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Pedersen, Anders P.; Olesen, Kirsten; Graudal, Lars Ole Visti

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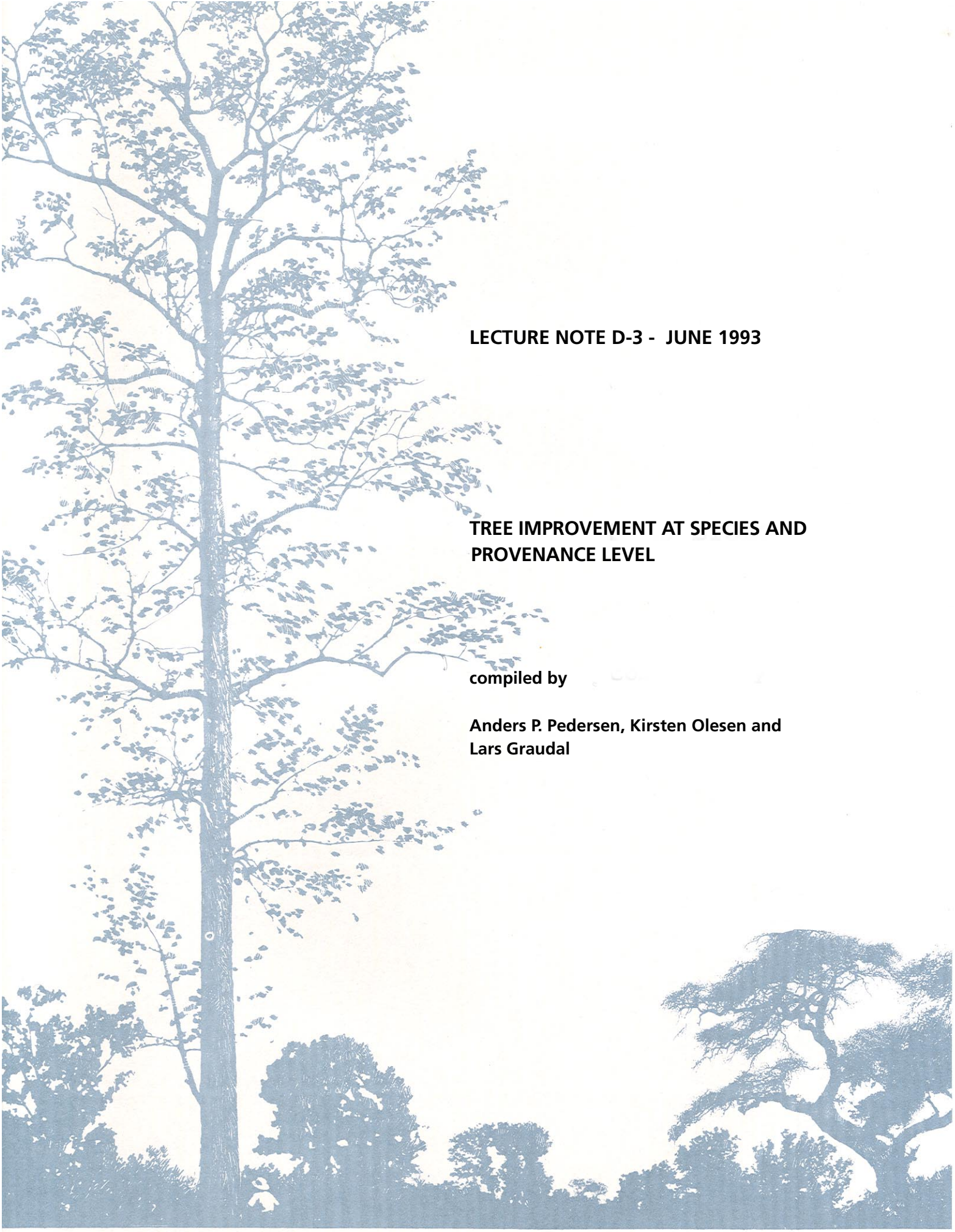

LECTURE NOTE D-3 - JUNE 1993

TREE IMPROVEMENT AT SPECIES AND PROVENANCE LEVEL

compiled by

Anders P. Pedersen, Kirsten Olesen and Lars Graudal

DANIDA FOREST SEED CENTRE

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Authors
Anders P. Pedersen, Kirsten Olesen and Lars Graudal

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1. INTRODUCTION

A tree-improvement programme involves all practices designed to produce genetically more desirable trees.

