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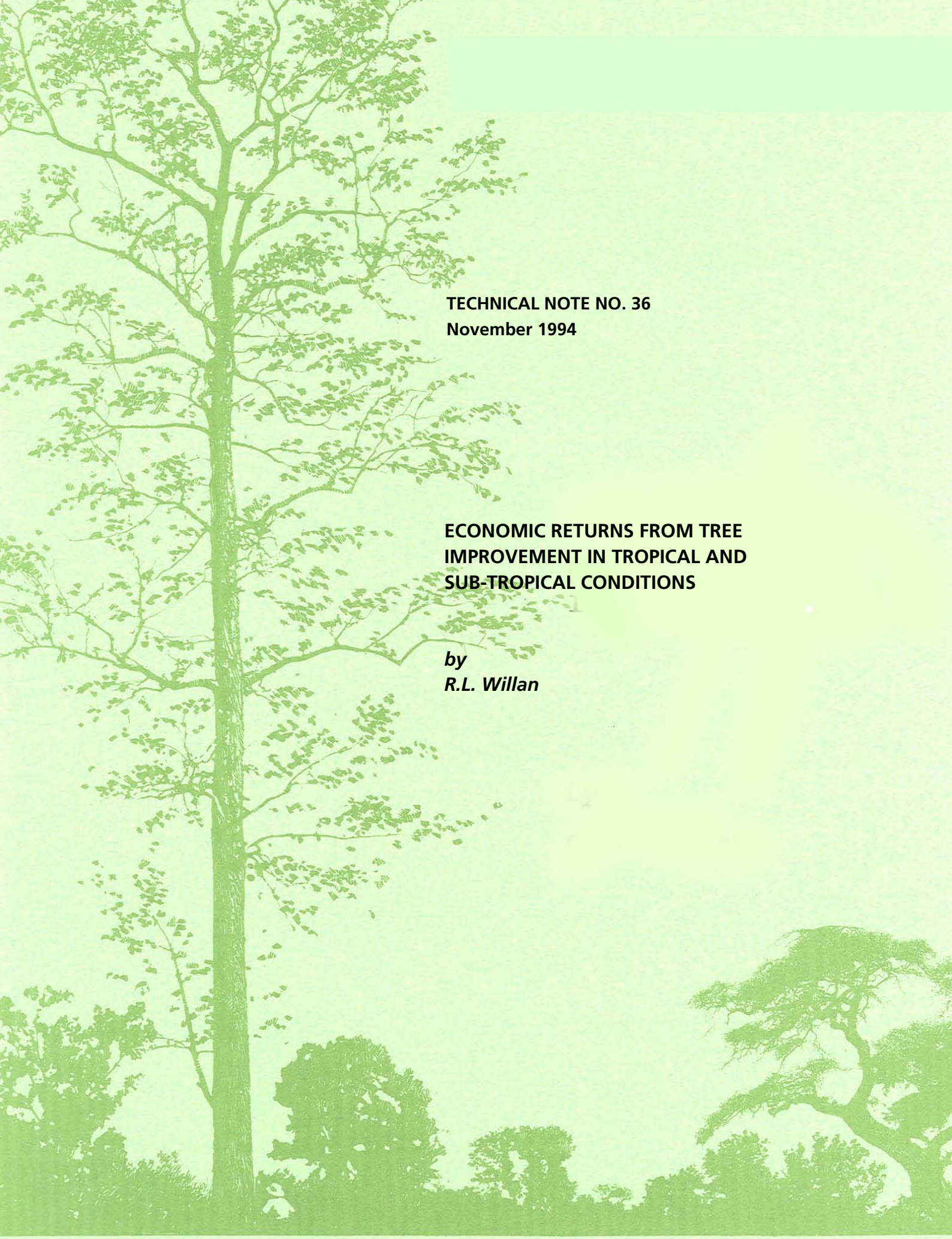

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ECONOMIC RETURNS FROM TREE IMPROVEMENT IN TROPICAL AND SUB-TROPICAL CONDITIONS

by
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DANIDA FOREST SEED CENTRE

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1. INTRODUCTION

A number of accounts have been published in the past on the economic returns to be expected from tree improvement. Most of them refer to experience in temperate conditions. The present note attempts to summarise evidence on the returns to be expected from tree improvement in tropical and sub-tropical conditions.

"Tree improvement" in this context is considered as covering genetic improvements obtained by selection, breeding and use of variation within a species. The gains obtained through selection *between* species are not discussed. The subject of species selection and testing is in itself very wide-ranging and has been discussed in numerous publications, e.g. "A Guide to Species Selection for Tropical and Subtropical Plantations" (Webb, Wood and Smith 1980). For the purposes of the present note, it should be assumed that within-species improvement is to be carried out within a species which is reasonably well-adapted, i.e. capable of surviving and growing, at least in respect of some of its provenances, on the sites where it is to be planted.

Within such a species, possible improvements may be conveniently subdivided as derived from:

(a) Selection between popUlations (varieties, races, provenances, seed sources),
(b) Selection of a number of individual parents within populations,
(c) Controlled breeding, including recombination and sation between selected provenances, parents or progeny,
(d) Vegetative propagation to multiply clones of superior s, without introducing new variation caused by sexual reproduction.

Most of the evidence available to date refers to the first two of these categories.

Growth rate, whether in height, diameter, basal area or volume, is the trait most commonly measured for improvement. It has the advantage of being easilt expressed in quantitative terms. Volume is often used for older stands, height and diameter for young ones.

Measurement of a sample of trees for specific gravity enables volume production per hectare to be converted to weight production per hectare. In the case of pulpwood, important additional components of wood quality include fibre length, cell width, cell-wall thickness and proportion of reaction wood.

Stem straightness and degree of branchiness (including incidence of forking) affect both handling costs and percentage conversion loss for industrial wood. Volume production can be converted easily into value production, whereas conversion into monetary terms of quality estimates, which are usually assessed on a scoring scale, often presents a problem. This is compounded if local timber markets have not yet developed clear price gradients dependent on diameter of log and degree of defect.

Security/risk is closely linked with adaptability to local climate and soils, and with susceptibility to local pests and diseases. In some cases cheap chemical treatments may be a more efficient means of control than a lengthy breeding programme (e.g. *Dothistroina* on *Pinus radiata* in New Zealand). In others, discovery or breeding of resistant genotypes may be critical to the success or failure of major planting programmes (e.g. resistance to *Marssonina* on poplars, blister rust on white pines). A particular problem in adaptability is the need to survive abnormally severe climatic conditions which may recur after only long long intervals. In some cases a non-indigenous provenance may grow best for a number of years but suffer catastrophic losses in an exceptionally cold or an exceptionally dry year.

An estimate of gains from provenance selection and the first cycle of individual selection within provenances (unrogued seed orchards), applicable to scale commercial plantations, is found in section 4. It will be shown that only a substantial annual planting area can justify the initial rather heavy outlay on plus tree selection. Small planting programmes cannot carry out their own selection programme economically.

Little is known about patterns of variation in the traits which characterise social forestry species, e.g. fodder production, chemical content, shade or soil improvement, but there is no reason to doubt that their potential for improvement in yield and quality is just as great as that of wood-producing species.

2. PROVENANCE RESEARCH

Most of the earlier provenance trials have been in temperate regions. One of the oldest is the series of IUFRO trials of Picea abies started in a number of countries in 1938. Results of the trial at Donjelt in S.W. Sweden at 41 years have been published recently (Ståhl 1986). In terms of volume production over the full period, the best provenance produced ten times the quantity of the poorest. Since the latter was represented by only one plot, it is more realistic to compare the best with the poorest of the fully replicated provenances (5 times); in this case the best was three times as productive. The improvement of the best over the average of all provenances was 46%, while that of the best over the local unimproved provenance was 39%.

