MICRO-ORGANISMS, NUTRIENTS AND TREE GROWTH

Micro-organisms, nutrients and tree growth C 30
- introduction: close associations with roots

How do micro-organisms influence trees?

All trees are affected by micro-organisms. Some of them, for instance:

(1) are decomposers, helping to break down litter and release nutrients (C 14; and D 13 in Manual 4);
(2) live immediately outside the fine roots; ***or***
(3) grow on the surface of leaves.

What are 'close associations with roots'?

Other kinds of micro-organisms in the soil have much closer relationships with trees, entering the roots and changing their structure.

Are they common?

Yes, close associations with woody plants appear to be widespread throughout the world. The great majority of tropical trees are thought to have at least one such association.

How important are they?

They are vital, especially on poor soils (C 62-C,D). Most of the micro-organisms closely associated with tropical trees play a particularly important part in:

(a) the nutrition of the individual tree (C 14), and so how well it grows;
(b) quantities and cycling of nutrients in the ecosystem (D 13, D 32 in Manual 4);
and probably
(c) improving the uptake of water (C 11, C 13).

NOTE: Many **soil-improving trees and shrubs,** which can reclaim degraded sites (D 22 in Manual 4), have at least two types of special associations with their roots.

What kinds of micro-organisms form close associations?

(A) Fungi;
(B) Bacteria; ***and***
(C) A few other groups, such as the *actinomycetes.*

But aren't these the things that cause disease?

A few kinds of fungi and bacteria can cause disease (C 45);
Most of them just break down litter, and are not harmful; ***and***
Some species form these special associations, with direct benefits for themselves and their host trees.

What do the useful micro-organisms gain?

(1) A ready supply of sugars and other organic substances for energy and growth;
(2) A protected place where they can live; ***and***
(3) Extra opportunities of spreading and multiplying.

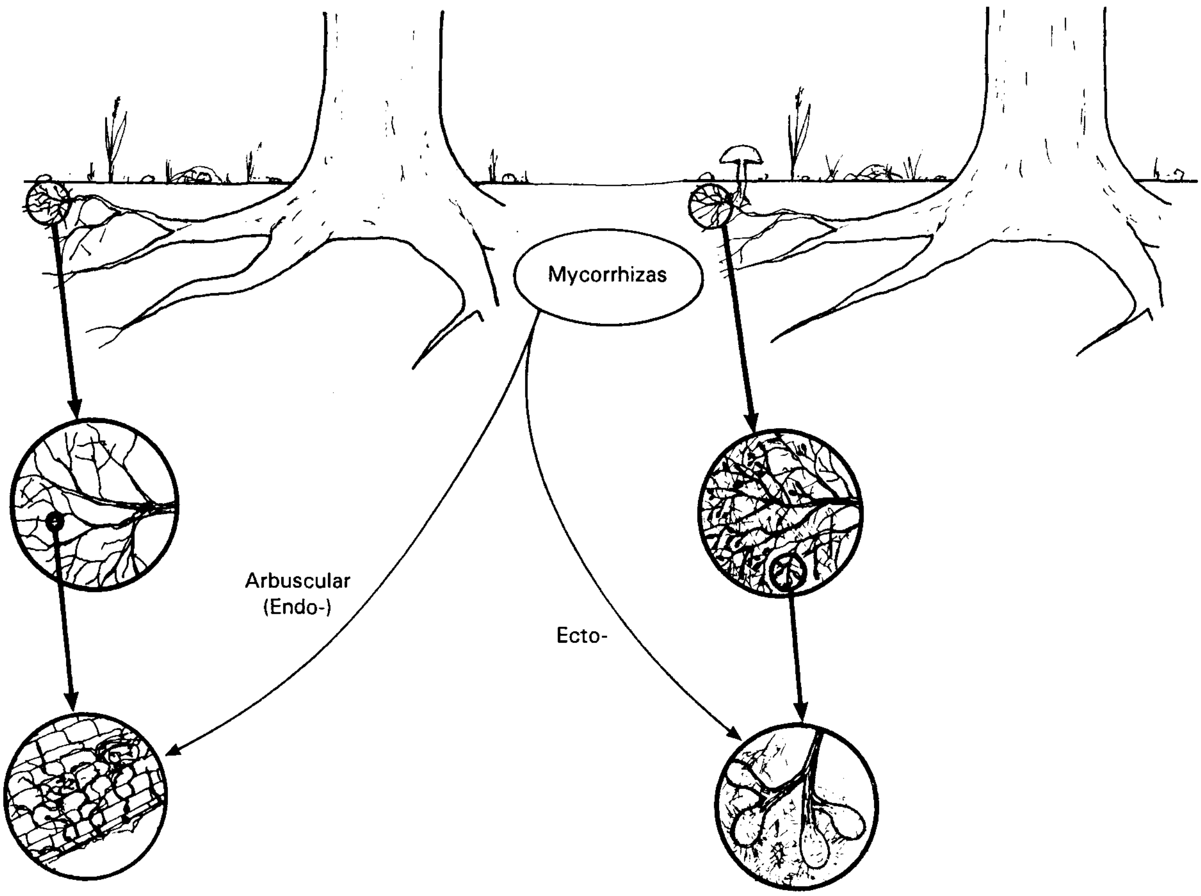
But won't that *reduce* the growth of my trees?

Not necessarily. It is often shortage of nutrients that limits the growth of trees in the tropics, though many other factors may also be involved (D 10-16 in Manual 4). Except where young trees are heavily shaded or unhealthy, plenty of sugars can be available for this 'trade-off' with the fungus in exchange for nutrients.

The general principles are becoming clearer about close associations with roots (C 62), but so far only a limited amount of research has been done on specific details.

Are there names for these associations?

Mycorrhizas are close associations between fungi and tree roots (C 31);
Root nodules are close associations between bacteria and tree roots (C 32); ***and***
Actinorhizas are close associations between actinomycetes and tree roots.



What are mycorrhizae like?

Mycorrhizal roots contain fungal tissue and have an altered structure. There are two different kinds:

(a) **Ectomycorrhizas,** in which fungal threads form a sheath *outside* fine rootlets of the tree, and penetrate *between* the root cells.

(b) **Arbuscular mycorrhizas** (endomycorrhizas, vesicular-arbuscular mycorrhizas or VAMs), where the fungi grow *inside* the cells of the roots. They occur in the outer part of roots that have not yet thickened and become woody, though not in the conducting cells within (C 10-11).

The fungi forming both types of mycorrhiza also produce:

(1) a very extensive system of very fine threads *(hyphae)* running and branching through the soil; ***and***

(2) very large numbers of resting spores.

Can you see ectomycorrhizas quite easily?

Yes, they can usually be spotted with the naked eye or a hand lens. Ectomycorrhizal rootlets are often short and relatively thick with blunt ends.

Most of the fungi involved form large fruiting bodies ('mushrooms') that are easily seen at certain times of year, though connection to a tree is difficult to establish.

Is it harder to see the arbuscular mycorrhizas?

Yes it is, for they cannot be seen with a hand lens, nor do the fungi involved form large fruiting bodies. However, infected roots are very common, and can be detected by using a simple staining technique and then looking at samples under a microscope.

How do mycorrhizas benefit the tree?

Through nutrients and probably water being passed to it from the fungus.

But surely a tiny fungus can't help the growth of a big tree!

Surprisingly it can, because:

(a) its threads can be very extensive, providing a **large surface area** for substantial amounts of nutrients and water to be taken up from the soil;
(b) some ectomycorrhizal fungi can break down, absorb and pass on nutrients from the soil that otherwise are **unavailable to tree roots.**

In fact, these fungi may be so important that some trees cannot thrive without them (C 31, C 60), and mycorrhizas can even form a substantial part of the root systems of some tropical trees. Equally, many of the fungi cannot thrive without the trees.

Which nutrients are passed to tropical trees by mycorrhizas?

Many kinds of nutrients are probably transferred, but **phosphorus** is especially important. This is one of the three elements needed in large amounts by trees (C 14), but in tropical soils it is often scarce or locked away in an unavailable form.

How can mycorrhizal fungi utilise 'unavailable' nutrients?

(1) The extensive network of fungal threads may **reach** immobile substances, such as phosphorus, more efficiently than a tree root *(one estimate suggests they may reach 400 times more soil); **and***
(2) Some ectomycorrhizal fungi produce special enzymes (C 14) that can **break down** resistant organic substances in the litter or soil, which other decomposers cannot do.

What about root nodules?