It is important that any tree improvement programme is planned and coordinated in accordance with the purposes and priorities of national tree planting programmes in such a way that emphasis is placed on species of present or expected future importance and duplication of trials is avoided.

The objective of any tree-improvement programme should be made clear and well-defined before the programme is initiated.

The purpose of a tree-improvement programme is to optimize one or more of the following points

(1) the quality of end use as timber, fuelwood, fodder, shelter, etc.
(2) survival (adaptation to climate and environment)
(3) resistance to pests and diseases
(4) growth rate.

Wrong selection as to growth rate will give less favourable results, while wrong selection as to adaptability, resistance and, possibly even more, end use may result in great losses or even complete disaster.

A tree improvement programme is usually divided into different stages:

(1) selection of desirable species
(2) selection of desirable provenances within a species
(3) selection of desirable families and individuals within a provenance
(4) controlled breeding, incl. recombination and hybridization.

The present Lecture Note deals with tree improvement at species and provenance level. Tree improvement at family and individual-tree level is dealt with in Lecture Note D-4. Although the levels are treated separately in this series of lecture notes, the different levels can be, and often are, combined.

The importance generally increases from selection of individuals through selection of provenances to selection of species, making selection of species the most vital choice in any tree improvement programme.

Reference is made to Lecture Note D-1 'Introduction to Tree Improvement', D-2 'Introduction to Forest Genetics', A-2 'Benefits from Tree Improvement', and A-3 'Natural Variation as a Basis for Tree Improvement'.

2. DEFINITIONS

A species is commonly defined as a group of individuals of similar morphology that are able to breed with each other but not with individuals from outside this group. There is, however, no general agreement on the degree of similarity in order that individuals are placed in the same species.

Usually it is not difficult to distinguish between the species as they vary in many characteristics, but in cases of doubt botanists should be consulted for verification.

The geographic location of a seed source is called its **provenance**. Within a species, provenances may vary e.g. in growth and adaptability on different sites.

3. SELECTION

3.1 Preparatory Considerations for Selection

The great differences between species that are immediately visible in nature makes it generally accepted that selection of species is the most important choice in any tree planting programme as well as in any tree improvement programme. It is in fact here all tree planters consciously or subconsciously begin.

It is a well-established fact that choice of seed source within a species is also of great importance. Lack of success in tree planting may be due to the fact that the chosen seed source comes from an area with different climatic and environmental conditions than those of the planting site, and that the adaptation to the growth conditions has made the seed source unsuited for the new planting site.

The law of diminishing returns is fundamental in tree improvement: as one gets closer to the ideal, costs and efforts become greater for each added unit of gain. As it can be seen in Figure 1, the increase in gain is greatest in the beginning of the programme, covering the stage of choice of species and provenances, which emphasizes the great importance of choice of species and provenance.

The natural distribution of some species covers large areas, other species have a limited natural distribution. The greater the distribution, the greater is the likelihood of a wide genetic variation because of different adaptation to the different local environments.

Genetic variation is the basis of tree improvement. Some species show large variation and some species are more uniform. The greater the variation, the greater the gain likely to be obtained from selection, and it may not be worth including a very uniform species in an improvement programme beyond the species and provenance level.