Other conclusions from this trial are that;

1. The better provenances could be selected on the basis of height growth from about 8 years, or about one eighth of the usual rotation, in this species.

2. A difference in height of 0.5 m (13% of the mean) at an age of 14 years corresponds to a difference in volume production of 100 m^3 solid stem wood (21% of the mean) at an age of 41 years. However, the differences in volume production will have been somewhat exaggerated by the small plot size and the good site quality.

3. Good provenances continuously produce higher volumes than average provenances. Thus the effect of correct provenance selection may be compared to an increase in site quality.

4. Planted stands and so-called ”land races” figure prominently among the most productive provenances.

In 8-10 year old trials of *Picea sitchensis* in Denmark and Scotland the best provenances were 11-16% better in height growth than the average (Madsen 1984, Lines and Samuel 1984) while, in Canadian trials of *Picea glauca* on 15 sites, height increment of the fastest provenances averaged over 20% more than that of the mean and 17% better than that of the local provenance (Carlisle and Teich 1971).

In the warm temperate or sub-tropical conditions of South-eastern USA, percentage gains of similar magnitude have been recorded. In a number of trials of *Pinus taeda* reported by Kraus, Wells and Sluder (1984), early height differences (age 15-20 years) were in the range of 10-15%, while the difference in volume production between the best and the average provenance, at ages from 21 to 35 years, varied between 30 and 80%.

Well-designed provenance trials in the tropics are, in general, much more recent than those in the tempe-

rate zone. However examination of some recently published results of trials of tropical and sub-tropical species suggests that provenance differences can be expected to be at least as great as those in temperate species. Because growth rates are usually a lot faster and rotations shorter in the tropics than in the temperate zone, a given percentage gain is worth a good deal more in terms of both volume production per hectare and net discounted revenue (net present value).

In the case of *Eucalyptus camaldulensis*, a species with a vast and varied range in Australia, volume yields in the most and least productive provenances in trials have been in the ratio of 3 to 1 at age 6 at Afaka (Nigeria) and 8 to 1 at age 10 at Gan Hadar (Israel), (FAO 1981). A more useful comparison, however, is between the best provenance and the mean of those under test. Where a species is indigenous, comparison of the best with the local provenance is valuable, while for an exotic species of which seed has been difficult to obtain in the past, comparison of the best "new" provenance with the hitherto most readily available "standard" provenance (e.g. Mountain Pine Ridge, Belize, for Pinus caribaea var. hondurensis) is also of great interest.

In recent years increasing concern has been expressed about the longterm effects of narrowing the gene-pool of plantation species which may result from the use of a few improved genotypes within a single provenance. For this reason a wise precaution is to maintain a broad gene pool by using a proportion of each of several superior provenances (say the best three) revealed by trials, rather than concentrating on the single best provenance. The immediate overall improvement may be slightly reduced, but this is compensated by the reduced risk of an excessive narrowing of the gene-pool. Appendix 1 shows examples of provenance trial results from the tropics and sub-tropics, including pines, eucalypts and several tropical broadleaved species. Where data is available, comparisons are made of:

(a) The »best« provenance with the mean of all provenances in the trial.

(b) The mean of the »best« three provenances with the mean of all provenances in the trial.

(c) The »best« provenance with the local or "standard" provenance.

Most available results refer to rate of growth, whether in height, diameter, basal area or volume, but a few comparisons in stem straightness and specific gravity are included.

Improvements cited in the following paragraphs, unless otherwise stated, refer to comparisons between the mean of the fastest growing 3 provenances with the mean of all provenances under test.

For the mean of the 3 fastest growing provenances, the greatest improvement in early height growth over the trial means occurred in *Cedrela odorata*, *Cordia alliodora*, *Eucalyptus camaldulensis*, *E. cloeziana* and *P. taeda*. The improvement in these species varied from 15-34% at ages between 4.5 and 7 years. *E. tereticornis*, *Pinus oocarpa/tecunumanii*, *P. elliottii* and *Terminalia superba* recorded gains of 10-14%. Some individual trials of *Pinus caribaea* var. *hondurensis* showed differences of 5 to 6%, but the average over 15 sites of the international trials of this species was 4% and in one trial it was as low as 1%. In *Pinus patula* trials in Zimbabwe, the best provenance was 3% better than the average.

In trials where both height and diameter increment were measured, improvement in diameter growth was comparable to, or slightly less than, improvement in height growth. In the teak trials, improvement varied between 6 and 12% for diameter increment (3 trials) and between 3 and 14% for basal area increment/ha (4 other trials). In Gmelina the corresponding figures were 8 to 15% for diameter increment (5 trials) and

6 to 18% for basal area increment (3 other trials). The figures for both teak and Gmelina are estimates of genetic differences (Keiding *et al.* 1986, Lauridsen *et al.* 1987) while for other species the figures are expressions of phenotypic differences.

In trials in which basal area/ha or volume/ha were measured, as well as height, the improvement in basal area increment due to selection of the best 3 provenances was 1.5 to 5 times that in height increment, while improvement in volume production was 2 to 6 times as great. Some of the differences in volume production must be discounted for various reasons (influence of small plot size and variable survival and stocking, increasing effect of differential competition as stands grow older).

The magnitude of differences between provenances varies considerably from species to species in the tropics, as it does in temperate conditions. In North America *Picea glauca*, which has an extensive range cover widely differing climatic and soil conditions, has been shown to exhibit differences between the fastest and the average provenance of at least 20%, while in *Pinus resinosa*, which has a restricted range, the provenance differences are less than 10% (Carlisle and Teich 1975). For warm temperate or sub-tropical conditions, experience has shown that *Pinus taeda*, with a wide latitudinal and altitudinal range, shows a good deal more variation in growth rate than *P. elliottii*, which has a more restricted range. Trials in African countries such as Malawi have confirmed results of comparable trials with these two species in the USA. *Eucalyptus camaldulensis* is a species with a vast range in Australia and has also exhibited large differences between provenances in comparative trials. To sum up the evidence for early heightgrowth differences between provenances of tropical and sub-tropical species, as shown by the results of replicated provenance trials, it can be said that, for the mean of the fastest provenances compared with the mean of all provenances under test:

1. ”Very variable” species are to show an improvement in the range of 15-30%.

2. ”Moderately variable” species are likely to show an improvement in the range of 5-15%.

3. ”Slightly variable” species are likely to show an improvement in the range of 1-5%.

The above classification is species, it is not yet possible to arbitrary and, for many tropical evaluate genetic variability. But it does serve to emphasize the fact that the benefits from provenance selection are much greater in some species than in others.

The question remains to what extent the actual differences recorded in trials can be repeated when it comes to large-scale planting. Extrapolation of trial results to commercial plantations depends on a number of factors:

1. Availability of seed from the same source(s) as the original provenance(s) which proved superior in the trials:

   Some variation is inevitable between the collection of small research quantities of seed from a few (25 -100) trees and the collection of larger quantities from more trees spread over a wider area. In some cases the latter may present positive advantages in subsequent generations, if mixture of seeds from over a wide area reduces the degree of in the offspring. Such effects may contribute to the improved performance of ”land races” and stands raised from seed collected in plantations, in comparison with those raised from seed collected in natural stands, which has been reported from a number of trials. But it is important that collection is carried out in the same seed zone as the original (similar latitude, altitude, rainfall, aspect and soil type).

