EUCAAS	*Eucalyptus*	*astringens*	*Myrtaceae*
EUCACA	*Eucalyptus*	*camaldulensis*	*Myrtaceae*
EUCACI	*Eucalyptus*	*citriodora*	*Myrtaceae*
EUCACL	*Eucalyptus*	*cladocalyx*	*Myrtaceae*
EUCACO*	*Eucalyptus*	*cloeziana*	*Myrtaceae*
EUCACR	*Eucalyptus*	*crebra*	*Myrtaceae*
EUCADE	*Eucalyptus*	*deglupta*	*Myrtaceae*
EUCADU	*Eucalyptus*	*dunii*	*Myrtaceae*
EUCAGL	*Eucalyptus*	*globulus*	*Myrtaceae*
EUCAGR	*Eucalyptus*	*grandis*	*Myrtaceae*
EUCAHO	*Eucalyptus*	*houseana*	*Myrtaceae*
EUCAKI	*Eucalyptus*	*kirtoniana*	*Myrtaceae*
EUCAMA	*Eucalyptus*	*maculata*	*Myrtaceae*
EUCAMI	*Eucalyptus*	*microtheca*	*Myrtaceae*
EUCAMO	*Eucalyptus*	*moluccana*	*Myrtaceae*
EUCAPA	*Eucalyptus*	*paniculata*	*Myrtaceae*
EUCAPB*	*Eucalyptus*	*papuana*	*Myrtaceae*
EUCAPE	*Eucalyptus*	*pellita*	*Myrtaceae*
EUCAPI	*Eucalyptus*	*pilularis*	*Myrtaceae*
EUCAPO	*Eucalyptus*	*populnea*	*Myrtaceae*
EUCARE	*Eucalyptus*	*resinifera*	*Myrtaceae*
EUCARO	*Eucalyptus*	*robusta*	*Myrtaceae*
EUCASA	*Eucalyptus*	*saligna*	*Myrtaceae*
EUCASM*	*Eucalyptus*	*salmonophloia*	*Myrtaceae*
EUCAST	*Eucalyptus*	*staigerana*	*Myrtaceae*
EUCATE	*Eucalyptus*	*tereticornis*	*Myrtaceae*
EUCATO	*Eucalyptus*	*torelliana*	*Myrtaceae*
EUCAUR	*Eucalyptus*	*urophylla*	*Myrtaceae*
EUGEAR	*Eugenia*	*aromatica* = SYZYAR	
EUGEJA	*Eugenia*	*jambos* = SYZYJA	
EUGEUN	*Eugenia*	*uniflora* = SYZYUN	
EUPHLO	*Euphoria*	*longana*	*Sapindaceae*
FAIDAL	*Faidherbia*	*albida*	*Mimosaceae*
FICUBE	*Ficus*	*bengalensis*	*Moraceae*

Code	Genus	Species	Family
FICUCA	*Ficus*	*carica*	*Moraceae*
FLEMCO	*Flemingia*	*congesta*	*Leguminosae*
FLEMMA	*Flemingia*	*macrophylla*	*Leguminosae*
FRAGVE	*Fragaria*	*vesca*	*Rosaceae*
GARCMA	*Garcinia*	*mangostana*	*Guttiferae*
GENIAM	*Genipa*	*americana*	*Rubiaceae*
GLIRSE	*Gliricidia*	*sepium*	*Mimosaceae*
GMELAR	*Gmelina*	*arborea*	*Verbenaceae*
GNETGN	*Gnetum*	*gnemon*	*Gnetaceae*
GREVRO	*Grevillea*	*robusta*	*Proteaceae*
GREWOP	*Grewia*	*optiva*	*Tiliaceae*
GUAZUL	*Guazuma*	*ulmifolia*	*Sterculiaceae*
GUILGA	*Guilielma*	*gasipaes*	*Palmaceae*
HARDBI	*Hardwickia*	*binata*	*Caesalpiniaceae*
HEVEBR	*Hevea*	*brasiliensis*	*Euphorbiaceae*
INGADU	*Inga*	*dulce*	*Leguminosae*
INGAED	*Inga*	*edulis*	*Leguminosae*
INGAPA	*Inga*	*paterna*	*Leguminosae*
INGASP	*Inga*	*spectabils*	*Leguminosae*
INGAVE	*Inga*	*vera*	*Leguminosae*
IPOMBA	*Ipomea*	*batatus*	*Convolvulac*
JATRSP	*Jatropha*	spp.	*Euphorbiacea*
JUGLSP	*Juglans*	spp.	*Juglandaceae*
KHAYSE	*Khaya*	*senegalensis*	*Meliaceae*
LACTSA	*Lactuca*	*sativa*	*Compositae*
LAGESP	*Lagerstroemia*	*speciosa*	*Lythraceae*
LANNSP	*Lannea*	spp.	*Anacardiaceae*
LEUCCO	*Leucaena*	*collinsii*	*Mimosaceae*
LEUCCU	*Leucaena*	*cunninghamia*	*Mimosaceae*
LEUCDI	*Leucaena*	*diversifolia*	*Mimosaceae*
LEUCES	*Leucaena*	*esculenta*	*Mimosaceae*
LEUCLA	*Leucaena*	*lanceolata*	*Mimosaceae*
LEUCLE	*Leucaena*	*leucocephala*	*Mimosaceae*
LEUCMA	*Leucaena*	*macrophylla*	*Mimosaceae*
LEUCPA	*Leucaena*	*pallida*	*Mimosaceae*
LEUCPU	*Leucaena*	*pulverulenta*	*Mimosaceae*
LEUCSA	*Leucaena*	*salvadorensis*	*Mimosaceae*
LEUCSH	*Leucaena*	*shannoni*	*Mimosaceae*
LITCCH	*Litchi*	*chinensis*	*Sapindaceae*
LYCOES	*Lycopersicon*	*esculentum*	*Solanaceae*
LYSIBA	*Lysiloma*	*bahamensis*	*Leguminosae*
MACATE	*Macadamia*	*ternifolia*	*Proteaceae*
MANGIN	*Mangifera*	*indica*	*Anacardiaceae*
MANIDU	*Manihot*	*dulcis*	*Euphorbiaceae*
MELALE	*Melaleuca*	*leucadendra*	*Myrtaceae*