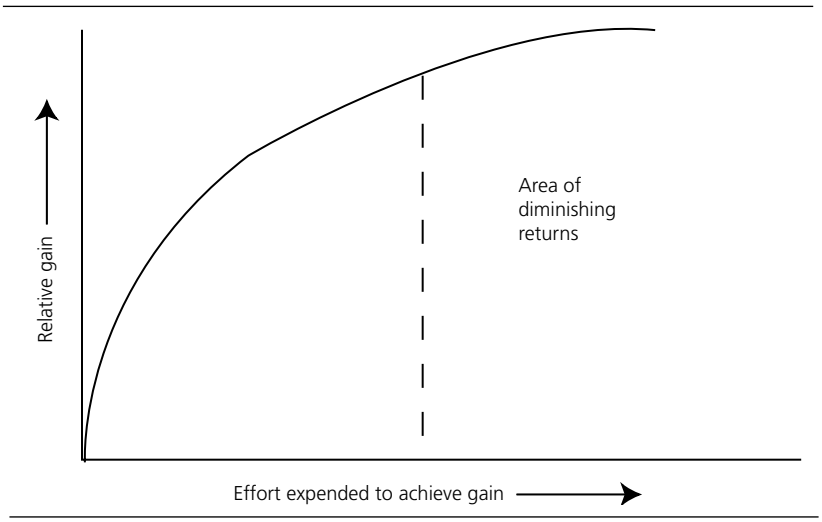

Figure 1. Gain from tree improvement as a function of increasing efforts; the so-called law of diminishing returns. (From Zobel and Talbert, 1984). Tree improvement at species and provenance level is shown on the left side of the figure, advanced tree breeding based on single trees is shown on the right side.

If the country has a national tree planting programme, it should be remembered that the selection of species for tree improvement should be made in accordance with this programme.

Local knowledge and experience from existing forest stands (of natural or introduced species), earlier trials, and botanical or private gardens may give a first hand indication of the potential of possible species.

Further knowledge should be gathered through study of available literature and correspondence or personal communication with forest colleagues in the country and abroad.

Results from species and provenance trials in other regions or countries may be useful if they come from the same or similar climatic zones and from similar environments, i.e. soil etc.

If information is lacking, a number of species is tried in small plots on sites that represent the proposed afforestation area. Provided the locations are carefully selected to sample the range of planting sites, extrapolation of performance from small plots to the whole afforestation area should not involve too great a risk.
A small wisely planned species trial tailored to the staff and financial resources available is often more likely to provide useful information than larger trials that are less well planned and implemented.
In species testing, it is important to choose a limited but sufficient number of seed sources/provenances of each species to avoid misjudgement of the species because of inappropriate representation of it. Ideally, the seed sources should represent the genetic variation in adaptability, variability, flowering and fruiting, and other important characteristics. In practice, one will have to do with less. Provenances from areas where the species seems to have its optimum should be included, and it may be fruitful to include seed sources from 'extreme' environments where they may have developed in a particularly appropriate way to overcome extreme conditions.

When introduction of new species is considered, the following should be taken into consideration:

(1) The performance and characteristics of the species in its native habitat
(2) The climatic and edaphic similarity between regions of origin and use.

Generally, species from similar or somewhat harsher climates as compared to the expected planting site will be most promising and safest to select. However, species from richer sites or more generous climates may possess greater growth potentials, which may give surprisingly good results. An example is *Prosopis juliflora* from Central America, now naturalized, vigorous and widespread on very dry and harsh sites in India and Africa. A famous example of a species from harsh sites performing well and even replacing local species on rich sites is *Eucalyptus camaldulensis* from Australia which performs well on many rich sites in Africa, Asia, America, and the Mediterranean.

In the case of introduced species, seed should whenever possible be collected from stands of known origin.

It is important that the seed sources are precisely identified in order that it is possible to go back for more seed of desirable sources and avoid the undesirable ones.

For promising species with naturally wide geographical or ecological ranges, further provenance testing is essential.

3.2 Selection Criteria

When species (or provenances) are to be selected, it is important to remember the purpose of tree planting and the priorities laid down in the national forest policy.

Choice of right species/provenance is a vital decision in any planting as well as improvement programme. The aim is to provide species/provenances that:

(l) will fulfil the purpose of planting,
(2) are well-adapted to the planting sites in question.