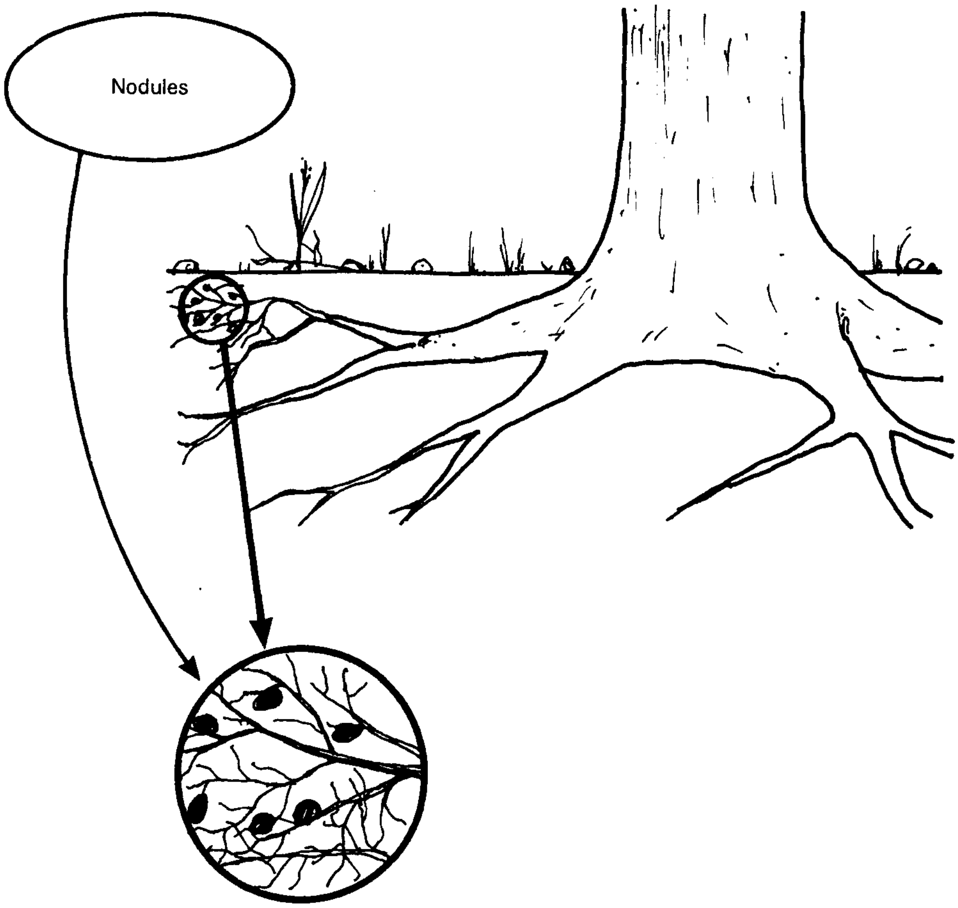
These are modified, roundish bodies on the roots, a few mm in diameter, in which large numbers of bacteria occur. Such nodules are easily seen and are well known on the roots of leguminous crop plants like beans and groundnuts. They also occur on many (though not all) leguminous trees, particularly those in the families Mimosaceae and Papilionaceae (C 32, C 62-D).

Which nutrient are they mainly involved with?

Nitrogen - the nutrient required in largest quantities by plants (C 14), but often readily lost and not freely available in tropical soils.

How do the bacteria help?

Nitrogen gas forms about 80% of the atmosphere, but in this form it is unavailable to plants. However, bacteria belonging to the group called **rhizobia** are able to turn nitrogen gas into soluble nutrients. These *nitrogen-fixing* micro-organisms can therefore add to the **total amount** of nitrogen that is available.



Can trees get hold of this extra nitrogen easily?

Yes, by soluble nitrogen passing:

(A) directly from the nodule into the rest of the tree; ***and***

(B) indirectly when nodules decay, so that the nutrients are released into the soil by decomposers and can then be absorbed by the tree's roots.

So you get a free fertiliser!

Yes, that's right. This is one of several reasons for planting mixtures of different species (D 30, D 53 in Manual 4). If nitrogen-fixers are included, the total amount of nitrogen that is cycling in the ecosystem is increased, which means that other trees and crops without root nodules may grow better, especially on poor soils.

Is that especially true of soil-improvers?

Most of these species, besides having nitrogen-fixing root nodules and mycorrhizas, are quick-growing colonisers that can become established on open or degraded land (D 22, D 32 in Manual 4).

Some examples with confirmed nitrogen-fixing ability are associations with *Calliandra calothyrsus, Gliricidia sepium, Inga jinicuil, Mimosa scabrella, Leucaena leucocephala, Sesbania grandiflora* and species of *Acacia, Albizia and Erythrina.*

What about actinorhizas?

These occur as root nodules on the roots of soil-improving trees such as *Alnus, Casuarina, Allocasuarina* and *Coriaria.* The micro-organisms belong to a kind called *Frankia,* and like rhizobia they help the tree to acquire nitrogen.

Research has shown that effective formation of nodules can vary considerably from one provenance of a tree species to another (C 5).

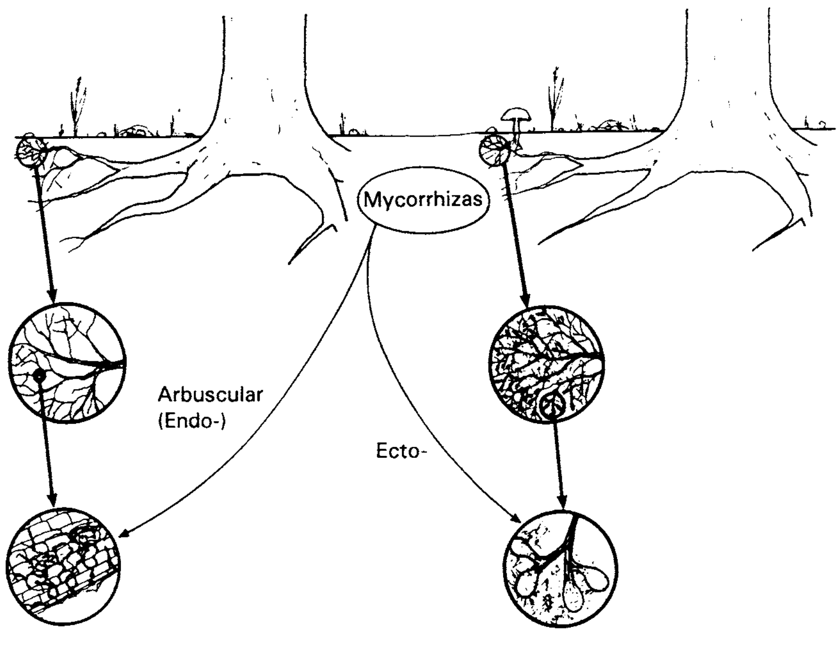
Micro-organisms, nutrients and tree growth C 31
- *mycorrhizas: fungi plus tree roots*

What have mycorrhizas got to do with tree nurseries?

A good nursery root system is one of the keys to growing and planting trees successfully (C 4, C 11, C 34). If the root systems of the planting stock are already mycorrhizal, the young trees are likely to establish better.

Which kinds of tropical trees produce ectomycorrhizas?

(a) All **dipterocarps,** for example *Dipterocarpus, Hopea* and *Shorea.*
(b) Some **leguminous trees,** like *Afzelia, Brachystegia, Eperua, Gilbertiodendron, Intsia, Microberlinia* and *Tetraberlinia* in the family Caesalpiniaceae; and *Aldinia, Pericopsis* and *Swartzia* in the Papilionaceae;
(c) Many **conifers,** such as pines and species of *Araucaria;*
(d) A few other **broadleaved** trees, including some eucalypts and oaks.



And which trees form arbuscular mycorrhizas?

Around 95% of all tropical forest trees are thought to do so. A few species of *Acacia, Afzelia, Eucalyptus, Hopea* and *Intsia* can even form both types of mycorrhiza.

Are there some groups of trees that don't form mycorrhizas?

It is thought that trees in the families Lecythidaceae, Proteaceae and Sapotaceae do not do so.

Does it matter which fungus forms the mycorrhiza?

It often seems to make quite a lot of difference, because particular species of fungi appear to be associated with certain groups of tree species. For example, ectomycorrhizas formed by the fungus *Pisolithus tinctorius* and the conifer *Pinus caribaea* have been studied by several workers (see Lapeyrie and Högberg, 1994 in C 62-C).

In ectomycorrhizas, different groups of fungi appear to be involved as the tree gets older.

Is there much variation within one kind of fungus?

Yes, there can be. Some *strains* of a fungus may form **more effective mycorrhizas** than others, just like some *clones* of trees make better growth (A 11 in Manual 1).

There is some evidence that a specific strain of a fungus might combine particularly well with a particular tree clone.

Can I tell which kinds of fungi are present?

Mats of threads can sometimes be seen amongst wet litter or in the topsoil, but these could belong to non-mycorrhizal fungi, and are too fragile to trace far.

Identifying the fungal species in the soil or the tree roots is possible, but it requires detailed microscopic study of roots, threads and spores, and sometimes the culture of individual fungi in the laboratory.

So it's not much use to me!

Yes, it could be.

Why is that?

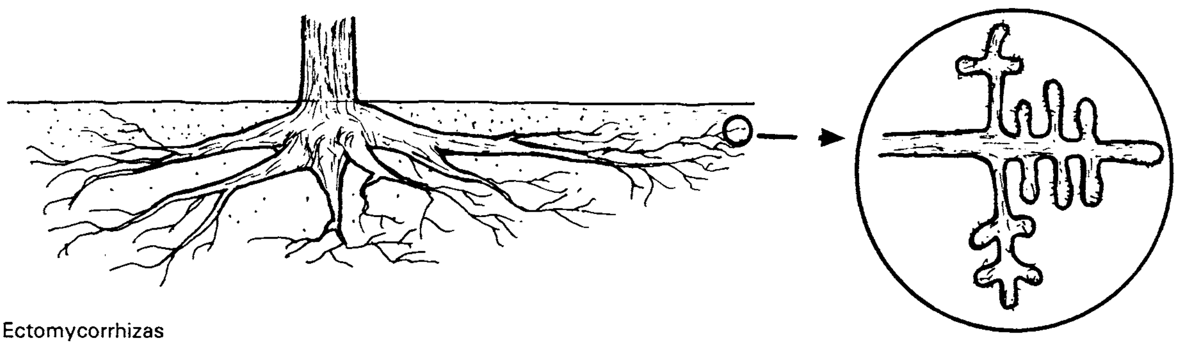
Although identifying species may be difficult, it is relatively straightforward to:

(a) detect the **presence or absence** of mycorrhizas; ***and***
(b) estimate the **frequency of infection** of roots with mycorrhizas.

But how can I make use of that?