2. The extent to which apparent phenotypic superiority in the trials is due to genetic superiority, which will be repeated in other plantings, or to environmental differences which may not be repeated:

   Well designed experimental layouts should enable an estimate to be made of the proportion of phenotypic differences which can be ascribed to genetic differences, i.e. the heritability (h^2) of the observed differences. In the series of teak and gmelina trials (Keiding *et al.*1986; Lauridsen *et al.* 1987), h^2 was calculated for each experiment and commonly lay within the range of 0.5 -0.9 for mean diameter. The h^2 product of times phenotypic differences were then used as the estimate of genetic differences (see appendix 1).

   A particular example of environmental effects is the fact that genuine diffferences in the trials may be exaggerated by edge effect between small (including line or single-tree) plots. By definition trees of the best provenance must be growing alongside less vigorous provenances and so suffer less competition than when growing alongside other trees of the same provenance in plantations. Such edge effects can be expected to increase with age and to affect diameter and volume growth more than height growth; to some extent they can be reduced by the use of larger plots surrounded by one- or two-row unmeasured strips.

3. The correlation between he differences in the trials at the date of measurement and height differences to be expected in operational plantations at rotation age:

   If the trials are measured at rotation age, correlation will of course be equal to 1.0, but in most cases it is necessary to take a decision on what to plant when the trials are still comparatively young. One series of studies made in North America (Lambeth 1980) examined the correlations of juvenile/mature height demonstrated for several species of conifer at different ages of juvenile selection and of rotation and found that they increased from about 0.5 for an age/age ratio of 20% to about 0.8 at age/age ratio of 50%. A possible compromise between delaying too long and making premature and inaccurate forecasts by selecting the best provenances too would be:

   (a) Base the decision on a final assessment made at a minimum of one third rotation age or (for very short rotation crops) four years, whichever is the greater. An age/age ratio of 33% gave a correlation of about 0.7 in Lambeth's studies, but their applicability to tropical crops has yet to be demonstrated.

   (b) If possible, stability of provenance ranking should be demonstrated by consistent results over at least two successive assessments.

   (c) As previously recommended, select several of the best provenances for seed production, not the single best, and establish seed stands of total area in excess of anticipated needs. Some modification in selection can then be made, if necessary, before the first seed is collected for commercial plantations. In the example in Appendix 2, initial provenance selection is made when the trials are 8 years old, but they will be 23 years old by the time seed for commercial plantations is collected from the seed stands. At that time, if early promise in one provenance had not been maintained, it would be possible still to reject it and collect seed from the remaining selected provenances.

4. Conversion of mature height differences to differences in total product at rotation age:

   Examination of yield tables for different site quality classes (to which stable provenance differences may be considered analogous) suggests that mature **height** differences between adjacent site classes

of say 10% are commonly associated with differences in **volume** production of 15-20%. If there is a premium on larger diameter classes, the increase in **value** production would be still higher.

5. Correlation of expected productivity at rotation age of the best provenances in the trial plots with their expected productivity when planted over areas of many thousands of hectares:

   This depends on how representative of the planting area as a whole are the sites used in the provenance trials. For example, results of perfectly conducted trials on a heavy clay soil will be of limited value if the planting area is later discovered to comprise 80% of free-draining sandy soils. The most efficient distribution of provenance trials to sample the major site types present in the planting area is itself dependent on the efficiency of preliminary edaphic and topographic survey. Often the survey will reveal several representative site types within the planting zone. These need to be sampled separately and the trials may indicate different preferred provenances according to site. Extrapolation of trial results to strongly contrasting sites or climates, without further testing, can never be justified, but satisfactory correlation within a reasonably homogeneous planting zone can often be expected. With Norway spruce in southern Sweden, a correlation coefficient of r = about 0.8 was obtained within a representative planting zone (Wellendorf *et al.* 1986).

No studies of all the above factors have been made, as far as is known, for tropical species. In their absence, it is considered that a reasonable estimate of the improvement levels to be expected from programmes of tropical provenance research (value differences in operational plantations at rotation age) are:

(1) »Very variable« species 10-20 %
(2) »Moderately variable« species 5-10 %
(3) »Slightly variable« species 1-5 %.

The above discussion considers only the quantity and size of logs produced. It is also possible to improve the quality. Appendix 1 includes only a few data about quality, but there is some evidence for the possibility of improving stem straightness in *Pinus kesiya* and *P.oocarpa/tecunumanii*. Growth and vigour traits may sometimes be negatively correlated with traits for stem and wood quality, hence it is realistic not to allow any general addition in improvement for these traits. For individual species, however, improvement in the ultimate value of the crop may depend on improving quality rather than volume production. For *P. kesiya*, for example, the results from Zimbabwe indicate that provenance selection for stem straightness should lead to a greater increase in crop value than selection for the much less variable traits of height and diameter growth in that species.

Although a single provenance is rarely the best on all sites, some international trials have identified certain provenances which are consistently among the best few over a wide range of site conditions. Examles from temperate species are some Ontario provenances of *Picea glauca* (Carlisle & Teich 1971) and some Rumanian provenances of *Picea abies* (Giertych 1976). The Albacutya provenance of *Eucalyptus camaldulensis* has performed outstandingly throughout the Mediterranean region, while the Katherine and Petford provenances have been consistently among the superior provenances in, respectively, dry tropical and semi-humid tropical (summer rainfall) regions (Lacaze 1978). In the international trials of *Pinus caribaea* var. *hondurensis*, the Guanaja, Alamicamba and Santa Clara provenances were among the fastest growing on a number of sites (Gibson, Barnes and Berrington 1983).

Mountain Pine Ridge in Belize was the seed source of most of the earlier exotic plantations of *Pinus caribaea* var. *hondurensis*. In recent international trials of this species, this source was usually near the average

of all provenances under test (Gibson, Barnes and Berrington 1983). As shown in Appendix 1, in several trials the best single provenance produced over 20% more volume and occasionally over 30% more than the unimproved MPR provenance. On the other hand, managed local landraces or local provenances have sometimes been among the best performers under test. Seed from the Eyfield (Queensland) clone bank of *P. caribaea* var. *hondurensis*, the original source of which was Mountain Pine Ridge, produced an average of 12% greater volume than the unimproved MPR source; on several sites the improvement was over 20%. Improved local land races or seed orchards were found to yield higher values than even the best of new unimproved introductions in the case of *Eucalyptus cloeziana* in Ivory Coast, *Pinus patula* in Zimbabwe, *Pinus taeda* in Malawi, *Tectona grandis* in Nigeria (Gambri) and Papua New Guinea (see Appendix 1). Similar improvement was derived from selection and management of plantations from indigenous seed sources of Tectona in Thailand and India. Thus some of the provenance trials have, incidentally, provided evidence of the value of local landraces. This does not alter the fact that the most valuable longterm gains are likely to be made by combining the identification of provenances best adapted to local conditions, through well designed comparative trials, with subsequent selection, propagation and breeding of the best genotypes within them.

3. SELECTION WITHIN PROVENANCES

Research has shown that, in many species, there is considerable variation within provenances or populations, as well as between them. After one or more provenances have been identified which show superior performance under local conditions, the next stage therefore is to select superior stands within the superior provenances and manage them as seed stands (seed production areas) and/or to select superior individuals and to concentrate genetic material from them into clonal or seedling seed orchards.

Some genetic gain may be obtained by the selection of superior stands and their management for seed production. This involves early and heavy thinning to remove the poorer phenotypes and to develop crowns on the remaining good phenotypes for heavy seed production. The selection intensity involved would be about 1 in 10 trees retained out of those originally planted, four or five times the intensity of selection in commercial timber stands at the same same age, but still a low intensity compared with the 1 in 1000 commonly advocated for plus-tree selection for seed orchards. Where the area of seed stand needed is only a small proportion of the total plantation area available, the selection of the stand itself will confer some additional improvement; the improvement of say the best 20 ha over the average of a total plantation area of 1000 ha should be significantly better than that of the best 20 ha out of a total of 50 ha. However, the improvement from selected and managed seed stands is unlikely to exceed one quarter to one half of that expected from an initial cycle of improvement from seed orchards. Its main advantages are its simplicity and cheapness and the possibility of harvesting improved seed within a few years of the application of treatment.