It is also important to remember that the characteristics we observe in trees are governed partly by genetics, partly by environmental influence.

Characteristics such as the form of the leaves or needles, flowers, fruits, and seeds, so-called qualitative traits, are to a great extent governed by genetics and are inherited through generations. Most of these are the characteristics that are decisive for the distinction between species. Characteristics such as growth rate and production of fruits or gum are greatly influenced by the environment. Generally, ‘either-or’ characteristics tend to be qualitative, having high heritability, whereas ‘more-or-less’ characteristics tend to be quantitative, having low heritability.

It is important to distinguish between natural and introduced species. Natural populations will normally after generations of natural selection be well adapted to its site. An introduced population is usually less adapted to the site on which it is growing. However, after a number of generations, such introductions may have adapted and become land races. Indigenous species are often safest but not necessarily best.

There are many subtle interactions between environment and trees that will determine the success or failure of a plantation, and there is no substitute for adequate species and provenance trials on typical sites as a basis for large scale afforestation.

4. TESTING

4.1 Species Trials

Species selection may pass through a number of trial stages that eventually will end in the selection of a few provenances of a few species well suited for the purposes and well adapted for the areas in question.

The stages may be as follows:

(1) **species elimination trials**, where a large number (20-40) of possible species is tested in small plots on one or a few sites for a short period (1/10 to 1/5 rotation) to determine survival and promise of reasonable growth; usually a few (2-3) sources/provenances of each species is tested.

Generally, local populations should always be included as these would be easily accessible and cheap future seed sources if they turn out to be competitive.

(2) **species testing phase/growth trials**, where a reduced number (5-10) of promising species are tested and compared in larger plots for longer periods (1/4 - 1/2 rotation); usually a larger number (3-5) of sources/provenances of each species is included, particularly for species with large natural distribution and great variation.

(3) **species proving phase/pilot plantations**, where the superiority of a few probable species are confirmed under normal plantation conditions.

4.2 Simple Designs of Species Trials

It is important to be realistic as to the dimensions of the trial and to carefully consider the ability to cope with different designs, assessment methods and analyses of the results. Robust and simple trials can give useful results and are better than more sophisticated trials if these are un-manageable by the staff or turn out

to go beyond the financial resources of the project or research station and therefore have to be left unfinished.

Figure 2 and 3 show useful and simple trial designs.

Treatment (Species)	Trees		Treatment (Species)	Trees	
15	x x x x x x x x x x		4	x x x x x x x x x x	
9	x x x x x x x x x x		6	x x x x x x x x x x	
4	x x x x x x x x x x		17	x x x x x x x x x x	
3	x x x x x x x x x x		2	x x x x x x x x x x	
7	x x x x x x x x x x		7	x x x x x x x x x x	
12	x x x x x x x x x x		13	x x x x x x x x x x	
13	x x x x x x x x x x	B	14	x x x x x x x x x x	B
10	x x x x x x x x x x	L	15	x x x x x x x x x x	L
5	x x x x x x x x x x	O	1	x x x x x x x x x x	O
20	x x x x x x x x x x	C	20	x x x x x x x x x x	C
2	x x x x x x x x x x	K	10	x x x x x x x x x x	K
8	x x x x x x x x x x		18	x x x x x x x x x x	
19	x x x x x x x x x x	I	9	x x x x x x x x x x	II
18	x x x x x x x x x x		16	x x x x x x x x x x	
6	x x x x x x x x x x		12	x x x x x x x x x x	
16	x x x x x x x x x x		3	x x x x x x x x x x	
14	x x x x x x x x x x		19	x x x x x x x x x x	
17	x x x x x x x x x x		11	x x x x x x x x x x	
11	x x x x x x x x x x		8	x x x x x x x x x x	
1	x x x x x x x x x x		5	x x x x x x x x x x	

Figure 2. A simple trial design suited for example for species elimination trials. It shows 20 species (treatments) in line plots with 10 trees in each plot in 2 replications.