(A) By knowing whether your young trees are infected; ***and***
(B) By inoculating them with mycorrhizal fungi, which:

(1) is not difficult; ***and***
(2) might make a substantial difference to their performance.



Ectomycorrhizas

How is infection with ectomycorrhizas detected and assessed?

By collecting samples of fine roots, and:

(a) finding out what percentage show the characteristic groups of short, slightly swollen ends to fine roots (C 30); ***and***
(b) checking under the microscope for the presence of the network of fungal threads covering the rootlets.

And what about arbuscular mycorrhizas?

Infection is checked by collecting samples of fine roots, treating them with a *clearing agent* that makes it possible to look through them, and using a coloured *stain* to show up the fungal cells. The proportion of roots containing fungus can then be estimated under a microscope.

What does one use to inoculate the root systems of trees?

There are four possible sources of mycorrhizal fungi, which use an *'inoculum'* from:

(1) topsoil containing fine roots, collected under trees of the particular species that are growing in natural forest, savanna or a well-established plantation;

(2) nursery or container soil that has recently been used to grow that tree species;

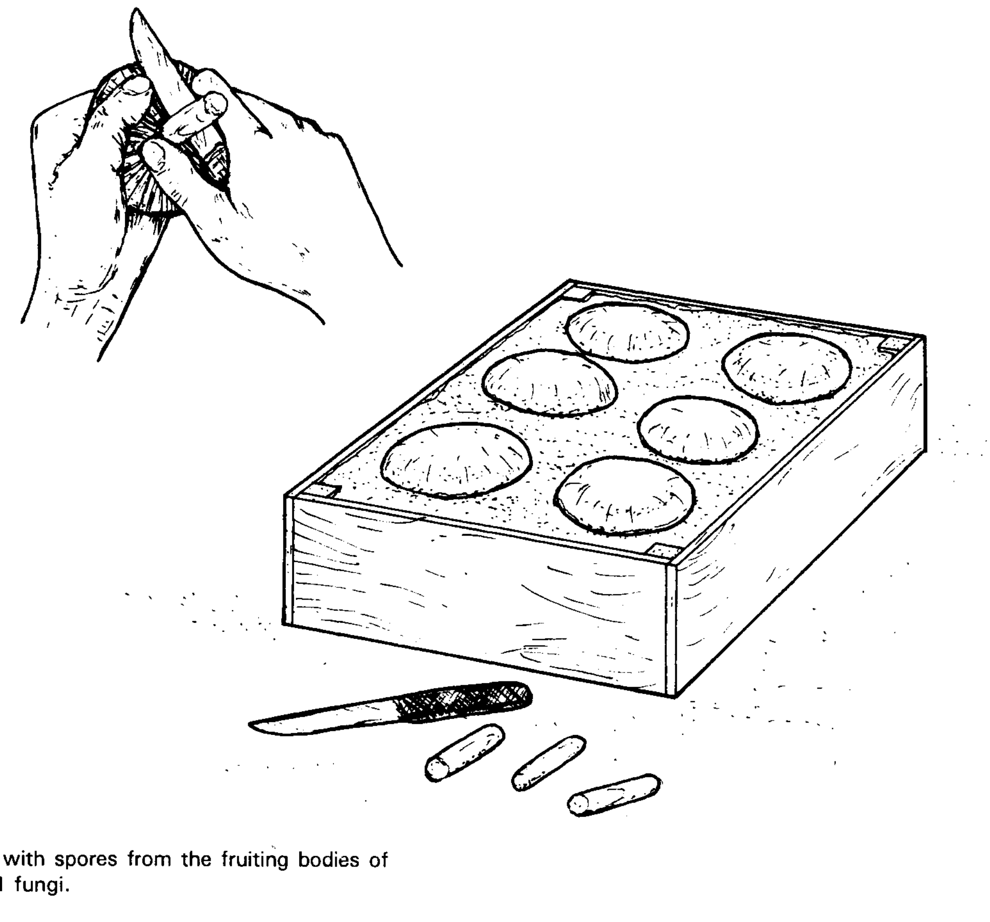
(3) spores or pieces of the fruiting bodies producing them, or *cultures* of kinds of fungi that have been shown to make effective ectomycorrhizas with the tree species.

(4) *soil cultures* of an arbuscular mycorrhizal fungus. For instance, strains of *Glomus* are beginning to become available.

Which source is the best?

Source (1) is a useful starting point if thriving stands of the tree species are available;
Source (2) is convenient if there is an existing nursery producing good plants;
Source (3), where available, is likely to prove the best way of obtaining ectomycorrhizas that can improve tree establishment, reliably and substantially.
Source (4) - simple methods have been developed for multiplying the quantities of inoculum for arbuscular mycorrhizas. These consist of growing crop plants such as cowpea, millet, sorghum or maize for a few months in a sterilised (C 44-45) and inoculated potting mix in large containers. These enriched soil cultures can then be added to soil mixes as required.

Note: national regulations and international certificates govern the import of soil and roots from one country to another, because of the dangers of transferring pests and diseases.



Inoculating soil with spores from the fruiting bodies of ectomycorrhizal fungi.

Isn't it hard to inoculate the young trees?

No. One just mixes a small amount of the inoculum into the topsoil of seed-beds (C 23) or with the soil mix used to fill seed trays or pots (C 6, C 42). Failing this, it is possible to put a little inoculum into the hole when a tree is planted in the field (Manual 5).

Which method is likely to be best?

Ideally, one would inoculate the germination or potting soil with **a mixture of known strains** of fungi. Then the young seedlings or rooted cuttings should form particularly effective mycorrhizas early in life, before they are exposed to the extra stresses of hardening (C 47), transport, planting, competition and browsing.

How would I know that inoculation had done anything?

By doing a small experiment (C 7, C 15) in which you potted up comparable plants in the same soil mix, with and without a fungal inoculation of about 5% by volume.
Both sets would need labelling (C 54) and looking after carefully (C 40, C 48).
For the layout, you could keep the two treatments in similar conditions near to each other, though not so close that spores could easily be transferred by water splashing on to the soil. Similarly, the containers could be raised clear of the ground to prevent seepage of water from pot to pot.

If the results were positive, you might do a more detailed experiment to compare several sources.

How big a difference can mycorrhizas make?

For ectomycorrhizas, introductions of pines, cypresses and other species into new areas have sometimes failed (C 60) without a first inoculation of nursery or forest soil from the country of origin, followed by transfer of infected soil from nursery to nursery. Increased growth of inoculated pines has also been found in several trials during the first 1-2 years after planting.

For arbuscular mycorrhizas, a suitable local fungus may more often be available, though inoculation can often still be beneficial. For example, in establishment trials with *Terminalia prunioides* in Kenya more than twice the number of plants given a mixed inoculation in the nursery survived through the first long dry season than in the uninoculated controls.

What other trees have been studied?

Among the kinds of trees that have responded to arbuscular mycorrhizal inoculation are:

(1) *Cedrela, Gmelina, Khaya* and *Tabebuia;*
(2) many leguminous trees, including *Acacia, Albizia, Calliandra, Cassia, Gliricidia, Leucaena, Pithecellobium, Prosopis, Sesbania* and *Tamarindus;*
(3) various fruit trees, including avocado, papaya and mango; ***and***
(4) shrubs such as cassava *(Manihot esculenta).*

Arbuscular mycorrhizal inoculation is standard nursery practice for large *Citrus* plantations in some countries, but more research will be needed before this stage can be reached with other tropical tree species.

When is inoculation especially needed?

It is likely to be most important when:

(a) **introducing species** from a different part of the same country or region, or from another part of the world *(especially for ectomycorrhizas);*
(b) the soil is naturally **poor in nutrients** *(such as infertile sandy areas);*
(c) planting is being done to **restore degraded land** *(D 22, D 32 in Manual 4);*
(d) the planting site has been recently **disturbed,** for example by frequent cutting, burning or farming; or near mines, buildings and roads *(especially important when most or all of the original trees have gone, and there are a lot of weeds);* ***and/or***
(e) site preparation is to be done with **heavy machinery** *(particularly if the surface soil is likely to be compacted, broken up or buried).*

Why is this so?

In all these cases the right kinds of mycorrhizal fungi may be absent or in short supply. Their growth and spread are usually interrupted by the removal of many trees, which exposes and disturbs the soil. Other fungi, associated for instance with persistent weeds, may have become common.

Planting introduced colonisers (D 14, D 32 in Manual 4) could help local species to regenerate naturally (D 2 in Manual 4), by restoring numbers of arbuscular mycorrhizal fungi.

When would inoculation be less important?

(A) For fertile planting sites, where mycorrhizas may play a less prominent role;
(B) When the nursery has already been producing thriving young trees that are mycorrhizal;
(C) If wildings (C 2) are collected with some of the local soil, especially directly under the seed tree. It has been found that naturally regenerating seedlings can even be sustained in dark, dry and nutrient-poor conditions through ectomycorrhizal 'bridges' with the parent tree.

Collecting wildings and soil.

How long can I keep the inoculum?

It is generally best to collect fresh material each time. However:

(1) fruiting bodies of ectomycorrhizal fungi can be stored dry for a year, as can spores extracted from them; ***and***

(2) nursery soil infected with arbuscular mycorrhizas can be multiplied repeatedly to provide inoculum.

What should I do if I run into problems with mycorrhizas?

You might contact (C 53):

(A) growers nearby to see whether they have solved a similar problem;

(B) the nearest forestry or agriculture department for advice; ***or***

(C) a local non-governmental organisation for help in finding out whether the problem has been studied. (See also C 62-C; and D 71 in Manual 4.)