Code	Genus	Species	Family
MELAQU	*Melaleuca*	*quinquefolia*	*Myrtaceae*
MELIAZ	*Melia*	*azedarach*	*Meliaceae*
MESUFE	*Mesua*	*ferrea*	
MIMOSC	*Mimosa*	*scabrella*	*Mimosaceae*
MORIOL	*Moringa*	*oleifera*	*Moringaceae*
MORUAL	*Morus*	*alba*	*Moraceae*
MUSAPA	*Musa*	*paradisiaca*	*Musaceae*
MUSASA	*Musa*	*sapientum*	*Musaceae*
NEPHLA	*Nephelium*	*lappaceum*	*Sapindaceae*
NEPHMU	*Nephelium*	*mutabile*	*Sapindaceae*
OLEAFE	*Olea*	*ferruginea*	*Oleaceae*
ORYZSA	*Oryza*	*sativa*	*Graminae*
OUGEDA	*Ougeineia*	*dalbergioides*	*Papilionaceae*
PANDGR	*Pandanus*	*graminifolius*	*Pandanaceae*
PANDTE	*Pandanus*	*tectorius*	*Pandnaceae*
PANIMA	*Panicum*	*maximum*	*Poaceae*
PARAFA	*Paraserianthes*	*falcataria*	*Mimosaceae*
PARALO	*Paraserianthes*	*lophantha*	*Mimosaceae*
PARKBI	*Parkia*	*biglobosa*	*Caesalpiniaceae*
PARKCL	*Parkia*	*clappertonlana*	*Caesalpiniaceae*
PARKJA	*Parkia*	*javanica*	*Caesalpiniaceae*
PARKSP	*Parkia*	*speciosa*	*Caesalpiniaceae*
PARTAR	*Parthenium*	*argentatum*	*Compositae*
PASPDI	*Paspalum*	*dilatatum*	*Poaceae*
PASSED	*Passiflora*	*edulis*	*Passiflorac*
PASSQU	*Passiflora*	*quadrangularis*	*Passiflorac*
PAULTO	*Paulownia*	*tomentosa*	*Scrophulariaceae*
PENNCL	*Pennisetum*	*clandestinum*	*Poaceae*
PENNPU	*Pennisetum*	*purpureum*	*Graminae*
PENTMA	*Pentaclethra*	*macrophylla*	*Mimosaceae*
PERSAM	*Persea*	*americana*	*Lauraceae*
PHASVU	*Phaseolus*	*vulgaris*	*Leguminosae*
PHOEDA	*Phoenix*	*dactylifera*	*Palmaceae*
PINUCA	*Pinus*	*caribaea*	*Pinaceae*
PINUCAHO	*Pinus*	*caribaea v hondurensis*	*Pinaceae*
PINUIN	*Pinus*	*insularis*	*Pinaceae*
PINUKE	*Pinus*	*kesiya*	*Pinaceae*
PINUME	*Pinus*	*merkusii*	*Pinaceae*
PINUOO	*Pinus*	*oocarpa*	*Pinaceae*
PINUTE	*Pinus*	*tecunumanii*	*Pinaceae*
PITHDU	*Pithecellobium*	*dulce*	*Mimosaceae*
PITHSA	*Pithecellobium*	*saman* = ALBISA	
PLATOC	*Platanus*	*occidentalis*	*Platanaceae*
PLATOR	*Platanus*	*orientalis*	*Platanaceae*
PLAYPI	*Platymiscium*	*pinnatum*	*Leguminosae*
POLYPE	*Polyalthia*	*pendula*	*Annonaceae*
PONGPI	*Pongamia*	*pinnata*	*Papilionaceae*
POPUEP*	*Populus*	*euphratica*	*Salicaceae*

Code	Genus	Species	Family
POPUEU	*Populus*	*euramericana*	*Salicaceae*
PROSAF	*Prosopis*	*africana*	*Mimosaceae*
PROSAL	*Prosopis*	*alba*	*Mimosaceae*
PROSCI	*Prosopis*	*cineraria*	*Mimosaceae*
PROSJU	*Prosopis*	*juliflora*	*Mimosaceae*
PROSPA	*Prosopis*	*pallida*	*Mimosaceae*
PROSTA	*Prosopis*	*tamarugo*	*Mimosaceae*
PSIDGU	*Psidium*	*guajava*	*Myrtaceae*
PTERJA	*Pterospermum*	*javanicum*	*Sterculiaceae*
PUERJA	*Pueraria*	*javanica*	*Leguminosae*
PUNIGR	*Punica*	*granatum*	*Punicaceae*
PUTRRO	*Putranjiva*	*roxburghii*	*Euphorbiaceae*
QUERLE	*Quercus*	*leucotrichophora*	*Fabaceae*
RHIZAP	*Rhizophora*	*apiculata*	*Rhizophoraceae*
RHIZMA	*Rhizophora*	*mangle*	*Rhizophoraceae*
RHIZMU	*Rhizophora*	*mucronata*	*Rhizophoraceae*
RHIZST	*Rhizophora*	*stylosa*	*Rhizophoraceae*
ROBIPS	*Robinia*	*pseudoacacia*	*Mimosaceae*
SALMMA	*Salmalia*	*malabarica*	*Bombacaceae*
SALVOL	*Salvadora*	*oleoides*	*Salvadoraceae*
SALVPE	*Salvadora*	*persica*	*Salvadoraceae*
SAMASA	*Samanea*	*saman* = ALBISA	
SANDIN	*Sandoricum*	*indicum*	*Meliaceae*
SCHIWA	*Schima*	*wallichii*	
SESAIN	*Sesamum*	*Indicum*	*Pedaliaceae*
SESBAE	*Sesbania*	*aegypticum*	*Fabaceae*
SESBAR	*Sesbania*	*arboreum*	*Fabaceae*
SESBBI	*Sesbania*	*bispinosa*	*Fabaceae*
SESBGR	*Sesbania*	*grandiflora*	*Fabaceae*
SESBSE	*Sesbania*	*sesban*	*Fabaceae*
SETAAN	*Setaria*	*ancep*	*Poaceae*
SHORSP	*Shorea*	spp.	*Dipterocarpac*
SOLAME	*Solanum*	*melongena*	*Solanaceae*
SOLATO	*Solanum*	*topiro*	*Solanaceae*
SOLATU	*Solanum*	*tuberosum*	*Solanaceaeum*
SORGVU	*Sorghum*	*vulgare*	*Graminae*
SPONCY	*Spondias*	*cytherea*	*Anacardiaceae*
SPONDU	*Spondias*	*dulcis*	*Anacardiaceae*
SPONMO	*Spondias*	*mombin*	*Anacardiaceae*
STERAP	*Sterculia*	*apetala*	*Sterculiaceae*
STYLHA	*Stylosanthes*	*hamata*	*Leguminosae*
STYLGU	*Stylosanthes*	*guienensis*	*Leguminosae*
SWIEMC*	*Swietenia*	*macrophylla*	*Meliaceae*
SWIEMH*	*Swietenia*	*mahogani*	*Meliaceae*
SYNCGL	*Syncarpia*	*glomulifera*	
SYZYAR	*Syzygium*	*aromaticum*	*Myrtaceae*
SYZYCU	*Syzygium*	*cuminil*	*Myrtaceae*
SYZYJU	*Syzygium*	*jambos*	*Myrtaceae*

Code	Genus	Species	Family
SYZYUN	*Syzygium*	*uniflora*	*Myrtaceae*
SYZYMA	*Syzyglum*	*malaccense*	*Myrtaceae*
TABERO	*Tabebuia*	*rosea*	*Bignoniaceae*
TAMAIN	*Tamarindus*	*indica*	*Caesalpinlac*
TAMXAP*	*Tamarix*	*aphylla*	*Tamaricaceae*
TECTGR	*Tectona*	*grandis*	*Verbenaceae*
TEPHVO	*Tephrosla*	*vogelli*	*Papilionaceae*
TERMAR	*Terminalia*	*arjuna*	*Combretaceae*
TERMCA	*Terminalia*	*catappa*	*Combretaceae*
THEOCA	*Theobroma*	*cacao*	*Sterculiaceae*
TOONCI	*Toona*	*ciliata*	*Meliaceae*
TRIFAL	*Trifolium*	*alexandrianum*	*Leguminosae*
TRISCO	*Tristanla*	*conferta*	*Myrtaceae*
TRITSA	*Triticum*	*saivum*	*Graminae*
VANIFR	*Vanilla*	*fragrans*	*Orchidaceae*
VETIZI	*Vetiveria*	*zizanioides*	*Graminae*
VIGNUN	*Vigna*	*unguiculata*	*Leguminosae*
VITIVI	*Vitis*	*vinifera*	*Vitaceae*
VOANSU	*Voandzeia*	*subterranea*	*Papilionaceae*
VOCHHO	*Vochysia*	*hondurensis*	*Vochysiaceae*
WRIGTI	*Wrightia*	*tinctoria*	*Apocynaceae*
XANTSA	*Xanthosoma*	*sagittifolium*	*Araceae*
XANTVI	*Xanthosoma*	*violacea*	*Araceae*
ZALAED	*Zalacca*	*edulis*	
ZEAMAY*	*Zea*	*mays*	*Graminae*
ZINGOF	*Zingiber*	*officinale*	*Zingiberaceae*
ZIZYMA	*Zizyphus*	*mauritiana*	*Rhamnaceae*