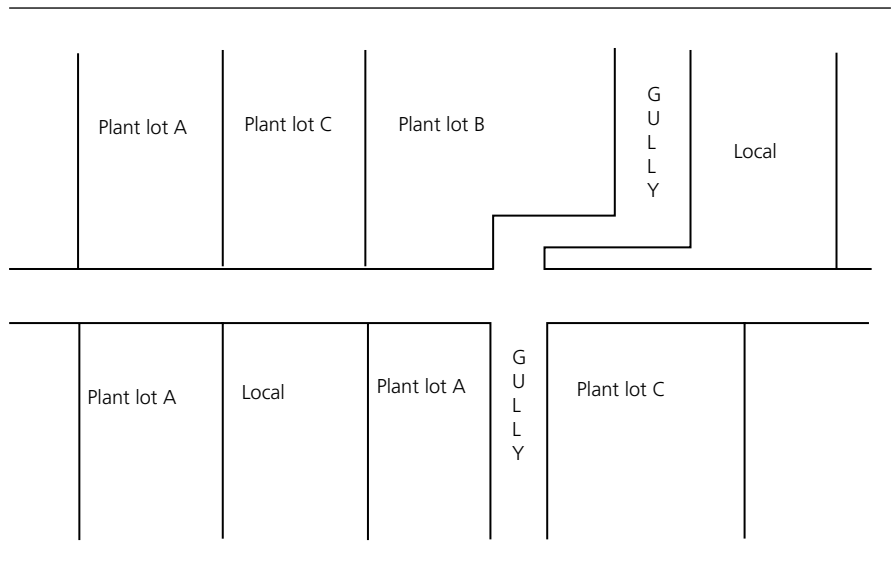

Figure 3. Sketch map of a practical example of a pilot plantation area showing three introduced (A, B and C) and one local seed source.

See further under 'Experimental Sites', below; more complicated designs are described in Lecture Note D-5 'Introduction to Principles in Design and Evaluation of Tree Improvement Experiments'.

4.3 Provenance Trials

A provenance trial, where many sources of a promising species are tested, is an essential tool for clarifying the extent of variation within a species.

For species with wide distribution, the selection of provenances may go through a number of phases:

(1) a range-wide provenance sampling phase,
(2) a restricted provenance sampling phase and
(3) a provenance proving stage.

In the initial phase, most often very little is known about the pattern of variation of the species in question, and qualified guesses have to be made on which provenances should be included based on environmental and distributional factors. 10-30 provenances are suggested in this phase, which usually lasts for 1/4 to 1/2 rotation.

As mentioned above, samples from areas where the species shows optimum performance should be included as well as areas with extreme environment and insular occurrences.

Additional samples should be taken where there are obvious and unusual phenotypic variation.

In large homogeneous areas, one has to make artificial borders to define provenance locality. It is recommended to make use of existing roads, rivers and other landmarks. It may be useful to use a grid system where the area is divided systematically in squares, and samples are taken from each or from a fixed frequency of the squares. Systematic sampling may reveal the direction and strength of possible trends in variation that are not visible in the field.

In order that random differences between trees can even out so that the seed sample represents the population well, it is usually recommended that seed is collected from 25-30 unrelated trees on average, the numbers mentioned by different authors ranging from 10 to 50.

In order to avoid narrowing down the variation through selecting trees which are closely related genetically (or trees which have an abnormally high incidence of self-pollination), it is generally considered that seed trees in natural stands should be between 100 and 300 m from each other. Adjacent trees in plantations are usually not closely related because the seed has been bulked and there need be no restrictions on spacing of seed trees.

Common standards suggest selecting 'average or not less than average' trees of dominant or co-dominant trees in 'average' stands. More detailed guidelines on which trees to collect from can, for example, be found in Willan (1985).

If possible, national standards should be included in order that new sources can be compared with well-known or acknowledged sources.
Local land races of exotics should also be included as these often compare favourably to new introductions.