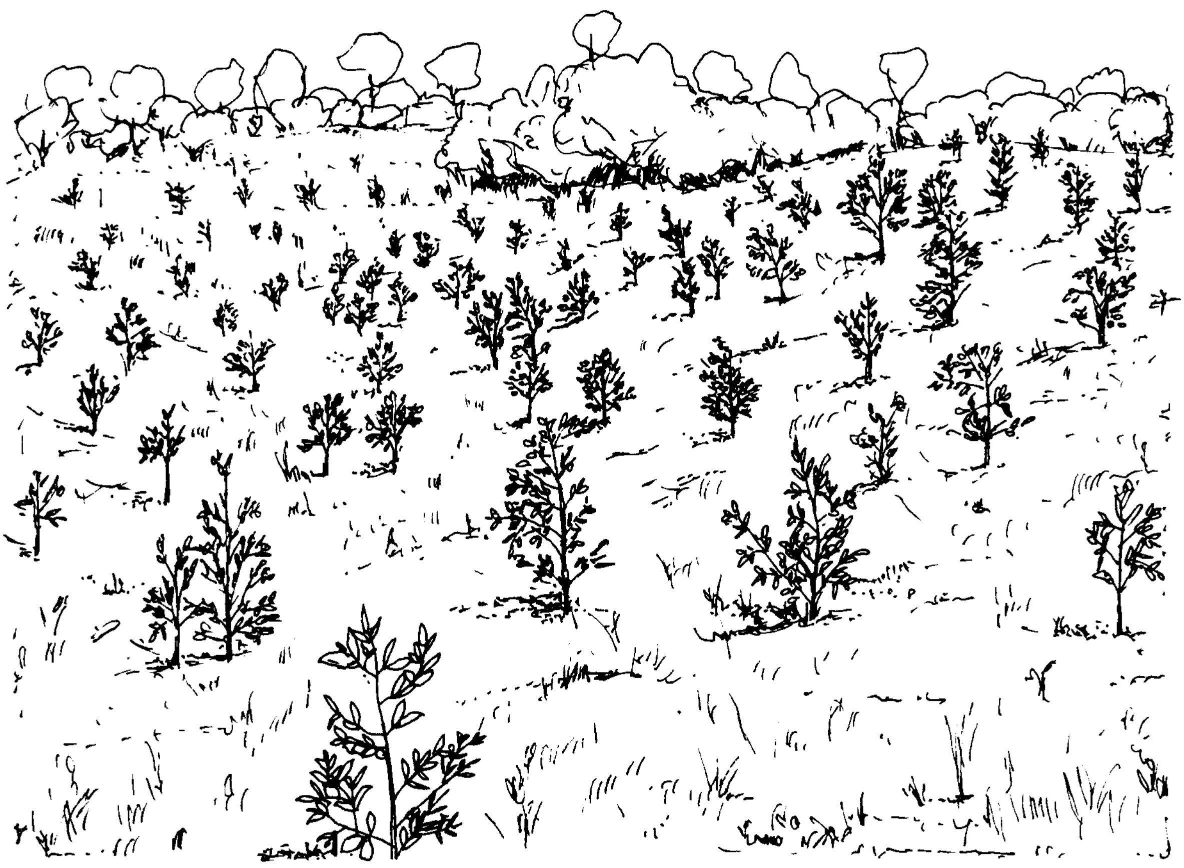
Do any nursery procedures affect mycorrhizas?

(a) **Soil sterilisation:** sterilising the nursery soil generally kills all the beneficial mycorrhizal fungi and decomposers as well as any disease-causing agents, insect pests and weed seeds (C 44-45). So if the soil should need to be sterilised (by heating or by chemicals), inoculation with mycorrhizal fungi might well be needed afterwards.

(b) **Control of plant diseases:** special care is needed with *fungicides,* or the mycorrhizal partner will be damaged or eliminated. However, they are not all equally toxic to fungi. For instance, it has been found with citrus that *thiazole* should be avoided.

(c) **Insecticides:** avoid excessive spraying, and try and prevent the chemical dripping down on to the soil. If any *systemic* insecticides are to be applied as a soil drench, you might do an informal trial first, and perhaps an experiment to compare different techniques and concentrations (C 15).

(d) **Fertilisers:** use sparingly or not at all (C 33), or you may reduce the likelihood of successful mycorrhizas forming, or of those that do being effective.



Restoring degraded land with a pure stand of a soil-improving tree, *Acacia mangium*.

Micro-organisms, nutrients and tree growth C 32
- *nitrogen-fixing root nodules*

What are nitrogen-fixing nodules?

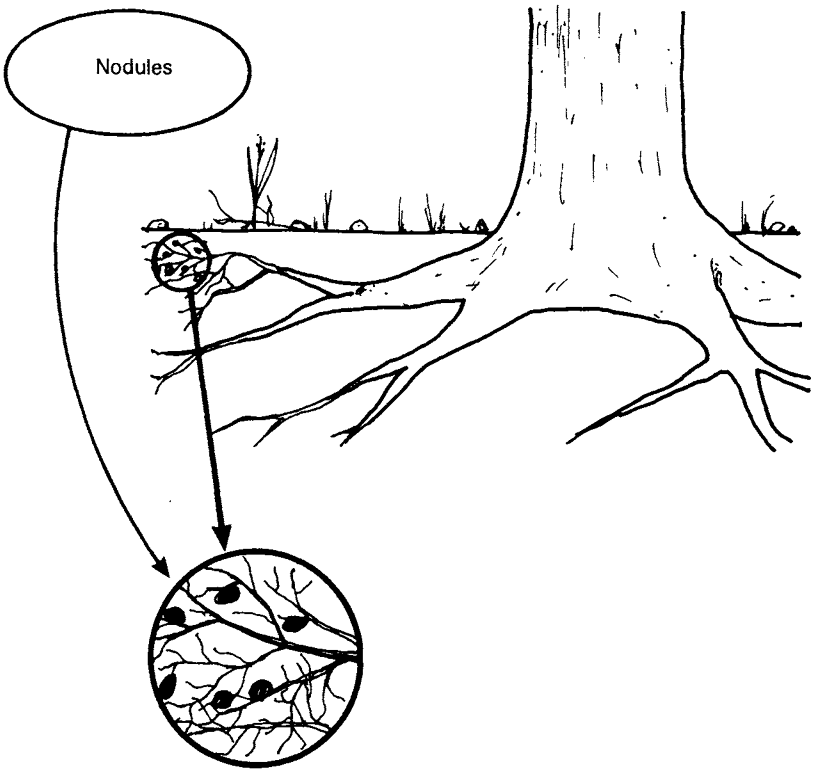
They are modifications to some of the fine roots of a tree, in which closely associated micro-organisms live. Generally these are bacteria called rhizobia, or sometimes actinomycetes called *Frankia.* Both of them have the ability to change atmospheric nitrogen into available nutrient form (C 30).

Aren't root nodules found mainly in annual crop plants?

They have been widely studied in legumes such as groundnuts and soybean, and in temperate zone grazing and crop plants. However, there are 18,000 or so leguminous species, most of which are trees, many of them tropical species.

Which kinds of trees have nodules?

(1) **Leguminous trees:** current research suggests that 90% or more of the hundreds of genera of tropical trees in the Mimosaceae and Papilionaceae may be found to have root nodules that fix nitrogen. However, less than a quarter of trees in the Caesalpiniaceae may do so, though in *Chamaecrista,* for instance, effective nodulation is the rule.
(2) **Non-leguminous trees:** a few genera are known, including *Casuarina* and *Parasponia.*



Are those used in agroforestry nitrogen-fixers?

Many of them. For instance Egli and Kalinganire (1988) (C 61-D) list the following for Rwanda: *Acacia albida, A. sieberiana, Albizia chinensis, A. lebbek, Calliandra calothyrsus, Leucaena leucocephala, Pithecellobium dulce* and *Prosopis chilensis* in the Mimosaceae; *Cajanus cajan, Erythrina abyssinica, Gliricidia sepium, Sesbania sesban* and *Tephrosia vogelii* in the Papilionaceae; with *Alnus acuminata* and *A. nepalensis* nodulating with *Frankia.*

Which legume trees *don't* form nodules?

Amongst those so far studied, the following are thought ***not*** to do so:

Caesalpiniaceae: *Bauhinia, Caesalpinia* and some species of *Senna (Cassia);*
Mimosaceae: *Adenanthera,* and perhaps certain species of *Acacia* and *Parkia;*
Papilionaceae: *Vatairea, Vataireopsis* and Brazilian *Pterocarpus.*

So are leguminous trees specially important?

Yes, they are. The many kinds that form effective nodules play unique roles through:

(A) adding to the **total amount of nitrogen** available within most tropical ecosystems (C 30; and D 10, D 13 in Manual 4);
(B) acting as **soil-improvers** in farmland and for reclaiming degraded soil (D 21-22 in Manual 4); ***and***
(C) improving the **general soil fertility** in nurseries (C 23) when used as hedges (C 46), shade trees (C 41) or windbreaks (C 25; and D 41 in Manual 4).

Does the planting stock itself need root nodules?

Having nodules on the young leguminous trees is likely to make a considerable difference if:

(1) they are effective in fixing nitrogen;
(2) the potting mixes (C 6) and nursery beds (C 23) are not very rich or heavily fertilised (C 33); ***and***
(3) the trees are being well looked after (C 40).

Research suggests that both the nitrogen content and the growth rates of nursery trees can be increased by root nodules.

How about when the young trees are planted out?

Already having effective nodules should add to the likelihood of planting stock surviving and establishing well. Such trees might grow well even in poor sites, and could soon contribute to the growth and yields of other trees and crops.

Is it easy to tell whether a tree has nodules?