Most of the evidence on the genetic improvement to be obtained from seed orchards refers to temperate conifers. There is much less on tropical conifers or on broadleaved species. Even for temperate conifers, most comparisons of the growth of stands from ”improved” and ”standard commercial” seed sources are from measurements made over half or less the rotation length. Nevertheless, the available evidence is fairly consistent. Carlisle and Teich (1978) have summed it up as follows: ”In most tree species we can expect at least 10% gain in growth and, in some, 15-25% growth gains ”. Additional gains may be obtainable in stem and wood quality and in disease resistance. The tabular summary prepared by Nikles (1970), of growth gains in a number of coniferous species at ages between 6 and 15 years, confirms this estimate.

Volume gains varied from 10% for phenotypic selection with wind pollination to over 20% for selection on the basis of progeny tests, combined with controlled pollination.

Eldridge (1982) found that seed from an unrogued, phenotypically selected, seed orchard of *Pinus radiata* in Australia produced an average of about 15% greater volume increment per hectare at ages 10-12 than the standard commercial seed source; it also doubled the percentage of outstandingly good trees in the stand. Hollowell and Porterfield (1986) suggested 8-15% volume gain at rotation age for *Pinus taeda*, with a single cycle of selection and roguing of 30-55% in the seed orchard; additional gains of 1% for specific gravity and 5% for stem quality should be possible (Porterfield 1974). For the same species in Texas, van Buijtenen and Saitta (1972) estimated volume gains of 15% plus a further 15% for combined stem form, crown form and specific gravity, from an initial round of selection and seed production from an unrogued grafted seed orchard. They predicted a further total 21% improvement from progeny testing and a new generation seed orchard. In the less variable *Pinus elliottii*, gains in overall volume production at 20 years (incorporating the benefits of both rust resistance and growth increase), estimated from a survey of seed orchards in south-eastern USA, were 7% for unrogued orchards and 13.2% after roguing (University of Florida 1988). In the case of *Pinus radiata* in New Zealand, Shelbourne (1969) predicted that percentage gains in straightness would greatly exceed those in diameter; in a clonal seed orchard established with clones selected at a rate of 1 in 1,000, gains were estimated at 11% for diameter increment and 47% for straightness.

In the UK, gains in height increment from the first cycle of selection have been reported as 15% for *Pinus sylvestris* at age 10 and 18% for *Picea sitchensis* at age 6 (Forestry Conunission 1985 a, b). Gains in subsequent cycles of selection ranged from 5 to 30%, depending on the degree of control of pollination, progeny testing, family reselection and orchard roguing.

The genus Populus is a good example of tree improvement in combination with vegetative propagation. In Italy, breeding for resistance to the fungus *Marssonina brunnea* is one of the most important objects of tree improvement. The well-known clone I 214 was found to yield 32% higher mean annual money income (before discounting) than clone I 488 in areas where *Marssonina* was absent, but 367% higher where the fungus was present and not treated chemically (Castellani and Prevosto 1970). In contrast, the superiority of I 214 to clone "Canadian" was relatively constant (56-60%) whether or not *Marssonina* was present.

Information on the effects of individual selection in tropical and subtropical species is sparse. The effects of natural, silvicultural and genetic selection in producing improved land races have been noted above, in connection with provenance trial results reported in the previous section, *for Eucalyptus cloeziana*, *Pinus patula*, *Pinus caribaea* var. *hondurensis*, *Pinus taeda* and *Tectona grandis*. Deliberate selection of superior individual trees within an introduced population can lead to significant further improvement. The gains have been reported in the table opposite.

In the cases of very high improvement, it is difficult to distinguish between the effects of individual selection and other effects. In the case with *E. grandis*, a signigicant part of the improved pulp yield can be assumed to be due to the intensification of establishment techniques. Rapid progress has also been helped by the relatively short rotation of eucalypts for pulp in Brazil (seven years) and the success with which *E. grandis* has been vegetatively propagated. It is of interest that Shelbourne (1969), in comparing different breeding strategies for *Pinus radiata*, estimated that selection of plus trees and commercial-scale vegetative propagation of the best trees only, if practicable, should give the highest gains in the shortest time.

In the examples of *Pinus elliottii* and *P. taeda* cited by Barnes, the plus trees were selected from the well-adapted Zimbabwe land race, while the control plots were from seed introduced from Louisiana, USA. Part of the differences can therefore be ascribed to provenance effects - the difference between an improved and adapted land race and a possibly ill-adapted exotic provenance. In addition the controlled full-sib crosses are more typical of a later and relatively sophisticated stage in a breeding programme than of the first stage of individual selection within a suitable provenance.

Species	Reference	Details	Trait & Age	Improvement
Eucalyptus grandis	Wallenberg 1984	"New system" = commercial scale planting of cuttings from 31 elite trees selected from 36,000 ha combined with intensive methods of establishment compared with 'old system' = plant seedlings from seed of commercial plantations, with less intensive establishment methods	Vol. yield/ha at age 7 Pulp yield per unit volume Total	112% 23% 135%
E. grandis	van Wyk	72 full-sib families, involving 18 female and 19 male parents, compared with commercial check - Mean of all 72 families - Mean of best 10 families - Best single family	Tree volumes at age 9 " ,. ..	47% 76% 132%
Pinus caribaea var. hondurensis	Reilly and Nikles 1978	"Minimum" improvement from unrogued clonal seed orchard, compared with commercial check Ditto "likely" improvement	Basal area/ha at: age 8 B.A./ha at age 8 plus predominant height at age 25	10% 10% 1m
Pinus patu1a	Barnes 1978	Mean of 24 polycross families from plus trees, compared with commercial checks	Tree vo1ume at age 5 Tree volume at age 8 Stem straightness at age 8 Branch size at age 5	17% 32% 8% 13%
Pinus patula	Barnes 1978	Second generation orchard, including best individual from each of "best" families (total improvement) 50% 'best' families retained 25% 'best' families retained	Tree volume at age 5 ,, ,,	 38% 50%
Pinus elliottii	Barnes 1978	Mean of 6 full-sib crosses of plus trees, compared with newly introduced provenance from Louisiana	Tree volume at age 7 Stem straightness	107% 4%
Pinus taeda	Barnes 1978	Mean of 4 full-sib crosses of plus trees, compared with newly introduced provenance from Louisiana	Tree volume at age 7 Stem straightness	535% 13%

For the purposes of the present note, most emphasis is given to the gains to be expected from a relatively simple initial stage of individual selection i.e. phenotypic selection of plus trees within a given population at an intensity of about one tree in a thousand and either concentrating the phenotypically superior geno-

types in a grafted seed orchard or collecting wind-pollinated seed from them and establishing a seedling seed orchard. From this relatively simple procedure it can be expected that improved results in large-scale plantations, after allowance for the same factors as considered above (see pages 6-8, items 1-5) will be as follows:

1. Provenances with "**high**" within-provenance variation are likely to show an improvement in total value production in the range of 15-30%.

2. Provenances with "moderate" within-provenance variation are likely to show an improvement in total value production in the range of 5-15%.

3. Provenances with "low" within-provenance variation are likely to show an improvement in total value production in the range of 1-5%.