In the second phase, 3-5 promising provenances may be tested for a duration of 1/2 to 1 rotation.

In the third phase, only 1 or 2 provenances will usually be tested in pilot plantations.

The different phases of species and provenance trials are often run more or less concurrently in order that results may be used for further trials as they become available. The outline in figure 4 shows an example.

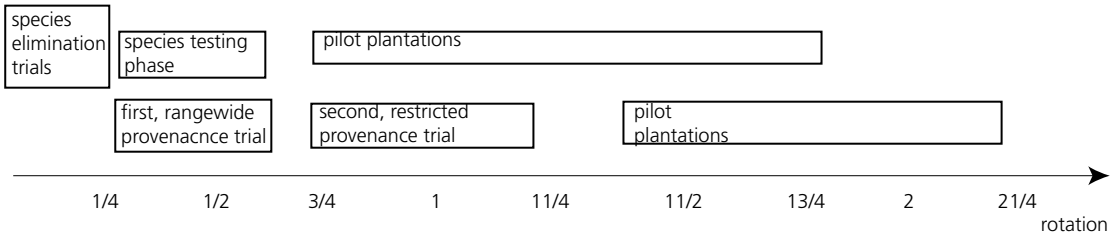

Figure 4. An example of the possible timing of different stages of species and provenance trials.

A given tree improvement programme will usually only comprise some of the total outline.

4.4 Experimental Sites

Each site should be as uniform as possible.

The sites should be representative of intended plantation areas to help ensure validity of experimental results.

Field trials of forest trees cover a large area which inevitably includes systematic variations in soil, micro-climate, topography, aspect, previous use, etc. The simplest method of avoiding population differences being confused with systematic site variation is by blocking. The experimental site is divided into blocks, each corresponding to the most important environ-mental sub-divisions; see the examples in figures 5 and 6. For most types of design the blocks should be of similar size, each having the same number of experimental plots.

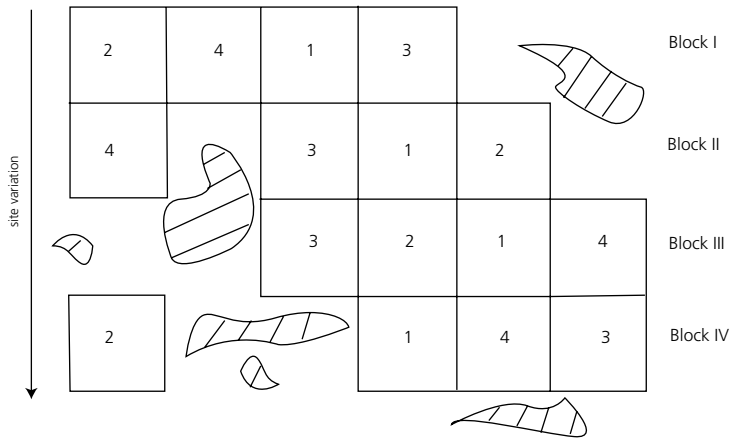

Figure 5. Example of block distribution. The site varies systematically in the direction of the arrow and there are rock outcrops as indicated (after Burley and Wood 1976).