8.4 Standard Symbols

Reminders:

- o Use the International System of Weights and Measures adopted in France in 1960.[19]
- o Use only metric units.
- o Use lower-case characters for names of units, with the exception of "Celsius."
- o Use lower-case characters in metric prefixes, with the exception of "M" (million).
- o Use lower-case letters for direct measurements; for example, v = volume of one tree.
- o Use upper-case letters to indicate totals per unit area; for example, V = volume/ha.
- o Use the same symbols for both singular and plural forms of terms; for example, 1 mm and 21 mm.
- o Do not follow the symbol with a period, except at the end of a sentence.
- o Separate the number and symbol with a space; for example, 21 cm, not 21cm.
- o Leave a blank space, not a period or comma, to separate three-digit groupings in large numbers; for example, 1 000 000, not 1,000,000 or 1.000.000.
- o If you use any special mensurational symbols, advise all cooperators and networks.[20]

bh breast height. In the metric system, which is preferred, breast height is 1.30 m above the ground line. Specify any other value used; for example, bh = 1.37 m (4.5 ft).

c circumference or girth.

cai current (for most recent year) annual increment.

d diameter. Diameters of trees or parts of standing trees usually include bark. Diameters of logs from felled trees usually do not include bark.

dab diameter above buttresses (non-standard term).

db diameter at the base (non-standard term).

dbh diameter at breast height.

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19 Interamerican Institute for Cooperation in Agriculture, "Reglas principales para la consignacion de unidades," *Desarrollo rural de las Americas* 13:3 (1981) pp. 182-89.

20 Mensural symbols are generally based on the 1956 IUFRO recommendations. See J. Van Soest et al., *La normalizacion de los simbolos en dasometria* (Rome: FAO, 1969).

dbhib diameter at breast height inside bark.

dbhob diameter at breast height outside bark.

dbn diameter at the bottleneck, above butt-swell (non-standard term).

dib diameter inside bark.

dk diameter of the tree crown.

dob diameter outside bark.

drc diameter at root collar.

e spacing. This is usually given in meters or decimeters; for example, e = 1 x 2 m, or 10 x 20 dm. Within-row spacing is usually given first, followed by spacing between rows.

f form factor. This usually indicates the relationship of the volume of the main stem to the volume of a cylinder with a diameter equal to the diameter at breast height and height equal to a stated portion of tree height, expressed as a decimal portion or percentage.

For example, if the diameter at breast height = 1 meter and stem height = 30 meters, then an equivalent cylinder has a volume of 0.5 squared times pi times 30 = 23.56 cubic meters. If tree volume = 20 cubic meters, then f = 20 divided by 23.56 = 0.85. For clarity, state the specific derivation of f.

g cross-sectional area of the tree stem(s) at breast height or 1.3 m.

G the sum of all the g's per hectare, unless another unit of area is specified.

h total tree height, unless otherwise specified.

hcom commercial height of a tree (height to top of usable logs).

hdom mean height of all dominant trees. For example, h100 = mean h of the 100 trees of largest diameter at breast height per hectare.

i increment. This may be in any unit.

ib inside (without) bark.

k tree crown.

mai mean annual increment.

n number of.

N total number per hectare or other specified unit of land area.

ob outside (including) bark.

pai periodic annual increment.

rc root collar. The most common heights are 5 cm in the nursery and 30 cm for trees in the field; however, no general standards have been adopted, so you must specifiy the height being used.

t age in years (unless specified otherwise) from date of planting.

v volume of the individual tree or tree segment. You must describe the unit referred to, such as merchantable stem, total stem, aerial (above ground), or total (stem + branches + roots).

V total volume per hectare.

8.5 Silvicultural Treatments

The treatments listed are meant for field trials. As such, they do not include treatments that deal primarily with seed handling or nursery studies. Additional treatments may be added as needed.

Although listed as primary and secondary treatments, in any one study the type of treatment may be from either list. Nevertheless, the distinction is thought to be useful because the secondary treatments tend to have a subordinate overall relationship to the primary one.

This is a preliminary listing, subject to revisions in consultation with network groups.

Primary	Secondary
Cleaning CL	CC = complete cleaning Ln = line cleaning, n meters wide Rn = radial cleaning, n meters around tree Tn = maximum age, n years F = frequency TM = tool manual (MA = machete, HO = hoe, HE = herbicide, CV = combination of various) EM = equipment mechanized (SC = soil cultivated, UC = understory cut, HE = herbicide, CV = combination of various)
Clone CS	Identify with species code (see code 3, section 8.3) plus clone or seedlot code of < 9 characters
Direct Seeding DS	IN = inoculation ME = method MO = month
Felling FL	P = period of year + (C = cold, H = hot, D = dry, R = rainy, V = variable = transition) H = stump height + h, cm T = tree age, years D = tree diameter + measurement height, m
Fertilization FE	CO = composition + (chemical code/amount, g) AP = application + S = surface, I = incorporated
Formation FO	L = single line, as boundary or live posts M = multi-line, as windbreak + no. tree rows H = hedgerow or live fence + no. tree rows I = isolated trees + spacing S = stand in group or block of trees

Primary	Secondary
Harvest HA	BC = block clearcut + length, m times width, m per block SC = strip clearcut + width, m ST = seedtree cut + no. seedtrees per ha SH = shelterwood + % removed S1 = 1-tree selection + criteria GS = group selection + criteria Other ____________________
Inoculation IN	RH = rhizobium FR = Frankia MY = mycorrhizae OT = other
Intercropping IC	CS = crop species CM = crop management TS = tree species TM = tree management
Irrigation IR	F = frequency A = amount, cm
Mulch MU	M = material (OR = organic, SY = synthetic IN = inorganic, Other ____________) T = thickness, mm R = radius, cm
Nurse Crop NC	S = species P = periodicity T = type: P = perennial A = annual; X = N-fixing N = non N-fixing O = other ____________________
Planting PL	ME = mechanized MA = manual (tool?) SL = slit HO = hole PI = pit DA = date (year, month) CU = culture: C = cleaning I = irrigation; F = fertilization P = pruning Other ____________________
Planting Stock PS	BR = bareroot BE = ball of earth ST = stump CO = container SC = small cutting PC = post-size cutting DC = direct seeding TC = tissue culture Other ____________________