Often they can be seen without difficulty when nursery plants are potted up, or by checking the outside of the root ball. However, especially in the field, you could miss nodules even though the tree does form them, because sometimes they:

(a) may break off very easily (as in *Acacia*);
(b) can be formed deep in the soil, especially in arid areas;
(c) might be found only at certain times of year.

Do young trees need to be inoculated?

Like other bacteria, rhizobia are so small that they are spread by the smallest current of air. Some of them are therefore likely to be present in most soil, unless it has just been sterilised (C 44-45). However, inoculation can often be useful, because:

(A) numbers present in the soil vary a lot. Since the micro-organisms generally do not survive in the soil for long periods, few may be present in degraded sites, for instance;
(B) different strains of rhizobia and *Frankia* apparently vary considerably in their ability to form effective nodules; ***and***
(C) as with mycorrhizas (C 31), there may not be inoculum in the local soil that will prove effective with introduced trees and shrubs.

For instance, inoculating with rhizobia has been recommended for *Albizia lebbek, Pithecellobium dulce* and *Prosopis chilensis.*
Adding certain strains of *Frankia* to potting mixes in the nursery trebled the wood production of *Casuarina* trees in the field (See Reddell *et al.*, 1989 in C 62-D).

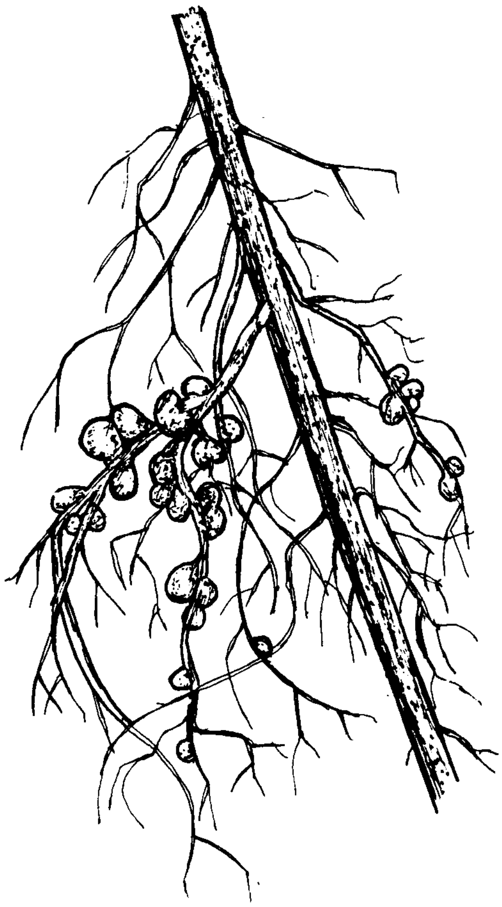
What is the best source of inoculum?

You could try:

(a) adding soil (and any root nodules you can find) from a thriving plot of leguminous trees to your seed beds and potting soil;

(b) if possible, using strains of micro-organisms already developed for tropical crops. These are likely to be more effective than those for the temperate zone; ***or***

(c) if available, using strains that are recommended for the particular tree species (already developed for *Leucaena* and certain species of *Acacia*).



Root nodules.

How does one do the inoculation?

Either by:

(A) thoroughly mixing around 5% of soil and chopped roots with nodules in the seed or potting mix; ***or***

(B) dusting seeds with a very small amount of powdered inoculum.

What about doing an experiment?

A pot plant experiment (C 15) could be very useful, comparing treatments such as:

(0) control - just the ordinary potting mixture;

(1) the same potting mixture + an inoculum of root nodules from groundnuts mixed into it;

(2) the same potting mixture + an inoculum of soil from under thriving plot of the desired tree species;

(3) the same potting mixture + an inoculum of soil from under a different, local leguminous tree species.

You might use 15-20 pots for each treatment, giving a total of 60-80 pots. Keep these under similar growing conditions, but slightly apart from each other and raised off the ground to reduce the risk of spreading bacteria from one treatment to another. Avoid fertilisers or a very rich potting mix.

Do trees vary much within a species in nodule formation?

Yes, this seems to be likely. Considerable variation has been recorded *between* different provenances (C 5; and Manual 2); and also *within* a provenance. So, if clonal cuttings are available (A 11 in Manual 1), these might be the best experimental plants.

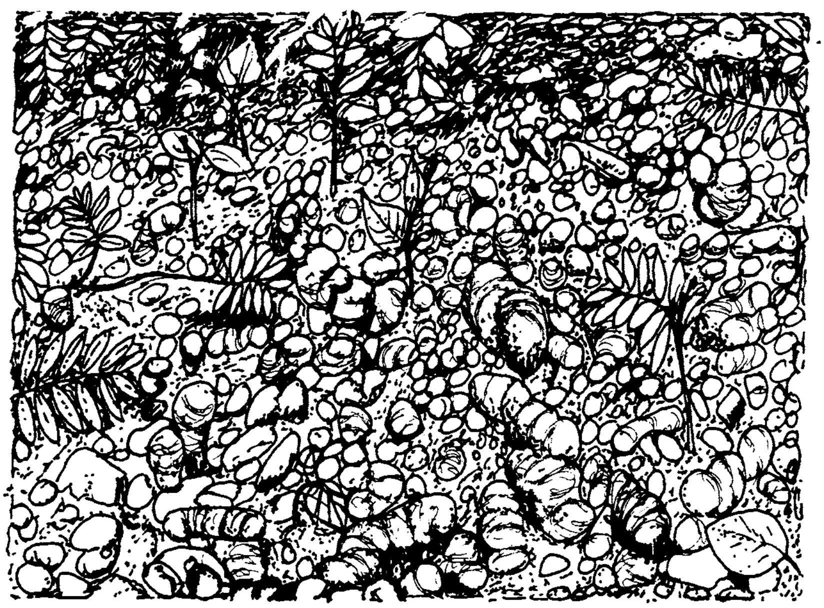
Can trees have root nodules and mycorrhizas?

Yes, some of them do (C 30); for example *Acacia nilotica* and *Leucaena leucocephala.* There is evidence that, without the mycorrhizas:

(a) the root nodules may not develop well; ***and***
(b) nitrogen fixation may be restricted.

It is likely that the phosphorus collected by the mycorrhizas allows normal production and functioning of the nodules.

A (above) — bare soil in degraded farmland.
B (below) — soil restored 18 months after direct sowing of *Leucaena*.



Micro-organisms, nutrients and tree growth C 33
- *wastes, composts and fertilisers*

Why do wastes have anything to do with tree nurseries?

Some wastes can be useful in various ways, for example by providing:

(1) containers of various kinds;

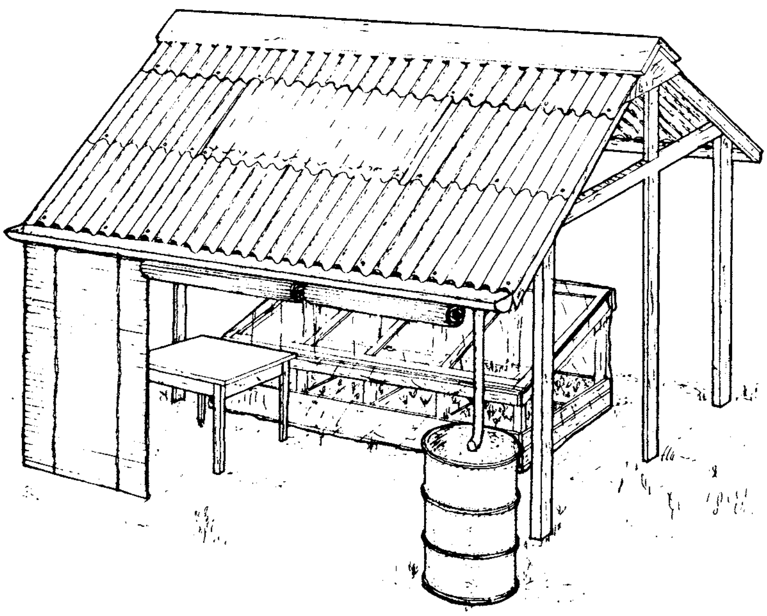
(2) suitable components for soil mixes (C 6) and rooting media (A 35 in Manual 1) that are free or cheap;

(3) valuable inputs of nutrients and/or organic matter to improve the fertility and structure of the nursery soil (C 23);

(4) mulch for seed and transplant beds to reduce soil temperatures and drying out;

(5) shade and shelter for young trees (C 41).

Waste water and rainfall can also be collected or encouraged to remain in the nursery soil (C 24) rather than quickly disappearing by evaporation or run-off.



What sort of old containers could be useful?

For instance:

(a) cleaned oil-drums for storing water (C 24);

(b) plastic containers, cut and given holes so that they can be used as plant pots (C 6); ***and***

(c) used fertiliser or other large polythene bags, for purposes like storing soil mixes or carrying plants.

Which waste materials can go into soil mixes and rooting media?

(A) **Town wastes** that have rotted into 'black soil' can provide organic matter and nutrients;
(B) **Sawdust** that has weathered for about a year and **rice hulls** add organic matter and improve the soil structure, though they contain fewer nutrients;
(C) **Fibre** from coconuts and from the inside of rotting palm stems are useful, richer components; ***and***
(D) **Composts,** prepared in the nursery out of most kinds of plant and animal waste, can be the most valuable of all additions.

What can be used to improve the nursery soil?