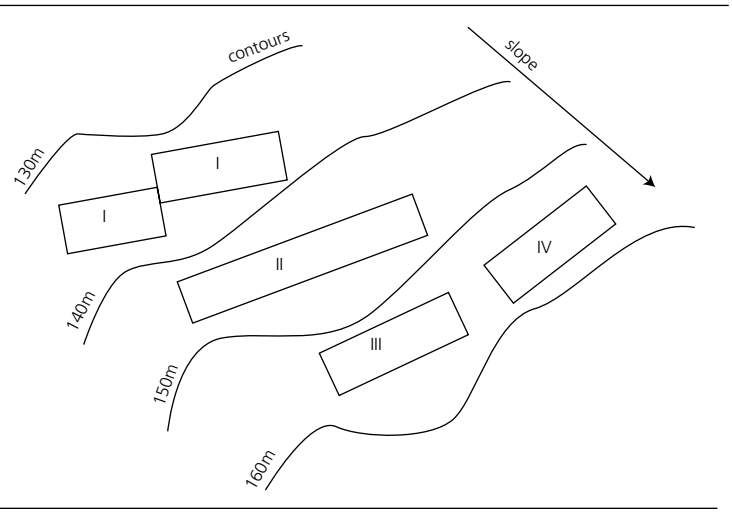

Figure 6. Example of block distribution on hill slope (after Burley and Wood 1976).

The number of replications should be 'adequate'. Theoretically, the precision of comparisons of population means is proportional to the square root of the number of replications. In practice, however, there is one main factor which reduces the gain in precision; that is, for any given plot size and number of populations, more replications mean a larger experiment and, consequently, a greater likehood of site heterogeneity.

It is common practice to have 3-4 blocks each of up to 25-30 plots. See the outline on page 10.

Assignment of each species or provenance to the plots at random is the best way to avoid bias in the estimation of population differences (through a particular population being planted on all 'good' or all 'bad' plots).

With increasing numbers of populations the simpler designs become less efficient because both random and systematic variation within replicates tend to

increase. This problem is approached in two ways: (a) plots are arranged in blocks which are smaller than a full replicate or (b) plot size is reduced. These methods are described in more detail in Lecture Note D-6.

More details on establishment of field trials and their assessment are found in Lecture Notes D-5 and D-6.

4.5 Outline of Species and Provenance Trials

Species elimination trials: 20-40 possible species; 2-3 provenances of each; duration 1/10 to 1/5 rotation; minimum plot: 5 trees in line plot; 'maximum' plot: 25 trees (5 x 5). 2 replications (blocks).

Species testing phase: 5-10 promising species; 3-5 provenances of each; duration 1/4 to 1/2 rotation; plot size: 16-25 trees (4 x 4 or 5 x 5) plus a 1-2 row buffer. 3-4 replications.

Species pilot plantation: 3-5 best species; 1-2 provenances of each; duration up to normal rotation; minimum plot: 100 trees (10 x 10) plus a 2 row buffer; maximum plot: normal stand size for plantation use.

First, range-wide provenance trials: 10-30 provenances; duration 1/4 to 1/2 rotation; plot size: e.g. 25 trees (5 x 5) plus a 1 row buffer. 3-4 replications.

Second, restricted provenance trials: 3-5 provenances; duration 1/2 to 1 rotation; plot size e.g. 100 trees (10 x 10) plus a 1 row buffer.
3-4 replications.

Provenance pilot plantations: 1-2 provenances; up to normal rotation in normal stand size.

Number of seed trees per sample of each provenance: generally recommended 25-30 unrelated individuals.

Amount of seed for each provenance sample: sufficient seed for about 12.000 plants to cover the total range of trials from species elimination trials to provenance pilot plantations (the latter of one ha).

5. USE OF TRIAL RESULTS

Tree improvement programmes take time. But it should not be necessary to wait for many years for the very best plant material. While a tree improvement programme is in progress, it should be considered how immediate seed supply can be improved by using the best currently available seed or plant material.

Recommendations of tested species and provenances should be issued as soon as trial results become available.

Species and provenance trials will usually result in the elimination of undesirable species or provenances, whereas the desirable ones may be used immediately for new plantations or included in further tree improvement programmes at species and provenance level, later at family and individual tree level. Reference is made to Lecture Note D-4.

When superior seed sources have been identified in provenance trials, new stands of these should be established for future seed supply in order to provide enough seeds of the desirable provenances and to avoid contamination from inferior trees nearby, but also to secure the conservation of the good seed sources for the future.

Reference is made to Lecture Note D-7 and D-8, 'Mass Production of Improved Material', 1 and 2.

Tree improvement is usually a non-ending process, where new species and provenances are tested to achieve even better planting results in the future.

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