Additional improvement should be obtainable in traits such as wood quality, stem straightness, pest and wind resistance. Plumptre and Barnes (1982) estimated that, in theory, improvements in quality traits in tropical pines could be at least as great as in volume traits but, because of possible correlation between desirable traits, they adopted a conservative level of improvement, equating total value gain with half the theoretical volume + quality gain.

In some species e.g. *Pinus kesiya* the gain in volume production from individual selection may be low but compensated by very substantial gains in quality, notably stem straightness; value improvement may therefore be as great as in other species, in which the main effect of selection is to improve volume.

It is desirable that methods of scoring quality traits such as stem straightness should be closely related to utilization value (Barnes and Gibson 1986). In some countries realistic assessment is made difficult because the timber trade does not afford recognition of the importance of stem and wood quality, through fixing adequate price differentials for log quality. Where a well developed system of timber prices has been developed, it should be possible to adapt quality scoring assessments to meet the appropriate criteria. Different scoring methods may be needed for different species. In Denmark, for example, there is a relatively steep price gradient for broadleaved species and a relative gentle one for conifers. The price ratio between the first and the third classes in *Quercus* is 3.3, in *Fagus* it is 2.3, in conifers it is 1.2 (Skoven Nyt 1986).

Davis (1970) pointed out that harvesting costs in South-eastern USA constituted 60-75% of total costs of wood delivered at mill, therefore a given percentage of increased harvesting efficiency may be 2-3 times as effective in increasing profitability as the same percentage increase in stumpage volume production. Stem straightness is a big factor affecting harvesting efficiency. He also calculated that a relatively small percentage increase in milling efficiency (5% reduction in processing time plus 5% higher conversion rate) should raise mill profits by 15-41%. Here again log form and wood quality exert a preponderant influence and it is likely that both traits have been underestimated hitherto in evaluating tree improvement benefits.

4. SURVEY OF EXPECTED GAINS FROM EARLY STAGES OF TREE IMPROVEMENT

In summary, the gains in total crop value over a rotation to be derived from tree improvement should, on average, be no less in tropical than in temperate species. For the early stages (provenance research followed by first cycle individual selection and seed production in managed but unrogued seed orchards) average gains may be conservatively estimated as follows:

Degree of variability between provenances	Value gain expected from provenance selection %	Degree of variability within provenances	Value gain expected from individual selection (first cycle managed but unrogued seed orchards) %	Total value gain expected %
High	10-20	High	15-30	25-50
	"	Moderate	5-15	15-35
	"	Low	1-5	11-25
Moderate	5-1O	High	15-30	20-40
	"	Moderate	5-15	10-25
	"	Low	1-5	6-15
Low	1-5	High	15-30	16-35
	"	Moderate	5-15	6-20
	"	Low	1-5	2-10

Further gains from later stages of selection and breeding (progeny testing, controlled pollination, vegetative propagation etc.) are likely to be of the same order as those expected from the first stage of within provenance selection, but are considered outside the scope of this note.

5. ECONOMIC ASPECTS

The expected value gains discussed in the previous sections need to be related to the costs incurred in the research and development needed to achieve them. One method which has been used in a number of economic analyses of tree breeding programmes is that of the Internal Rate of Return (IRR) or Financial Yield, i.e. the rate of interest at which total returns exactly equal total costs, when all are discounted to a common point in time.

Results of several economic studies of individual tree selection and seed orchard establishment and management have been summarized by Stier (1986). Most of them refer to work in North America and the range of IRR, for all except one report, is between 6% and 20%. The exception is a programme in *Picea glauca* in which the IRR was between 2.3% and 6.9% (Carlisle & Teich 1971). The trend was from lower IRRs « 10%) for slower growing species in cool to cold temperate conditions, e.g. *Picea glauca* and *Pinus resinosa*, to higher IRRs (> 15%) for *P. taeda* and *P. elliottii* in warm temperate or subtropical conditions. As a general rule, any IRR over 8% may be considered satisfactory and anything over 12% highly satisfactory when assessing projects at the national economic level.

There is very little information on the economic benefits and costs of tree improvement in tropical species, nor on those of provenance selection, considered in isolation, for any species. An attempt to evaluate provenance research in the hypothetical case of a tropical pine, such as *Pinus caribaea* var. *hondurensis*, is shown in Appendix 2. For the conditions and assumptions of this case study, the IRR varies from 9.7% for a value improvement of 2.5% to 11.2% for a value improvement of 20%.

Reilly and Nikles (1978) analysed costs and benefits of improved yields, through clonal seed orchards, in *Pinus caribaea* var. *hondurensis* in Queensland. They based costs on those actually incurred in the Kennedy Seed Orchard. Operations included:

- Year 1 Start of plantation searching for plus trees
- Year 4 First grafting of section 1 of seed orchard
- Year 10 First collection of seed from orchard
- Year 10-22 Annual collection of seed from orchard
- Year 22 Seed collection ceases. Orchard allowed to grow on to produce timber
- Year 11-23 Annual planting of improved nursery stock, one year after seed collection
- Year 46-58 Annual harvesting of improved crop after rotation of 31 years.

They estimated that one hectare of seed orchard produces an average annual crop of 28 kg of seed, sufficient to plant about 380 ha.

They considered four different possibilities of improving the value of the crop and calculated the IRR for each, as follows:

Source of improvement	Value Improvements over commercial checks %	IRR %
A Minimum 10% increased basal area/ha at age 8 (conservative estimate based on progeny test results).	10.4	13.9
B Likely 10% increased basal area/ha at age 8 plus an increase in predominant height at 25 years of 1 metre.	14.7	15.2
C 10% increased basal area/ha at age 8 plus improved straightness ld: 1% better recovery from first three thinnings and 2% better recovery from 4th thinning and final fell 19.	?	14.6
D No improvement in basal area growth. Improvement in straightness as in C.	?	9.9

(The fact that in (increased basal area/ha and improved straightness) is only slightly better than A (increased basal area only) is probably due to the negative correlation between straightness and basal area increment).
The above rates of return are for seed production from unrogued orchards. The authors found that, for a discount rate of 8% the initial selection of plus trees accounted for 36% of the discounted cost of improvement, seed orchard establishment 30% and seed orchard maintenance 34%.

Whereas the total costs of establishment and maintaining seed orchards are proportional to the area of orchard needed to supply improved seed and hence to the area of commercial plantations to be established annually, the cost of searching for and selecting plus trees is largely independent of the areas to be planted. This accounts for the important fact that the profitability of a tree improvement programme depends not only on the percentage increase in value of the crop but on the scale of planting. To take a hypothetical example, assuming the same proportion of costs (36% -30%-34%) as experienced in the above Queensland example:

Annual planting area (ha)	10,000	1,000	100
		18,000	18,000
		15,000	1,500
		17,000	1,700
Total discounted cost ($) of:			
-plus tree selection	18,000		
-seed orchard establishment	150,000		
-seed orchard maintenance	170,000		
Total discounted cost ($) of improvement operations	338,000	50,000	21,200
Discounted cost/ha ($) of:			
-plus tree selection	1,8	18	180
-seed orchard establishment	15	15	15
-seed orchard maintenance	17	17	17
Total discounted cost/ha ($)	33,8	50	212
Discounted national revenue/ha ($) derived from tree improvement	100	100	100
Discounted profit or (loss) /ha ($)	66,2	50	(112)
Total discounted profit or (loss) of tree improvement enterprise ($)	662,000	50,000	(11,200)

It can be seen that only a substantial annual planting area can justify the initial rather heavy outlay on plus tree selection. Small planting programmes cannot carry out their own selection programme economically. Their appropriate course of action is to purchase the relatively small quantities of improved seed which they require from bigger tree improvement enterprises, whether these are conducted by national forest services, cooperatives or large private companies. A prerequisite of such purchases is good information on the degree of improvement expected (selection intensity of plus trees, results of progeny tests if available) and the suitability of the populations from which the selections were made for the planting region in question. Since the cost of seed is a small part of total establishment costs, a relatively modest increase in productivity justifies paying a considerably higher price for the improved seed from which the plantations will be raised. Reilly and Nikles (1978) calculated for *Pinus caribaea* that, for the increased yield described above and an interest rate of 8%, seed purchasers could afford to pay for improved seed about four times the then current price for unimproved seed. Davis (1967) found that a small increase in plantation yield of 2.5-4% in *Pinus taeda* would justify paying 2-3 times the commercial seed price for improved seed. For *Picea abies* in Denmark, Barner (1986) cited calculations by P.H. Andersen that, for an improvement of 10-15% and a discount rate of 5%, if the investor were prepared to invest the entire increase of Net Present Value in improved seed, he could afford to pay nearly 20 times the current price of unimproved commercial seed.