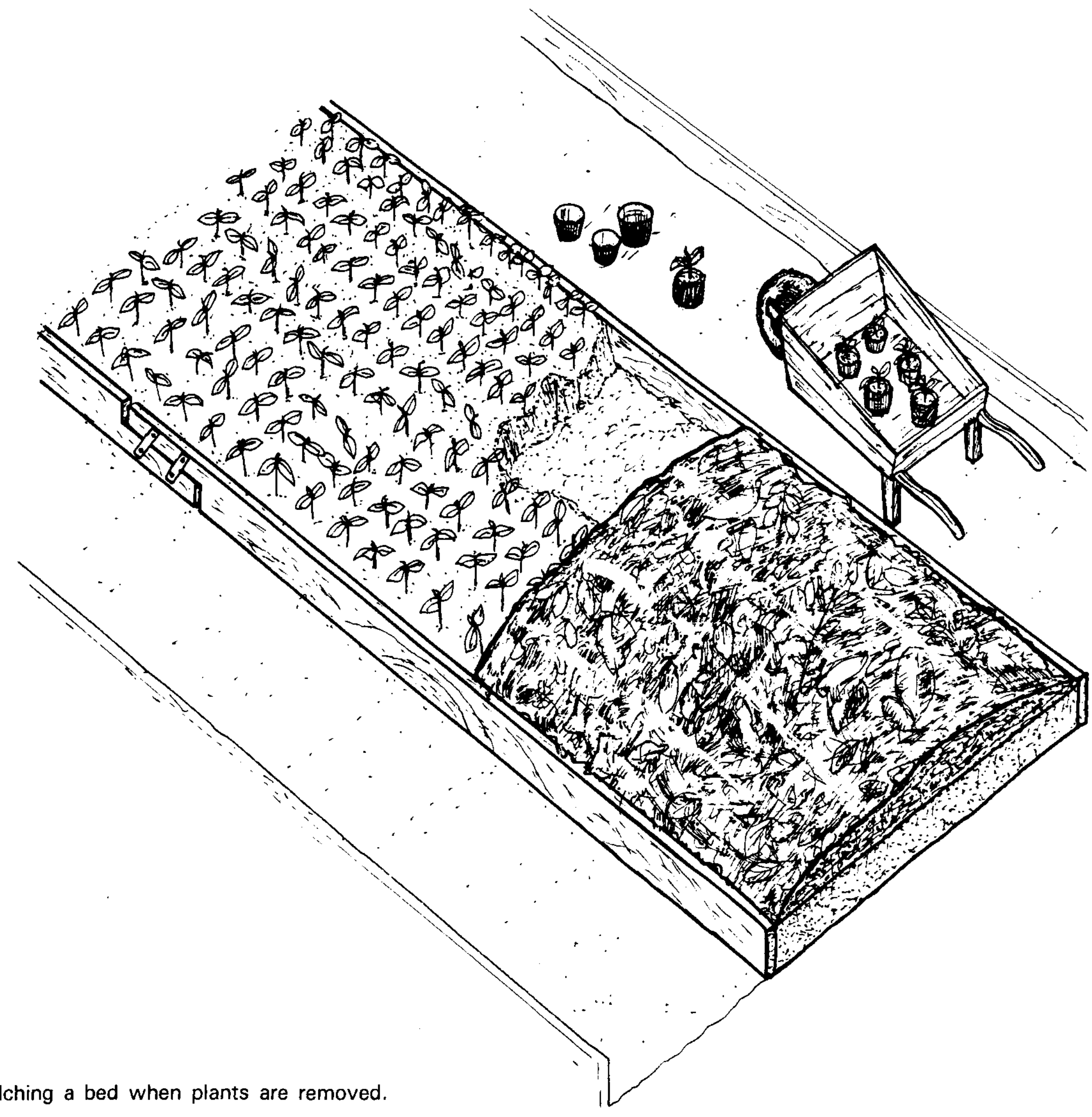
As well as the wastes just mentioned, you might improve the soil in transplant beds by:

(1) digging in leaflets from branches of leguminous trees (C 32) when finishing the beds;

(2) growing a green manure or a nitrogen-fixing crop in the bed before putting in trees (C 26); ***or***

(3) putting on a mulch when a particular bed is not in use.

Fresh sawdust might be used to build up a wet, low-lying part of the nursery (C 23).



Mulching a bed when plants are removed.

How should a mulch be made?

Various kinds of soil covering can be used (see Goor and Barney, 1968 in C 61-A; and Manual 5), including cut grass, other kinds of leaves, sawdust, bark chippings or pieces of black polythene sheet.

Which wastes are useful for shade and shelter?

Cut poles and palm fronds, banana leaves or tall grasses could be useful to put up low or high shade over young trees (C 41).

Pieces of strong clear or white polythene sheeting from the covers of furniture and bedding are often suitable for building poly-propagators (A 31 in Manual 1), or protecting delicate seedlings from rain and wind (C 41).

Might some wastes be harmful?

Yes, they could be. Here are some examples to avoid:

(a) materials that could pollute the nursery soil (C 23) or the water supply (C 24);
(b) broken glass, thorns or spines, which can cause cuts and infections if they get into the potting mix or the nursery topsoil;
(c) weeds that have ripening fruits or persistent underground organs (C 44);
(d) plants and soil that are contaminated with spores carrying diseases, or with the eggs or resting stages of insect pests (C 45); ***or***
(e) water that contains a lot of nutrients and is full of bacteria or algae.

Is there anything that can be done about these things?

(1) Some sharp items can be sieved out (C 51) from components such as 'black soil', and disposed of carefully;
(2) Soil and plant material contaminated with pollutants, weeds, pests or diseases could be sterilised (C 44-45), burnt or taken far away from the nursery; ***and***
(3) Water can be cleaned by running it through gravel or sand.

What are composts?

They are made by mixing together plant and perhaps animal wastes to rot, in a pile, a large container or a pit (say 1.5 m deep).

The heat given off by the micro-organisms which break down these organic wastes can make the compost hot enough to kill some weed seeds, spores and insect eggs.

How does one make a good compost?

It is important to:

(A) mix several different kinds of material together;
(B) keep the compost heap moist by watering it in dry weather; ***and***
(C) turn it over from time to time, especially if it becomes very wet.

More details can be found in GTZ (1976) and Napier and Robbins (1989) in sheet C 61-A).

When is a compost particularly valuable?

Being rich in nutrients and organic matter, well-made compost is an especially useful addition when:

(a) the nursery or potting soil is hard, very sandy or full of clay (C 23);
(b) it is naturally infertile, or has been degraded (D 22 in Manual 4);
(c) there are enough people at the nursery to collect the materials to make it; ***and***
(d) alternative materials are unavailable, too distant or too expensive.

For any nursery, compost is a simple way of replacing some of the continual outflow of nutrients in planting stock.

Does a mulch do that as well?

Yes, it is one of the reasons for using it. Besides adding organic matter and nutrients, mulching could also help in the nursery by:

(1) **suppressing weed growth** in:
  (a) seed beds before and after sowing, and transplant beds before and after use;
  (b) containers in which young trees will stay for some time;
  (c) planted stockplant lines that are being repeatedly harvested for cuttings (A 27 in Manual 1);
(2) **protecting seed beds** containing fairly large seeds against:
  (a) overheating and rapid drying out of the surface soil;
  (b) the direct impact of heavy raindrops on germinating seedlings;
  (c) washing and/or blowing away of fine soil particles; ***and***
(3) **reducing the deposition of silt** on nursery paths and roads.

Mulch is also very useful when young trees have just been planted out (Manual 5).

Compost heap.

Wouldn't mulching encourage young seedlings to rot?

It might do if:

(a) it was applied during very wet weather;
(b) large, thick leaves were used; ***and***
(c) the mulch contained a lot of spores of the *damping-off* fungus (C 45).

But it would be unlikely to when:

(1) used in drier weather;
(2) lighter, chopped material was used; ***and***
(3) the mulch was lifted to aerate it after heavy showers.

Wouldn't it be simpler just to add fertilisers?

Yes, this can be an easy way of adding nutrients; but most fertilisers:

(A) do not provide the other benefits of composts and mulching; ***and***
(B) depend on external inputs, rather than sustainable management by recycling existing nutrients.

But surely fertilisers might be needed to get good growth!

Yes, sometimes they certainly could be. However, it is important to realise that fertilisers can have several disadvantages, such as:

(a) costing a lot to buy, and being heavy to transport to the nursery;
(b) causing damage to the roots of the young trees if too much is applied;
(c) often being quickly washed away during watering and by heavy rainfall; ***and***
(d) ending up contaminating water supplies (C 24).

What would be good reasons to add fertilisers?

They could be added to:

(1) **growing nursery plants,** if there are problems because of nutrient shortage or a need to change the pH (C 6, C 23, C 60);

(2) **potting mixtures** (C 6), especially when it is known that the:

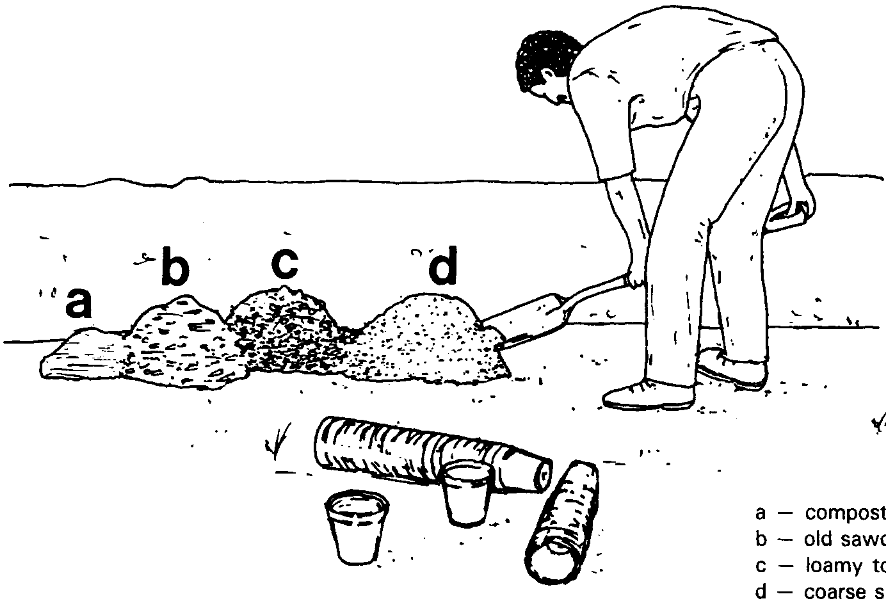
(a) components all lack a particular nutrient (C 14), or more than one of them, so that tree growth would be seriously hampered;

(b) young trees need to grow in the same pots for a considerable time; ***or***

(c) rates of growth need to be increased, so that trees will be large enough at planting time (C 34);

(3) **stockplants** that are being repeatedly cut back (A 27 in Manual 1); ***and***

(4) **research trees,** to maintain good, uniform growth (C 7) or as treatments in experiments (C 15).