Primary	Secondary
Pollarding PO	H = height, m F = frequency, months A = age
Protection PR	CH = chemical ______________ SI = silviculture ______________ BI = biological ______________
Progeny PG	Identify with species code plus progency code of < 9 characters FP = female parent MP = male parent SE = seedlot
Provenance PV	Identify with species code plus provenance code of < 9 characters
Pruning PN	TH = tree h, m SM = selection method UD = upper d MO = month, 01-12 PH = pruned h, m or % PM = pruning method
Seedlot SE	Identify with species code (see code 3, section 8.3) plus seedlot code of < 9 characters
Silviculture SV	CL = clean FL = felling FE = fertilization IC = intercropping IR = irrigation MU = mulch PO = pollarding PN = pruning ST = sprout thinning TH = thinning
Silvopastoral SL	AS = animal species AM = animal management FS = forage species FM = forage management TS = tree species TM = tree management
Site SI	PD = permeable depth BD = bulk density TX = topsoil texture SX = subsoil texture TT = topsoil thickness ST = subsoil thickness TO = topsoil organic matter SO = subsoil organic matter TP = topsoil pH SP = subsoil pH TC = topsoil color SC = subsoil color TN = topsoil nitrogen SN = subsoil nitrogen TF = topsoil phosphorous SF = subsoil phosphorous TK = topsoil potassium SK = subsoil potassium TS = topsoil salinity SS = subsoil salinity
Site Clear SC	BD = bulldoze SL = slash PL = plow BE = bed TE = terrace FI = fire (Separate multiple codes with underline, e.g., BD_TE)

Primary	Secondary
Spacing ES	GE = geometry (SQ = square RE = rectangular SY = systematic = Nelder/fan/plaid) DI = distance (between tree, m x between rows, m)
Species SP	6-character code (see code 3, section 8.3)
Sprout Thinning ST	N = number of residuals on stump M = month of cut T = sprout age SS = sprout selection method
Thinning TH	M = method (C = crop tree, H = high, L = low, M = mechanical, O = other) W = weight (% removed of T = trees, G = basal area, V = volume) I = interval, years
Understory Cropping UC	IC = initial cropping only (taungya) PA = permanent undercropping of annuals PP = permanent undercropping of perennials
Variety VA	2-character code attached to the 6-character species code when variety is known and relevant. Ordinarily, the first two characters of the varietal name; e.g., *Pinus caribaea* variety *hondurensis* would be PINUCAHO. (See also section 8.3.)

Appendices

Appendices A, B, and C are condensed versions of the recommended procedures for the Forestry/Fuelwood Research and Development Project (as of December 15, 1988).

The 1987 humid and subhumid regional network trials were installed in 1987. The arid and semi-arid regional network trials are scheduled for installation in 1989.

Appendix D contains suggested material for further reading.

Appendix A

Network Trials: Humid and Sub-humid Zone

(Summary of Recommended Procedures)

Objectives:

- o To increase knowledge of growth, site requirements, and management practices of priority multipurpose tree species (MPTS) to meet the needs of small-scale farmers in Asia for fuelwood, fodder and other tree products in humid and subhumid regions of Asia.
- o To provide a focus for network development; and
- o To help improve methodologies used in forestry research.

Experimental Design

Design is randomized complete blocks with 4 replications, using a factorial of 3 species x 2 provenances each x 3 management treatments. This equals 18 treatment combinations per block x 4 replications or 72 plots (see Table A.1). A sample block layout is shown in Figure A.1, and a standard plot layout is shown in Figure A.2.

Layout

Treatments are randomly assigned to plots in complete blocks of 18 plots. Each plot is uniquely numbered and consists of 7 rows spaced 2 m apart. Each row contains 7 trees spaced 1 m apart; 7 rows x 7 trees = 49 trees/plot x 72 plots = 3528 trees/3 = 1,176 trees of each species. There are two provenances of each species; 1,176/2 = 588 trees of each species/provenance combination. Plot size is 7 x 14 m = 98 sq m/plot x 72 plots = 7,056 sq m of experimental area.

Trees are numbered beginning at the northwest corner and proceeding east, from 1 to 7. The first tree in the second and succeeding rows is under tree number 1. The central 9 (3 x 3) trees are measured each six months. The outer two rows of each plot are buffer rows; if any measurement trees die before age 24 months, a replacement tree is selected in the adjacent buffer row. After age 24 months, dead measurement trees are not replaced.

Two trees (both even- or odd-numbered) are randomly chosen from the outer buffer row each six months for destructive sampling of foliage and wood weight and specific gravity (Figure A.3). If insufficient trees are available in the outer row, trees are similarly selected from the inner buffer row.

Seedling Production

Containers are made of plastic and are 10 x 15 cm flat in size with at least 8 to 12 perforations. They are filled with a potting medium of 50% clay, 40% sand, and 10% compost by volumes, with 30 to 50 g of 12-24-12 fertilizer mixed in thoroughly with 10 liters of medium. The pH should be 6.0 to 7.5. Pots may be placed on plastic sheets if flooding is no problem.

Table A.1. Species, genotypes, and treatments for 1987 network trials

Factor A Species and Code	Factor B Provenance and Seedlot	Factor C* Cutting Management C	PO	PR
Acacia mangium	Iron Range QLD, #15677	1	2	3
ACACMA	Boite PNG, #15642	4	5	6
Acacia auriculiformis	Morehead QLD, #15477	7	8	9
ACACAU	Bensbach/ Balamuk PNG, #15648	10	11	12
Leucaena diversifolia	Hawaii K156	13	14	15
LEUCDI	Hawaii hybrid KX3 (K743)	16	17	18

* C = control (no cutting)
PO = pollard (at 2m at 24 months)
PR = prune (50% of height at 18 months)

TRT 12 Aric PNG Pruning Plot 1	TRT 6 Mang-PNG Pruning Plot 2	TRT 16 Leu K156 Control Plot 3	TRT 18 Leu K156 Pruning Plot 4	TRT 11 Aric-PNG Pollard Plot 5	TRT 3 Mang-QLD Pruning Plot 6
TRT 17 Leu K156 Pollard Plot 7	TRT 9 Aric-QLD Pruning Plot 8	TRT 1 Mang-QLD Control Plot 9	TRT 15 Leu KX3 Pruning Plot 10	TRT 4 Mang-PNG Control Plot 11	TRT 8 Aric-QLD Pollard Plot 12
TRT 10 Aric-PNG Control Plot 13	TRT 14 Leu KX3 Pollard Plot 14	TRT 2 Mang-QLD Pollard Plot 15	TRT 7 Aric-QLD Control Plot 16	TRT 13 Leu KX3 Control Plot 17	TRT 5 Mang-PNG Pollard Plot 18