The genetic improvement to be obtained from a first stage seed orchard can be further increased by roguing, i.e. by the removal of those clones or families in the orchard which have shown themselves as inferior in progeny tests. Several authors have shown evidence that intensive roguing (50% -70% poorest families/clones removed) can yield an added genetic gain of about half the original gain from the unrogued orchard. This has to be set against the additional cost of the progeny tests and the roguing operation, and the reduced quantity of improved seed which will be produced, at least temporarily, from the remaining trees in the orchard. It may be considered preferable to maintain an orchard producing say 100 kg of seed a year having 10% genetic improvement, then to rogue it and be left with an annual seed yield of 50 kg having 15% genetic improvement. For these reasons van Buijtenen and Saitta (1972) concluded that, in the local conditions of *P. taeda* orchards, roguing a first stage orchard was of doubtful value, but that progeny tests were still an essential tool for selecting clones or families for a new second stage orchard. For other species and with careful choice of initial spacing and the timing of the roguing operation, it may more than pay for itself.

The above examples suggest that, for a tropical pine such as *P. caribaea*, the selection of plus trees and their establishment and management in a seed orchard should yield an IRR of 12-15%.

Some authors have evaluated tree improvement projects not in terms of the IPP but of the Net Present Value (NPV), sometimes referred to as Net Present Worth or Net Discounted Revenue. With this method a realistic rate of interest is assumed (usually the "Real Rate" which equals the nominal rate less the rate of inflation) and the NPV represents the total value of returns less the total value of costs, all discounted to a common point in time, which is usually the start of the project. The NPV method is now generally preferred.

Carlisle and Teich (1971) calculated that tree improvement work on *Picea glauca* in Canada should yield an annual increase in discounted revenue of $832,000, compared with annual expenditure of $123,000. They assumed a 6% interest rate, a value improvement of 15%, moderately fertile sites and a planting programme of about 40,000 ha a year.

In Appendix 2, the median case of 6% interest and 10% improvement shows an NPV of $594,000 by year 58, on a planting programme of 1000 ha a year. In this particular case (10% improvement, 6% interest) the total discounted costs would be recovered by the time of the third year of harvesting (year 45 of the project), thereafter all harvesting returns would be profit.

All the calculations shown in Appendix 2 refer to profitability at the end of the first commercial rotation. In practice the superior provenances would continue to be used in subsequent rotations, even if no further investments were to be made in tree improvement. The additional benefits from subsequent rotations can be estimated by calculating the "infinity multiplier" which can be applied to the single rotation NPV, on the assumption that the improvements of the first rotation will be maintained in all subsequent rotations in perpetuity. For 6% interest rate and a rotation of 16 years, the "infinity multiplier" is 1.65 and the "infinity NPV" would thus become $594,000 x 1.65 = $980,000.

Graphs 1-3 illustrate, for a single commercial rotation, relationships between percent value gain, various interest rates, IRR, NPV and Benefit/Cost Ratio. Graph 2 shows, **inter alia**, the relationship of percent value and interest rate to the "Break-even" line, at which the Benefit/ Cost ratio is 1.0, i.e. discounted revenue exactly equals discounted costs. It can be seen that, for the example given in Appendix 2, a percent value gain of 2.5% would be required to break even at 10% rate of interest, while for a low interest rate of 2% a value gain of 0.2% would be sufficient.

Castellani and Prevosto (1970) calculated that, for an annual research and development cost of about $250,000, the substitution of the superior poplar clone I 214 for the two inferior clones I 488 and "Canadian" over a total area of 75,000 ha would result in an increase in annual income (before discounting) of between 3.25 and 3.75 million dollars, depending on the incidence of the fungus *Marssonina brunnea*.

Van Wyk and van der Sijde (1983) calculated that, for a 5% improvement in pines and 30% in eucalypts, an annual planting programme of about 50,000 ha (two fifths pine, three fifths eucalypt) and annual expenditure of about 0,5 million dollars, the eventual annual increase in harvesting value (before discounting) would be about 20 million dollars.

Plumptre and Barnes (1982) calculated that, for fast-growing lowland tropical pines (mainly *P. caribaea* and *P. oocarpa*) combined between and within provenance selection should improve volume production by a minimum of 20% and quality by 5% and that this improvement, if applied to 1,5 million ha (the predicted global area of these species by year 2000), would provide an increased annual harvesting value early next century (before discounting) of over a hundred million dollars.

In all these cases, the additional benefits to be gained in processing and marketing wood products are likely to be several times the increase in value of unprocessed logs. Where large planting areas are concerned, it is clear that relatively modest inputs of research and development can produce very large financial benefits.

Increased production from tree improvement offers several alternative courses of action. For example a 15% increased yield per ha would enable forest planners to fulfil a 15% increase in demand. If, on the other hand, demand is expected to remain static it could be fulfilled by a 15% smaller plantation area. The reduced area could be obtained by rejecting the lowest quality sites and so increasing the average yields on the area retained, or by rejecting the least accessible planting sites and thus reducing average logging and transport costs. Either choice provides further economic benefits. Alternatively, the full area could be retained and the rotation reduced. Any reduction in the period, over which the returns from final felling must be discounted will improve the IRR of the project, but this advantage may be lost if wood quality and hence value is inferior at the lower age. Detailed knowledge of species charateristics is needed to appraise the various alternatives offered by tree improvement benefits.

In addition to increasing returns, tree improvement may reduce costs. If improved provenances and genotypes grow faster from the start, they will close canopy and cease to need tending at an earlier age. Reduction in the number of weedings from say 5 to 4 may be possible and the saving of cost so early in the rotation could have a significant effect on the economic success of the project. At the same time improvement in crop uniformity may make it possible to change from selective thinning methods to a cheaper system of line thinning. Quantitative assessment of reduction in management costs as a result of tree improvement is usually not included in economic analysis, but the savings may be substantial.

The evidence seems overwhelming that, wherever there is a substantial afforestation programme, tree improvement (both provenance research and individual selection) in the tropics will more than pay for itself. Economic returns are likely to be excellent in most species. Looked at another way, no one can afford the substantial losses which will result from implementing a realistic improvement programme.