Which ways can they be applied?

(A) **As ordinary fertilisers** in the potting mix or scattered lightly over a bed;

(B) **As 'slow-release' pellets** in the soil, which last longer;

(C) **Dissolved in water,** which is often useful, because:

(1) it can be done during the regular watering (C 43), for example every 1-4 weeks;

(2) nutrients can be applied at times when rapid growth is desired; ***and***

(3) 'feeding' with nutrients can be stopped or changed when the trees are to be hardened (C 47); ***or***

(D) **As a foliar feed** of very dilute micro-nutrients (C 14), sprayed on the foliage.

Whichever method is used, the fertilisers should be balanced (C 14) and not too rich in nitrogen (C 34).

How much fertiliser should I add?

This depends a great deal on what is already being supplied to the young trees in the nursery soil or potting mix, in the water supply and by closely associated micro-organisms (C 30-32). *"Little and often"* is usually a good motto for applying fertilisers. The doses for tree nurseries are generally less than those recommended to increase the yields of agricultural crops. A rough guide to start with might be:

(a) *Potting mixes:* 1-5 g of solid fertiliser per litre of soil, or 1.5 g/l for slow-release fertiliser;

(b) *Nursery beds:* 25-50 g of solid fertiliser per m^2, worked into the top 20 cm;

(c) *Dissolved in water:* 30-50 milligrams of fertiliser in 10-25 ml water per container (or 3-5 g/l in a watering can), washed off the leaves immediately afterwards.

How do I find out what suits my conditions?

Further information on fertilisers can be found in Carter (1987), Goor and Barney (1968), GTZ (1976) and Pancel (1993) in C 61-A, and from local manuals. If you think that fertilisers might be beneficial in your nursery you could do an experiment (C 15), in which for instance you might compare adding 0, 10, 25 and 62.5 g NPK per m^2.

Sample results: *average gain in height of experimental trees after 6 weeks.*

Treatment number	**0**	**1**	**2**	**3**
NPK added to bed (g/m^2)	0.(control)	10	25	62.5
Gain in height (weeks 0-6)	3.4	15.6	16.7	13.9
Significance of differences	***	n.s.	*	

(See sheets C 55 and C 69 for assessing and analysing your results)

When should I *not* use fertilisers?

Avoid adding them:

(1) when the potting or nursery soil is rich enough anyway, for this would be unnecessary;
(2) if adding mycorrhizal or root nodule inoculations (C 30-32), because this is likely to discourage infection;
(3) to the rooting medium when rooting cuttings (A 35 in Manual 1), since for some time there are no roots to absorb them;
(4) to the germination medium (Manual 2), as seeds usually contain enough stored nutrients to last until they are transplanted;
(5) to the leaves when they are wet, for they could be damaged unless it is washed off at once;
(6) if young trees are under water stress, or are actually wilting, since fertilisers could increase the stress still further (C 41);
(7) just after transplanting or repotting, as the roots should grow into the new soil first; ***or***
(8) just before planting out, because this would stimulate rapid shoot growth at an inappropriate time (C 34, C 47).

Are there some cheaper substitutes for commercial fertilisers?

Yes, there are several locally available sources, such as:

for nitrogen: the leaves, roots, twigs and small branches of nitrogen-fixing crop plants, bushes and soil-improving trees (C 32);
for phosphorus: bone meal, made by grinding up animal bones; ***and***
for potassium: ash from recent wood or charcoal fires.

How would I use them?

For transplant beds, you could apply:

nitrogen as a compost dug in or mulch laid on the soil; by growing a green manure and digging it in; or by letting leaves of suitable shade trees or hedges fall on it;
phosphorus worked into the topsoil every year or two; ***and***
potassium as a top dressing.

For potting mixtures, an appropriate NPK supplement could be added where needed.

Micro-organisms, nutrients and tree growth C 34
- *size of planting stock*

How big should I grow my nursery trees?

This depends a great deal on:

(A) the tree species, and sometimes the particular genetic origin used (C 4-5);
(B) the conditions you grow them under in the nursery; ***and***
(C) what will be the climate, terrain and soil type of the planting site (D 11-12 in Manual 4), and what other plants will be growing there (D 14).

Do I want the maximum possible growth?

Generally no, because very vigorous growth in the nursery usually means:

(a) **larger leaves** that lose a lot of water and are easily torn (C 12-13);
(b) **taller stems** that may be inconvenient to handle and more liable to damage; ***and***
(c) **large containers** to accomodate very big root systems, which will be heavy to carry and perhaps difficult to plant (C 6, C 47); ***though***

Occasionally yes, for example when:

(1) trying to get young trees quickly to the desirable size for planting;
(2) speeding up the early stages in multiplying a new clone (A 20 in Manual 1); ***and***
(3) in certain types of experiment (C 15), when studying the potential for rapid growth.

For enrichment planting of woodland (D 24 in Manual 4) with trees such as *Pterocarpus,* success has been achieved in India by growing nursery trees rapidly in very rich soil in large containers, and planting them when 3-4 m tall.

Are there any general guide-lines?

(1) In most cases, bigger doesn't necessarily mean better planting stock.
(2) Root systems need to be more extensive than shoot systems (C 4).
(3) The greater the likely climatic stress (C 41) after planting, the better the *quality* of the young trees needs to be.

Why should there be more roots than shoots?

Because when trees go to the planting site:

(a) their stems and leaves have a waxy protection against drying out on their surfaces, and the small holes in them can be closed (C 12). Thus their structure allows them to tolerate a certain amount of water stress (C 41);
(b) the surfaces of young roots lack protection, and when disturbed they are less able to withstand drying out (C 11); ***and***
(c) unless the roots can deliver enough water to prevent severe water stress in the shoot (C 13), the newly planted tree will suffer a severe check to growth, shrivelling of leaves, die-back of shoot tips or death.

How can I control tree size in the nursery?

Primarily by choosing an appropriate sowing date for seeds (Manual 2) and the date of taking cuttings for rooting (Manual 1), so that the young trees should have grown to the desired size by the expected time of planting;
Secondarily by:

(A) choosing the size of the containers used (C 6, C 15);
(B) using a richer or a less rich potting mix, and nursery soil for beds; ***and***
(C) discouraging roots from growing out of containers, and root pruning young trees growing in beds (C 4).

Can't I alter the size just before planting?

Well, this could be done, for instance by:

(1) cutting off some or all of the foliage;
(2) pruning back the shoot system; ***and/or***
(3) breaking or chopping off some of the root system.

Isn't that a bit drastic?

Yes it is, particularly reducing the root system just then, for it is the key to successful establishment (C 4, C 11). Aim instead to control the way roots grow in the nursery rather than having to do a 'hacking' job at planting time.

Nevertheless, some commonly used types of planting stock do involve considerable pruning at the last minute (C 47).

What constitutes a good nursery root system?

One that is of a suitable size and type (C 4) to sustain the young tree:

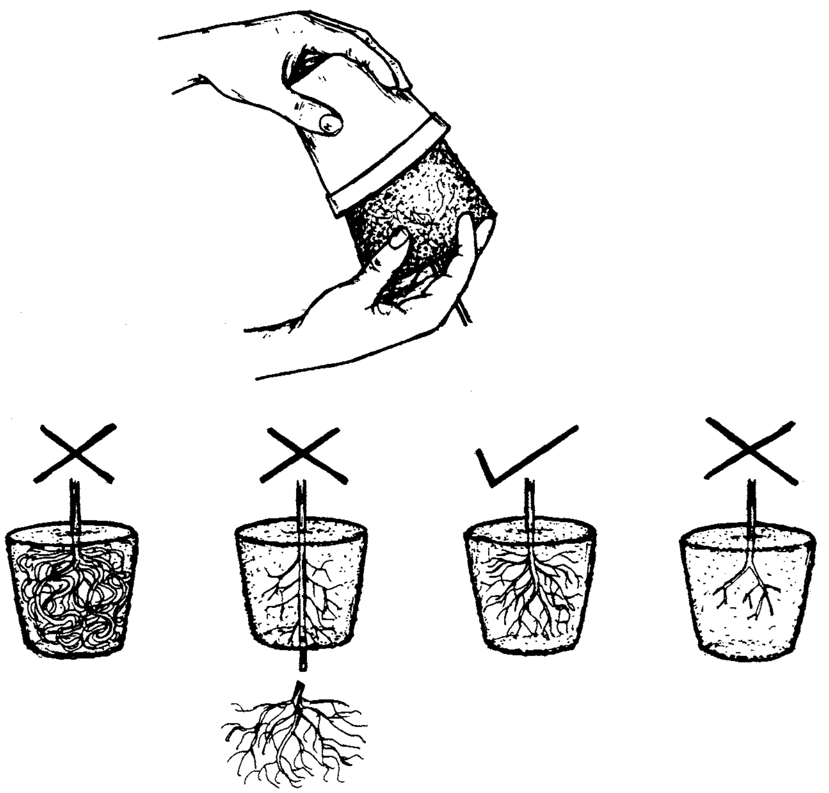
(A) *while in the container:*
- (1) being grown on in the nursery;
- (2) transported to the planting site;
- (3) waiting to be planted; ***and***

(B) *after planting:*
- (1) without the attention previously given in the nursery;
- (2) while making new root growth rapidly, to become established; ***and***
- (3) soon being able to support new shoot growth.