Figure A.1. Example of block layout

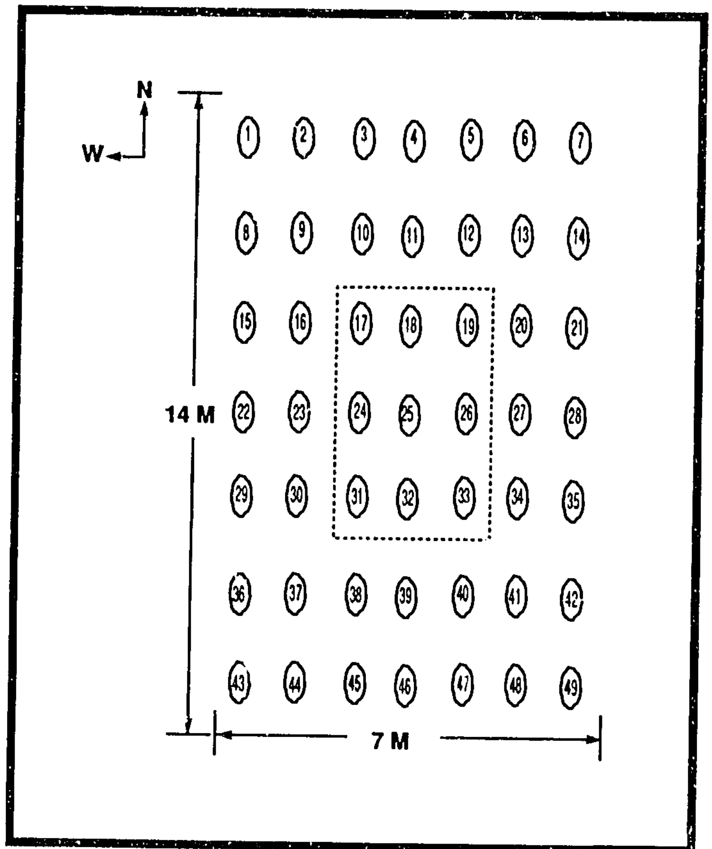

Figure A.2. Tree layout on plots

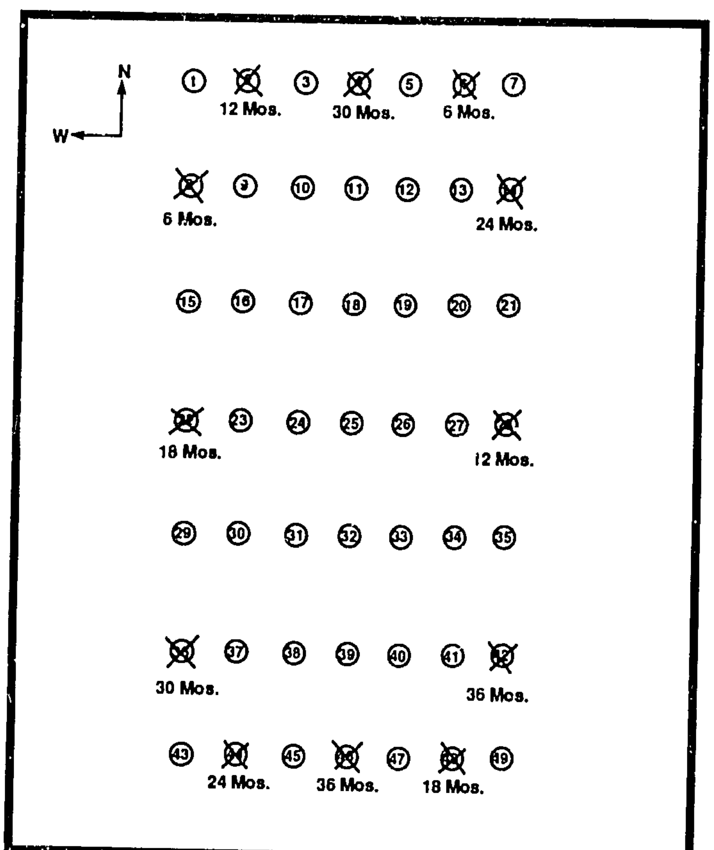

Figure A.3. Example of sampling for biomass

Treat *Leucaena diversifolia* (LEUCDI) seed 30 seconds in water at 80° C, then soak 24 hours in tap water; swollen seeds are sown. Treat both *Acacia auriculiformis* (ACACAU) and *Acacia mangium* (ACACMA) 30 seconds in water at 80° C, and soak 10 minutes in tap water; repeat combination three times, then air-dry and sow. Inoculate with *Rhizobium*.

Sow LEUCDI directly in bags. Sow ACACAU and ACACMA in seed flats, then transplant to bags when hypocotyl is erect but before seedcoat is shed.

Shading, if used, is less than 76%. Remove at least two weeks before outplanting.

Water well in the morning if upper part of pots is dry. Control damping off and root rot with fungicides as necessary.

Remove weeds from pots as soon as observed when soil is damp.

Prune any roots outside the container periodically with a scissors-type shear.

Cull seedlings for good health and height of 30 cm for planting.

Field Establishment and Care

Clear all vegetation from experimental area and remove. Till adequately. Dig holes 25 x 25 x 25 cm. Cultivate topsoil within 15 cm of hole. Place 20 to 30 g of 12-24-12 fertilizer in bottom of hole and cover with soil.

Soak soil in containers immediately before transport. Pack to prevent avoidable shaking. Place in protected, shaded area until planting. Water daily.

Distribute seedlings less than four hours before planting. Do not dislodge soil from roots. Set seedling with root collar at ground line. Firm soil with flat part of foot. Mulch with dry grass. Replace dead seedlings first two months only.

Every two to three months, cut all weeds in the experimental area and pull those within 50 cm of seedlings to prevent weed competition. Weed as necessary thereafter.

Construct firelines more than 19 m wide before fire season, and cut and remove vegetation within the fire lines regularly during the dry season. Monitor pests and diseases and control as necessary, especially the Leucaena psyllid, up to age 1 year.

To help prevent human and animal damage to trees, communicate to all neighbors the study objectives and long-term importance for local population.

Measurement and Recording

See sections 6.0 and 7.0.

Appendix B

Network Trials: Arid Zone

(Summary of Recommended Procedures)

Objectives:

- To increase knowledge of growth, site requirements, and management practices of priority multipurpose tree species (MPTS) suitable to meet the needs of small-scale farmers for fuelwood, fodder, and other tree products in arid regions of Asia;
- To provide a focus for network development; and
- To help improve methodologies used in forestry research.

Experimental Design

Design is randomized complete blocks with only three replications, using a factorial of 4 species x 2 pruning regimes = 8 treatment combinations per block x 3 replications = 24 plots.

Treatments

Treatment factors are species and pruning (see Table B.1). In addition to the three species common to all locations, each cooperator is to select one or more additional species, either native or exotic. This selection can include a local source of one of the three network selections. A useful selection would be a species or variety intensively planted locally to serve as a standard of comparison.

Layout

Blocks are subjectively located to minimize variation within each block, and plots are laid out to maximize unavoidable variation within every plot of that block. Treatments are randomly assigned to plots in complete blocks of eight plots (see Figure B.1).

Each plot is uniquely numbered and consists of eight rows with 12 trees each. Rows are 2 m apart, and trees within rows are also 2 m apart (see Figure B.2); 8 rows x 12 trees = 96 trees per plot; 96 trees x 24 plots = 2,304 trees for four species; 2,304/4 species = 576 trees of each species.

Row length is 12 trees x 2 m spacing = 24 m; plot depth is 8 rows x 2 m spacing = 16 m; plot area is 24 x 16 m = 384 sq m; study area is 384 sq m x 24 plots = 9,216 sq m, plus surround. A buffer row of a local species will be planted around the entire experiment.

Trees are numbered serially beginning at the northwest corner and proceeding east from 1 to 12. The first tree in the second row and in succeeding rows is aligned beneath tree number 1 (Figure B.2).

Table B.1. Treatments for arid-zone network trials.

Species and Code	Cutting*	Treatment No.
Acacia nilotica ACACNI	Control	1
A. nilotica ACACNI	Prune	2
Prosopis cineraria PROSCI	Control	3
P. cineraria PROSCI	Prune	4
P. pallida PROSPA	Control	5
P. pallida PROSPA	Prune	6
Local species (see section 8.3)	Control	7
Local species (see section 8.3)	Prune	8

* Control = no pruning. Prune = remove all branches up to 1/3 of total height or 2 m of bole from ground level (whichever is less) at the beginning of each winter.