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Appendix 1

Examples of Provenance Trial Results from The Tropics and Sub-Tropics

1 Species	2 Site, No. of provenances in trial, reference	3 Age	4 Trait	5	6	7
				% Phenotypic Improvement		
				Best to average	Mean of 3 best to average	Best to local or standard
Cedrela spp.	La Séguié, Ivory Coast. Lat. 6° 15'N. 7 provenances Ref: Delaunay 1978 a.	78 mth.	$\bar{h}$	44**	34	
Cordia alliodora	Tumaco, Colombia. Lat. 1° 38'N. 12 provenances. Ref: INDERENA 1985.	73 mth.	$\bar{h}$ $\bar{d}$	22** 30**	22 26	
Eucalyptus camaldulensis	Afaka, Nigeria. Lat. 10° 37'N. 16 provenances. Ref: Jackson & Ojo 1973.	56 mth.	$\bar{h}$ v/ha	29 71	15 57	
E. camaldulensis	Mtao, Zimbabwe. Lat.19° 22'S. 30 provenances. Growth in first coppice rotation (after one seedling rotation) Ref: Quaile & Mullin 1984.	66 mth.	$\bar{h}$ $\bar{d}$ BA/ha	41** 25** 45**	28 25 51(a)	
E. cloeziana	Pointe Noire, Ivory Coast. Lat. 4° 49'S. 1 local land race + 18 Australian provenances (1 Ref: Bovet & Delwaulle 1983.	66 mth.	$\bar{h}$ Ba/ha v/ha	22 54 76	15 48 61	-18 (1 -17 -29
	(1 Comparisons in columns 5 & 6 are among the 18 Australian provenances only. Comparison in column 7 is between the best Australian provenance and the local landrace, which proved to be still better.					
E. tereticornis	Frankfort, S. Africa. Lat. 25° 02'S (1620 mm MAR) 23 provenances. Ref: Darrow 1983.	82 mth.	$\bar{h}$ Ba/ha	13 41	13 30	
E. tereticornis	Roodewal, S. Africa. Lat. 23° 01'S (810 mm MAR) 23 provenances. Ref: Darrow 1983.	90 mth.	$\bar{h}$ Ba/ha	17 89	14 41	
Gmelina arborea	Edea, Cameroon. Lat. 04° 00'N. Alt. 30m. MAR 2630 m. 10 provenances. Ref: Lauridsen, Wellendorf & Keiding 1987.	55 mth.	$\bar{d}$	12++	10	
Gmelina arborea	Subri, Ghana. Lat. 05° 10'N Alt. 150 m. MAR 2030 m. 11 provenances. Ref: Lauridsen, Wellendorf & Keiding 1987.	56 mth.	Ba/ha	21++	18	
Gmelina arborea	La Gloria, Colombia. Lat. 10° 40'N. Alt. 25m MAR 1200 m. 11 provenances. Ref: Lauridsen, Wellendorf & Keiding 1987.	35 mth.	$\bar{d}$	10++	8	

1 Species	2 Site, No. of provenances in trial, reference	3 Age	4 Trait	5 % Phenotypic Improvement Best to average	6 Mean of 3 best to average	7 Best to local or standard
Gmelina arborea	Mancherial, Jaipur, India. Lat. 18° 52'N. Alt. 200m MAR 1100 mm. 6 provenances. Ref: Lauridsen, Wellendorf & Keiding 1987.	55 mth.	$\bar{d}$	17^{++}	10	
Gmelina arborea	Poitete, Solomon Islands. Lat. 07° 50'S. Alt. 100m MAR 3500 m. 11 provenances Ref: Lauridsen, Wellendorf & Keiding 1987.	52 mth.	$\bar{d}$	8^{+}	8	
Gmelina arborea	Gambari, Nigeria. Lat. 07° 12'N Alt. 600m. MAR 1300 mm 19 provenances. Ref: Lauridsen, Wellendorf & Keiding 1987.	52 mth.	Ba/ha	17^{+}	13	
Gmelina arborea	El Tormento, Mexico. Lat. 18° 36'N. Alt. 50m MAR 1070 mm. 11 provenances Ref: Lauridsen, Wellendorf & Keiding 1987.	58 mth.	$\bar{d}$	24^{+}	15	$0^{(2}$
	(2 Local land race was best in growth and health, but not in quality.					
Gmelina arborea	Opro, Ghana. Lat. 07° 10'N. Alt. 200 m. MAR 1400 mm 8 provenances. Ref: Lauridsen, Wellendorf & Keiding 1987.	55 mth.	Ba/ha	9^{+}	6	
Pinus caribaea var. hondurensis	Jari, Brazil. Lat. 0° 52'S 13 provenances. Ref: Gibson, Barnes & Berrington 1983	75 mth.	$\bar{h}$ $\bar{d}$ ub v/tree	6 6 19	4 3 13	4 6 23
Pinus caribaea var. hondurensis	Nabou, Fiji. Lat. 17° 59'S 15 provenances. Ref: Gibson, Barnes & Berrington 1983.	82 mth.	$\bar{h}$ d ub v/tree	4 13 24	5(b) 7 17	5 15 38
Pinus caribaea var. hondurensis	San Pedro, Ivory Coast. Lat. 4° 44'N. 15 provenances. Ref: Gibson, Barnes & Berrington, 1983	105 mth.	$\bar{h}$ d ub v/tree	8 4 21	6 3 15	11 9 35
Pinus caribaea var. hondurensis	Loudima, Congo. Lat. 4° 13'S 9 provenances. Ref: Gibson, Barnes & Berrington, 1983	100 mth.	$\bar{h}$ d ub v/tree	2 1 11	1 1 6	4 1 18
Pinus caribaea var. hondurensis	Chati, Zambia. Lat. 13° S 7 provenances. Ref; Gibson, Barnes & Berrington, 1983.	86 mth.	$\bar{h}$ $\bar{d}$ ub v/tree	7 2 12	3 3(a) 11	
Pinus caribaea var. hondurensis	Anasco, Puerto Rico. Lat. 18° 20'N. 13 provenances. Ref: Gibson, Barnes & Berrington, 1983.	69 mth.	$\bar{h}$ $\bar{d}$ ub v/tree	3 9 25	5(a) 5 20	3 7 23

1 Species	2 Site, No. of provenances in trial, reference	3 Age	4 Trait	5 % Phenotypic Improvement Best to average	6 Mean of 3 best to average	7 Best to local or standard
Pinus caribaea var. hondurensis	Average improvement for up to 17 provenances on 15 sites, using corrected provenance means. Ref: Gibson, Barnes & Berrington, 1989.		$\bar{h}$ $\bar{d}$ ub v/tree	5^{**} 3 15^{**}	4 3 10	2 1 12
Pinus elliottii	Luwawa, Malawi. Lat. 12° 11'S 25 provenances. Ref: Ingram 1984.	15 yrs.	$\bar{h}$ Ba/ha	15^{*} 13^{*}	10 17(a)	
Pinus kesiya	Usutu, Swaziland (high altitude) 9 provenances. Ref: Morris 1984.	10 yrs 10 yrs 7 yrs	$\bar{h}$ $\bar{d}$ v/ha	7^{*} 2 16		
Pinus kesiya	Usutu, Swaziland (high altitude) 9 provenances. Ref: Morris 1984.	10 yrs 10 yrs 7 yrs	$\bar{h}$ $\bar{d}$ v/ha	4^{*} 1 8		
Pinus kesiya	Means over 6 sites in Zimbabwe. 21 provenances. Ref: Mullin, Quaile & Mills 1984.	11.5 yrs	$\bar{h}$ $\bar{d}$ str.	4^{*} 5^{*} 15^{*}		
P. oocarpa/ tecunumanii	Nzoia, Kenya, Lat. 0° 56'N Alt. 1700 m. 15 provenances. Ref: Chagala & Gibson, 1984.	8 yrs	$\bar{h}$ d ub v/ha str.	16^{*} 8^{*} 79^{*} 26^{*}	13 8 52 36(b)	
Pinus patula	Means over 6 sites in Zimbabwe (alt. 990-1925 m, 885-2000 m) 8 Mexican provenances + 2 improved Zimbabwe land races. (3 Ref: Barnes & Mullin 1984.	7 yrs	$\bar{h}$ d str. SG	3^{*} 0 6^{*} -1		- 5 - 1 -10 3
	(3 Comparison in column 5 is among the 8 Mexican provenances only. Comparison in column 7 is between the best Mexican provenance and improved seed from a local seed orchard. The seed orchard source is superior in all measured traits except Specific Gravity.					
Pinus taeda	Nthungwa, Malawi, Lat. 11° 44'S 36 provenances, including 7 Zimbabwe or Malawi land races and 29 indigenous provenances from USA.(4 Ref: Ingram 1984.	15 yrs	$\bar{h}$ Ba/ha	27^{*} 52	23 45	- 9 -18
	(4 Comparisons in column 5 and 6 are among the 29 USA provenances only. Comparison in columnm 7 is between the best USA and the best local land race; the latter is superior in both height and basal area growth.					
Tectona grandis	Huey Som Poi, Thailand. Lat. 18° 40'N. 8 provenances Ref: Keiding, Wellendorf & Lauridsen 1987.	81 mth.	$\bar{d}$	18^{++}	12	0(5
	(5 Local source, a superior stand selected and managed for seed production, was best in this trial.					
Tectona grandis	Aracruz, Brazil. Lat. 19° 46'S 12 provenances. Ref: Keiding, Wellendorf & Lauridsen 1987.	121 mth.	$\bar{d}$	10^{++}	9	