Is it mainly a question of size?

Well, the **number** and **length** of the roots are two of the important points. If the root system is:
too small, it is unlikely to be able to provide enough water (C 13) or nutrients (C 14) for the young tree to survive, let alone grow well; ***but if it is***
too large, the tree may be difficult to plant properly (Manual 5).

In general, the root system should be as big as can easily be planted well.



What else is important about the roots?

The **type of roots present** is as important as the size of the root system.
In the great majority of species, good planting stock needs:

(a) a lot of short roots, instead of a few long ones;
(b) a bushy root system, rather than a single taproot (C 4);
(c) many fine, absorbing rootlets as well as some thicker ones that can grow into structural roots (C 11);
(d) a compact root ball holding a good deal of soil, or a soil block, rather than bare roots;
(e) fairly straight roots, instead of ones that go round and round the inside of a container (C 6).

Inoculation with closely associated micro-organisms (C 30-32) may also make a considerable difference to how well a root system gets established.

But how can I know what is going on?

(A) By checking regularly to see if trees are rooting through from containers into the soil;
(B) By gently tapping out a few plants, if they are growing in *tapered* containers (C 6), examining the roots on the outside of the root ball, and then putting the tree back into its pot;
(C) By washing out the root systems of a few sample plants from time to time, if there are some spare trees, and the batch is not specially valuable; ***and if not***
(D) By looking at some root systems when the trees are being potted or transplanted (C 42).

Do I need to prune the roots back at this stage?

Sometimes no, for example if:

(a) potting up seedlings from shallow trays or small pots into larger containers;
(b) transferring rooted cuttings from the rooting medium to pots (A 35, A 53 in Manual 1);
(c) growing tree species that naturally form a bushy root system;
(d) handling species that respond badly to root damage; ***or***
(e) there is a serious risk of root rotting diseases (C 45); ***but***

Sometimes yes, for instance when:

(1) potting up seedlings with long roots out of a seed bed;
(2) handling older *wildings* (C 2; and Manual 2);
(3) growing species that tend to make a strong taproot and few branch roots; ***or***
(4) long roots are growing out of containers into the soil beneath. Here you could:
   (a) twist the pots round, or move them, every 1-3 weeks;
   (b) set the containers on flat stones, paving slabs or concrete; ***or***
   (c) raise them clear of the ground on wire mesh or boards.

What else could I do if the roots aren't as I want them?

You might try different:

(1) dates of potting up (C 42);
(2) types or sizes of container, for example root-trainers (C 6, C 61-B);
(3) potting mixes;
(4) amounts of shade, and rates of reducing it (C 41, C 47).

Won't all that mean a lot of work?

Not necessarily. As well as following the suggestions in manuals (C 61-A), you could:

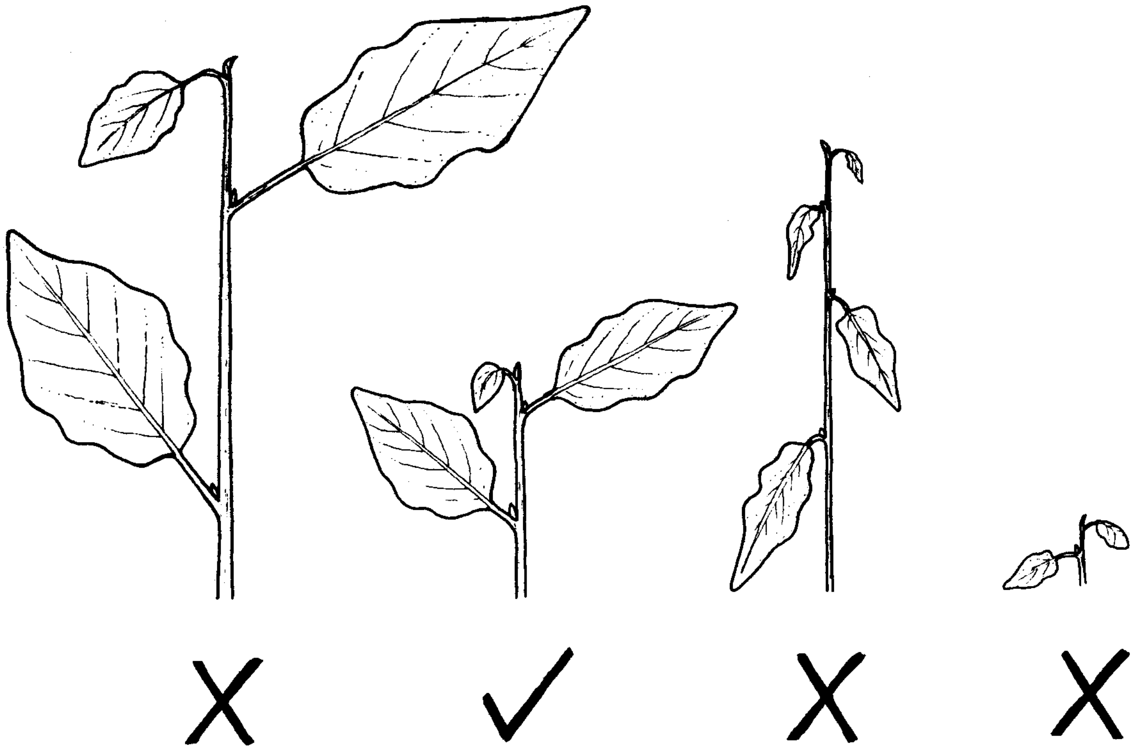
(a) check with other tree growers as to how they obtain good root systems;
(b) compare these techniques with your existing methods in an informal trial; ***or***
(c) do a formal experiment looking at various possible modifications (C 7, C 15).

It is worth a good deal of effort to find ways of growing really good planting stock.

How big should the shoot system be?

(1) No bigger than the roots can support during the first few weeks after planting;
(2) Not too tall to be transported conveniently; ***and***
(3) Not too thin and spindly, or the plants may fall over and be blown about in the wind.

A sturdy, shortish shoot system may often be the best, even when there are weed problems in the planting site (Manual 5).



What about the leaves?

Aim for a potting mix and growing conditions that give **plenty of moderate-sized, dark green leaves.** A lot of nutrients in the potting soil (C 6, C 33) generally mean vigorous stem growth and large leaves (C 12), which may:

(a) lose a lot of water, putting the young tree under extra stress (C 13, C 41);
(b) be more liable to get damaged.

So big leaves are best avoided, except when:

(1) the number and/or size of leaves is to be sharply reduced before planting (C 47), or the trees are going to be planted when naturally leafless;
(2) growing stockplants, where the leaves will be trimmed before taking the cuttings (A 41 in Manual 1); ***or***
(3) experience has shown that they can be valuable on a particular species.

And what about the buds and branches?

In some tree species, it is important to have a good bud at the tip of the leading shoot, because lateral buds and branches:

(a) do not readily replace leaders (as for example palms and pines); ***or***
(b) grow at an angle, rather than forming a good replacement leader; ***but***

In many other cases, specific types of bud are unimportant because:

(1) new vertical leaders are produced freely from branches or the lower part of the stem after damage or cutting back; ***or***
(2) a bushy shoot habit is desired.

In species which grow by flushes, it is preferable for the buds to be inactive or growing slowly when the trees are planted out.

Does the main stem need to be straight?

Yes, this is generally best for:

(a) trees being grown for timber or raw materials (D 36-37 in Manual 4);
(b) tall shade or ornamental avenue trees (D 41); ***but***

It may not matter for:

(1) fruit trees (D 33) and ornamental shrubs (D 41);
(2) trees for forage or firewood (D 34-35);
(3) plants for hedges (C 46) or shelterbelts (D 41).

How can I keep the leader straight?

In several ways, including:

(a) selecting genetic origins that are naturally straighter (C 5);
(b) choosing a nursery site that is sheltered from the wind (C 20, C 25), and if necessary tying each plant to a small cane;
(c) avoiding over-rich potting soils (C 6);
(d) cutting out one leader if the tree forks; ***and***
(e) trimming back all but one replacement branch after damage.

What other things influence the balance between roots and shoots?

The internal control systems of the tree (C 14) are affected by:

(A) **Overhead shade:** young trees *kept* in very heavy shade tend to have elongated stems and a poor root system.
NOTE: ***this does not apply to temporary heavy shading for a week or two after potting up (C 41);***
(B) **Self-shading:** naturally bushy and fast-growing species can easily become spindly if they shade each other and their own lower leaves. Spacing out the pots is the answer, in a way that stops them falling over;
(C) **Pot size:** trees grown in very small containers can easily have more top than root;
(D) **Nutrients:** plants grown with a lot of nutrients often have a smaller root system relative to the shoot system than those in less rich soils; ***and***
(E) **Closely associated micro-organisms** that form mycorrhizas or nodules (C 30-32) may in some cases mean that the tree's shoot system is relatively larger than its actual root tissue.