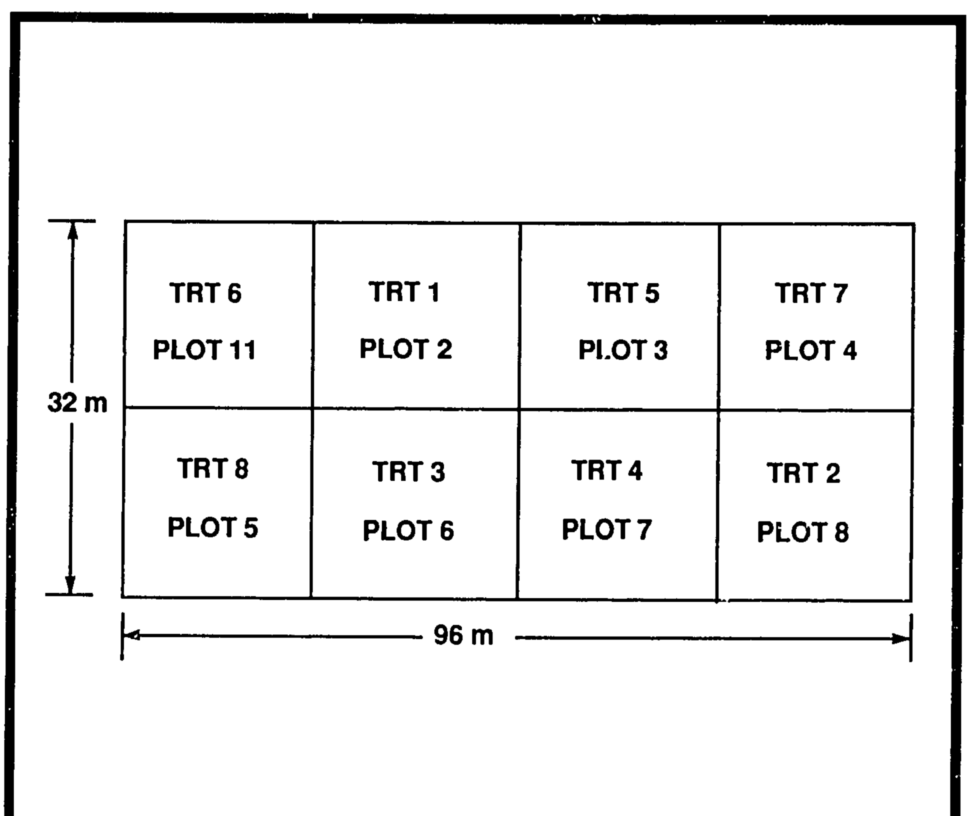

Figure B.1. Example of block layout.

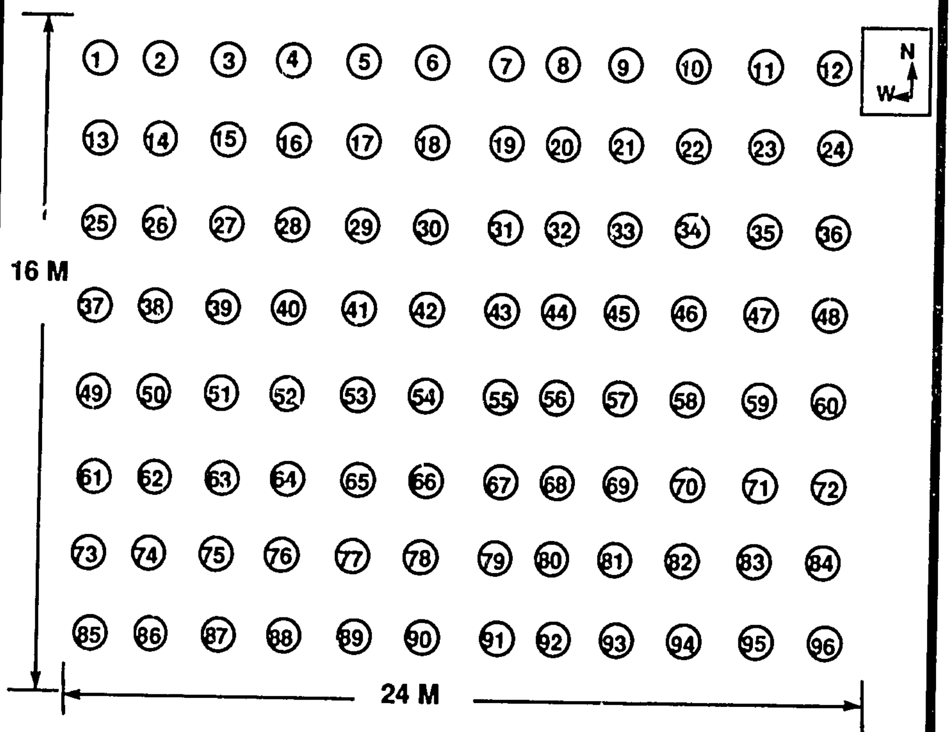

Figure B.2. Tree layout on plots.

Nursery Management

Containers should be plastic bags, 10 x 15 cm flat, with at least eight perforations in the lower part of bag. Fill with a locally proven potting soil or a mixture of 50% clay, 40% sand, and 10% compost or rotted farmyard manure, with benzene hexachloride (BHC) added to control termites. If flooding is not a problem, the pots may be placed on plastic sheets to prevent roots entering the soil.

Treat seeds of *Acacia nilotica* (ACACNI), *Prosopis cineraria* (PROSCI), and *P. pallida* (PROSPA) by soaking 30 seconds in water at 100° C, and soak 12 to 24 hours in clean water at room temperature. If seeds are swollen, they are ready for you to inoculate with pelleted rhizobium or steep in a mixture of water, rhizobium, and gum arabic, then sow directly in seed flats or containers. If not swollen, repeat treatment up to three times. Sow residual seed in a seed flat, and transplant seedlings obtained to containers when seedling is erect but before seedcoat is shed.

Water well in the morning if soil in upper part of the pots is dry. If water is scarce, water in the late afternoon, but take great care not to overwater. Damping off and root rot can be controlled with fungicides as necessary. Unless a special need is encountered, do not shade seedlings.

Remove weeds from pots as soon as observed, when soil is damp.

Move pots periodically, preferably monthly, to prevent roots entering the soil; prune any roots outside the container with a scissors-type shear. Grade by height and place in descending size in bed area. At planting time, assign trees of uniform height to a given plot. If number of seedlings is adequate, cull all seedlings with diameter at root collar (drc) less than 6 mm.

Establishment

Clear level sites completely, then plow or hoe. Where wind is a serious problem or on a slope, leave contour bands of vegetation and pile cut vegetation along contour. Construct a clean fireline completely around the experimental area before the dry season. Dig pits 30 cm in diameter and 45 cm deep before planting time.

Wet (but do not saturate) soil in seedling containers immediately before transport. Place on a mat of grass and pack securely to avoid preventable shaking. Transport seedlings in covered vehicle. Store in shade until actual planting.

Remove container carefully; prune root tips if coiled. Fill pit only until surface of soil is 15 cm below general ground level while planting seedling with root collar at the surface of the fill-soil. This provides initial protection and a basin for irrigation. Firm soil without disturbing root ball and earth from container. Water immediately, unless soil is near field capacity. Mulch with dry grass if available, or stones. Replace mortality periodically for the first two months only.

Maintenance

Weed periodically as needed. During the first year, keep the soil moist. If there is no rain, water with about 7 liters per tree at least once per fortnight. Adjust amount as needed for the specific site. Protect from insects, disease, rodents, wildlife, livestock, and people throughout the study. Communicate to neighbors and employees the study objectives and long-term importance for the local population.

On all plots, thin half the tree positions at age three by removing every other line running from NW to SE, including diagonal rows of trees 1-92, 3-94, 5-96, 7-72, 9-48, 11 and 24, 25-90, 49-88, and 73 and 86 (see Figure B.2). If a tree scheduled for removal is already dead or missing, do not remove an adjacent tree to compensate.

At age six, thin half the remaining tree positions by removing every other remaining diagonal line running NE to SW, including trees 4-37, 8-85, 12-89, and 60-93.

At age nine, thin half the remaining tree positions by removing every other remaining tree in the NE to SW diagonals that were not cut at age six; that is, numbers 6, 13, 21, 28, 36, 43, 50, 58, 65, 80, 87, and 95.

All sprouts following thinnings are removed at the same times as are weeds.

On plots to be pruned, prune all surviving trees at the beginning of each winter as closely as possible without damaging the stem cambium. Prune all stems to the lesser of 1/3 total height or 2 m above the ground, using a scissors-type shear if available and practical.

Measurement and Recording

All measurements are in metric units.

Measurement is annual and includes trees not removed in any thinnings. These trees are numbers 2, 10, 17, 32, 39, 47, 54, 61, 69, 76, 84, and 91 (see Figure B.2). If any trees have died, no substitution is made.

Diameter (d) is measured annually at breast height (1.37 m) and stump height (10 cm). Any stem originating below the point of measurement is also measured. For multi-stemmed trees, tree d is considered to equal the square root of the sum of the individual diameters squared. If it is difficult to decide whether the axis is a stem or a branch (that is, the axis is neither vertical like a stem nor near horizontal), any axis with a diameter at measurement height less than 1/2 the d of the main stem at that height is considered a branch.

Length (l) is measured along the main stem from the groundline (on the uphill side of slopes) to the uppermost tip of the main stem. Length of subsidiary stems is not measured.

Total height (h) is an optional measurement, and is the vertical distance from the uppermost tip to the ground level of the base of the tree. For erect and straight trees, $h = l$; for leaning or crooked trees, $h < l$.

Four trees for biomass determination are selected at random from those removed in each thinning. It is desirable to divide the trees to be thinned into four diameter classes, then select one tree at random from each class. Weight of wood (stems plus branches) and of fodder (foliage plus fruit) are determined separately. The material is weighed fresh, as soon as the tree is felled, then again after drying at 60° C until weight is constant.

See sections 6.0 and 7.0 of the manual for full discussions of measurement and for recording measurements and observations.

Appendix C

Network Trials: Semi-arid Zone

(Summary of Recommended Procedures)

Objectives:

- o To increase knowledge of growth, site requirements, and management practices of priority multipurpose tree species (MPTS) to meet the needs of small-scale farmers for fodder, fuelwood, and other tree products in semi-arid regions of Asia;
- o To provide a focus for network development; and
- o To help improve methodologies used in forestry research.

Experimental Design

The basic design is a randomized complete block with only three replications, using a factorial of 4 species x 2 cutting regimes = 8 treatment combinations x 3 replications = 24 plots (see Table C.1).

Treatments

Treatment factors are species and pruning (see Table C.1). In addition to the three species common to all locations, each cooperator is to select one or more native or exotic species. These can include a local source of one of the three network selections. It would be useful to select a species or variety intensively planted locally to serve as a standard of comparison.

Layout

Blocks are subjectively located to minimize variation within each block, and plots are laid out to maximize unavoidable variation within every plot of that block. Treatments are randomly assigned to plots in complete blocks of eight plots (Figure C.1).

Each plot is uniquely numbered and consists of 3 rows x 10 trees in each row = 30 trees per plot x 24 plots = 720 trees for 4 species; 720/4 species = 180 trees of each species (Figure C.2).

Rows are 10 m apart, and trees are 1 m apart within rows. Row length is 10 trees x 1 m spacing = 10 m; plot depth is 3 rows x 10 m spacing = 30 m; plot area is 10 x 30 m = 300 sq m; study area is 300 sq m x 24 plots = 7,200 sq m, plus surround.

Trees are numbered serially beginning at the northwest corner and proceeding east from 1 to 10. Numbering in rows 2 and 3 is also from west to east.

Nursery Management

Containers should be plastic bags, 10 x 15 cm flat, with at least eight perforations in the lower part of the bag. Fill with a locally-proven potting soil or a mixture of 50% clay, 40% sand, and 10% compost or rotted farmyard manure, with benzene hexachloride (BHC) added to control termites.

Table C.1. Treatments for the semi-arid zone network trials.

Species and Code	Pruning*	Treatment No.
Acacia nilotica ACACNI	Control	1
A. nilotica ACACNI	Prune	2
Dalbergia sissoo DALBSI	Control	3
D. sissoo DALBSI	Prune	4
Eucalyptus camaldulensis EUCACA	Control	5
E. camaldulensis EUCACA	Prune	6
Local species (see section 8.3)	Control	7
Local species (see section 8.3)	Prune	8

* Control = no pruning. Prune = remove all branches up to 1/3 of total height or 2 m of bole from ground level (whichever is less) at the beginning of each winter.

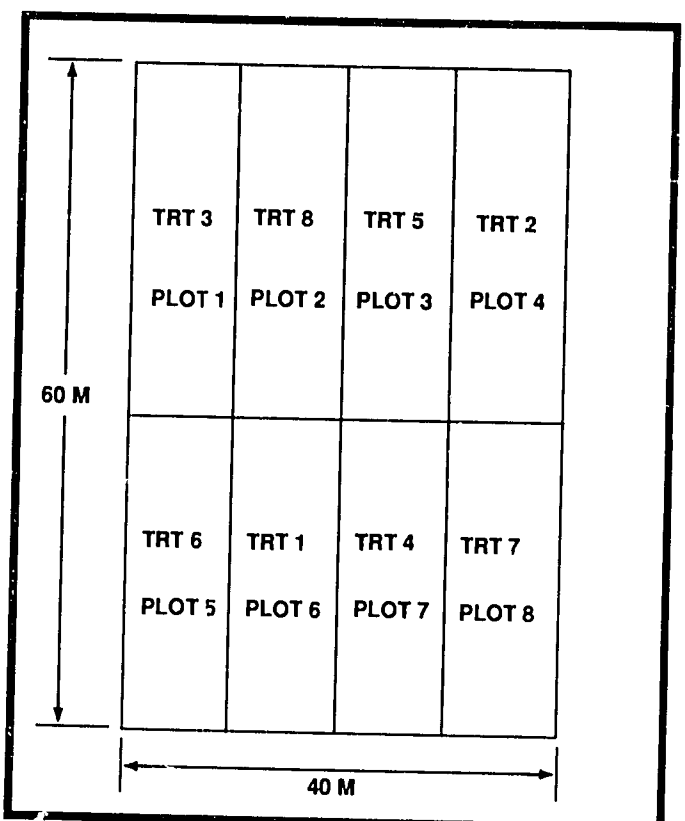

Figure C.1. Example of block layout

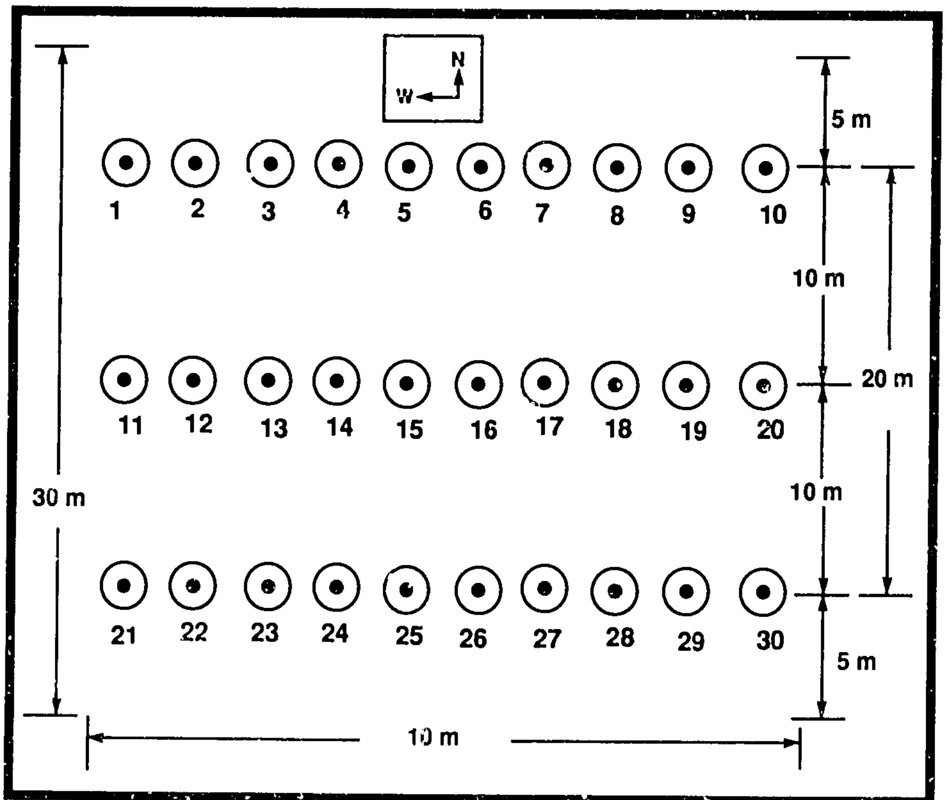

Figure C.2: Tree layout on plots (not to scale).

If flooding is not a problem, the pots may be placed on plastic sheets to prevent roots entering the soil.

Treat seeds of *Acacia nilotica* by soaking 30 seconds in water at 100° C, and soaking 12 to 24 hours in clean water at room temperature. If seeds are swollen, either inoculate with pelleted rhizobium or steep in a mixture of water, rhizobium, and gum arabic. Next, sow seeds in germination flats or directly in containers. If seeds are not swollen, repeat the treatment up to three times. Sow residual seed in a seed flat. When seedlings are erect (but before seedcoats are shed), transplant to containers.

Treat *Dalbergia sissoo* by soaking pod fragments containing seed for 24 hours in water at room temperature and inoculate as described above. Sow directly in containers or sow in a germination flat and transplant as you did for *Acacia nilotica*.

The seed of *Eucalyptus camaldulensis* does not require pre-soaking or inoculation. Sow sparsely in a disinfected medium and transplant when seedlings have two to four true leaves.

Water well in the morning if the soil in the upper part of pots is dry. If water is scarce, water in the late afternoon, but take great care not to overwater. Damping off and root rot can be controlled with fungicides as necessary. Unless a special need is encountered, do not shade seedlings.

Remove weeds from pots as soon as observed, when soil is damp. Be especially careful to avoid damaging young *Eucalyptus camaldulensis* while weeding.

Move pots periodically (preferably monthly) to prevent roots entering the soil. Prune any roots outside the container with a scissors-type shear. Grade by height and place in descending size in bed area. At planting time, assign trees of uniform height to a given plot. If number of seedlings is adequate, cull all seedlings with diameter at root collar (drc) less than 6 mm.

Establishment

Clear level sites completely, then plow or hoe. Where wind is a serious problem or on a slope, leave contour bands of vegetation and pile cut vegetation along contour. Construct a clean fireline completely around the experimental area before the dry season. Dig pits 30 cm in diameter and 45 cm deep before planting time.

Wet, but do not saturate, soil in seedling containers immediately before transporting to the field. Place on a mat of grass and pack securely to avoid preventable shaking. Transport seedlings in an enclosed vehicle. Store in shade until planting.

Remove container carefully. Prune root tips if coiled. Fill soil into the pit only until the surface is 15 cm below the natural ground level, while planting the seedling with root collar slightly below the surface of the fill-soil. This will provide initial protection and a basin for irrigation. Firm soil without disturbing root ball and earth from container. Water immediately, unless soil is near field capacity. Mulch with dry grass, if available, or stones. Replace mortality periodically for the first two months only.

Eight meters of the 10 m between rows will be planted to a cover crop, *Stylosanthes hamata*, at approximately the same time the trees are planted, leaving 1 m unplanted on each side of all three rows on each plot. To maintain uniform treatment of all rows, leave a 1-meter strip clear of cover crop around the planted trees, and plant cover crop 4 m outside each external row and 1 m along both sides of each plot.

Maintenance

Weed periodically as needed. Keep soil in the upper rooting zone moist during the first year. If there is no rain, water with about 7 liters per tree at least once per fortnight. Adjust the amount as needed for the specific site. Protect from insects, disease, rodents, wildlife, livestock, and people throughout the study. Communicate to neighbors and employees the study objectives and long-term importance for the local population.

Thin half the trees at age 3 (removing trees 1, 3, 5, 7, 9 from row 1, trees 12, 14, 16, 18, and 20 from row 2, and trees 21, 23, 25, 27, and 29 from row 3 (see Appendix B, Figure B.2). Remove all sprouts from the thinning stumps at the same time as weeds are removed.

On plots to be pruned, prune all surviving trees at the beginning of each winter, as closely as possible without damaging stem cambium. Prune all stems to the lesser of 1/3 total height or 2 m above the ground, using a scissors-type shear if available and practical.

Measurement and Recording

All measurements are in metric units.

Trees to be measured annually are those not removed in thinnings: numbers 2, 4, 6, 8, 10, 11, 13, 15, 17, 19, 22, 24, 26, 28, and 30 (see Appendix B, Figure B.2). If any trees have died after the first 2 months, no substitution is made.

Measure diameter (d) annually at breast height (1.37 m) and stump height (10 cm). Also measure any stem originating below the point of measurement. For multi-stemmed trees, tree d is considered equal to the square root of the sum of the individual diameters squared. If it is difficult for you to decide whether the axis is a stem or a branch, any axis with a diameter at measurement height less than 1/2 the d of the main stem at that height is considered a branch.

Measure length (l) along the main stem from the ground line (on the uphill side on slopes) to the uppermost tip of the main stem. Do not measure the length of subsidiary stems.

Total height (h) is an optional measurement and is the vertical distance from the uppermost tip to the ground level at the base of the tree. For erect and straight trees, $h = l$; for leaning or crooked trees, $h < l$.

Select four trees at random from the thinning to determine biomass. Divide the trees to be thinned into four diameter classes, and select one tree at random from each class. Determine separately the weight of wood (stems plus branches), wood specific gravity, and fodder weight (foliage plus fruit). Weigh the material fresh as soon as the tree is felled, and again after drying at 60° C until weight is constant.

See sections 6.0 and 7.0 for detailed discussions of measurement and recording measurements and observations.

Appendix D

For Further Reading

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The Forestry/Fuelwood Research and Development Project (F/FRED) is designed to help scientists address the needs of small-scale farmers in the developing world for fuelwood and other tree products. It provides a network through which scientists exchange research plans, methods, and results on the production and use of trees that meet the household needs of small farmers. These tree, in project terms, are multipurpose tree species (MPTS).

F/FRED is being carried out by the Winrock International Institute for Agricultural Development. Winrock was established in 1985 through the merging of the Agricultural Development Council (A/D/C), the International Agricultural Development Service (IADS), and the Winrock International Livestock Research and Training Center. Winrock's mission is to improve agriculture for the benefit of people--to help increase the productivity, improve the nutrition, and advance the well-being of men, women, and children throughout the world. Winrock's main areas of emphasis are human resources, renewable resources, food policy, animal agriculture and farming systems, and agricultural research and extension.

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