1 Species	2 Site, No. of provenances in trial, reference	3 Age	4 Trait	5 % Phenotypic Improvement Best to average	6 Mean of 3 best to average	7 Best to local or standard
Tectona grandis	Maredumilli, India. Lat. 17° 36'N 11 provenances. Ref: Keiding, Wellendorf & Lauridsen 1987.	104 mth.	Ba/ha	18^{++}	11	$0^{(6}$
	(6 Local source was easily best in growth and health but was inferior in stem quality.					
Tectona grandis	Gambari, Nigeria. Lat. 7° 12'N 12 provenances. Ref: Keiding, Wellendorf & Lauridsen 1987.	93 mth.	Ba/ha	4^{+}	3	$0^{(7}$
	(7 Local land race is one of two best provenances.					
Tectona grandis	Afaka, Nigeria. Lat. 10° 37'N 10 provenances. Ref: Keiding. Wellendorf & Lauridsen 1987.	93 mth.	Ba/h	19^{+}	12	20
Tectona grandis	Black River, Papua New Guinea. Lat. 9° 04'S. Ref: Keiding, Wellendorf & Lauridsen 1987.	117 mth.	Ba/h	23^{++}	14	$0^{(8}$
	(8 Local land race is easily best for growth, but not in stem quality.					
Tectona grandis	Tract 105, Puerto Rico. Lat. 18° 15'N. 9 provenances. Ref: Keiding, Wellendorf & Lauridsen 1987.	83 mth.	$\bar{d}$	13^{*}	6	
Terminalia superba	Mopri, Ivory Coast. Lat. 5° 50'N 16 provenances. Ref: Delaunay 1978b.	69 mth.	$\bar{h}$ $\bar{d}$	13^{+} 6	10 6	

* Phenotypic improvement significant at P = 0.05
** Phenotypic improvement significant at P = 0.01
\+ Estimate of genetic improvement, with heritability = h^2 between 0.35 and 0.8
++ Estimate of genetic improvement, with heritability = h^2 between 0.8 and 1.0

(a) "Best" individual provenance was selected for superiority in height growth, but was not necessarily superior in diameter or basal area growth. This accounts for the fact that the "nean of the best three" is sometimes a higher figure than the corresponding figure for the "best" provenance.

(b) "Best" individual provenance was selected for superiority in volume growth, therefore in some cases showed lower height growth than "mean of best three", or lower score for straightness than "mean of best three".

Abbreviations

Lat. = Latitude
Alt. = Altitude
MAR = Mean annual rainfall
$\bar{h}$ = Mean height
$\bar{d}$ = Mean diameter
mth = Months
Ba/ha = Basal area per hectare
v/ha = Volume per hectare
ub v = Under bark volume
str. = Straightness
SG = Specific gravity
yrs = Years

Appendix 2

Calculation of Costs, Returns and Profitability

of a Hypothetical Programme of Provenance Research

Assumptions

1. A country wishes to find and introduce superior provenances of a tropical for production of long-fibre pulpwood, for local use or for export.

2. A modest planting scheme is planned, with an annual planting area of 1000 ha.

3. The country already has plantations or indigenous forests of the species (or of a comparable species) within its own frontiers. Seeds of the local provenance or of a »standard« introduced provenance, such as the Mountain Pine Ridge provenance of Pinus caribaea var. hondurensis, are readily available.

4. A pulpwood rotation of 16 years is planned. The local or »standard« provenance produces a mean annual increment of utilisable pulpwood of 15 m3 /ha/yr on this rotation. An average price of $30 per m^3 (delivered at port of export or main national markets) is expected. On average, no more than one third of this price, $8-10, would make up the stumpage price. Additional calculations would be required to split the profit of the enterprise between the growing, harvesting, transport and marketing operations. This appendix is concerned only with the overall benefits of the provenance research programme described. If the programme is a national one, it is the total benefit to the country which is important, rather than the relative profits of the forestry and forest industries sectors.

5. The economic analysis consists in comparing the **additional** costs, associated with procuring seed of a range of provenances, testing them on several sites within the country and establishing seed production areas (SPAs) of the best provenances sufficient to plant annually 1000 ha, with the **additional** returns expected from the superior provenances. All costs and returns are discounted to year 0 of the project.

6. Five »real« discount rates, 2%, 4%, 6%, 8% and 10% have been used. These are equivalent to nominal interest rate less inflation rate. Economic analysis covers additional costs and returns up to year 58 of the project, by which time the entire area planted with the superior provenances will have completed one full rotation of 16 years.

7. Main assessment of the provenance trials will be made at age 8, or half the commercial rotation age. Thereafter additional »semi-bulk« quantities of seed of the superior provenances will be procured for establishment of seed production areas.

8. Seed production will commence at age 8 but commercial quantities will be produced only from age 12. From age 12 to age 30 the seed production areas should produce annually sufficient seed from each hectare of SPA to establish150 ha of commercial plantations. The smaller quantities of seed harvested between age 8 and age 12 will be used to establish new SPAs to rep:ace or expand the area of the initial SPAs as these become overmature.

9. Because of site differences within the country and as a means to ensure against narrowing of the national gene pool, a single superior provenance will not be planted for seed production. It is expected that there will be two SPAs of 5 ha each for each of the three best provenances identified in the provenance trials. This area should produce 3 times as much improved seed as needed, extra seed will be a reserve against contingencies.

10. Costs may be divided into seed procurement costs, and establishment and maintenance costs.

11. In the case of seed procurement, of both research quantities for provenance trials and semi-bulk quantities for establishing seed production areas, a system of international cooperative effort yields the greatest benefits to the most countries. In the present case, it is assumed that exploration and collection of provenance seedlots continues over 3 years (years 0-2 of project), while collection of semi-bulk seed supplies continues for two years (years 12-13 of project). It is further assumed that 20 countries participate in the benefits of the international operation, therefore the case study country will only need to bear 1/20th of the total cost of these seed operations.

12. In practice, international seed collecting operations in forestry are sometimes financed by donor agencies, e.g. Danida operating through the Danida Forest Seed Centre or ODA operating through the Oxford Forestry Institute. In such cases the cost to the introducing country would be reduced. Whoever pays for the various operations, the fact remains that a modest initial expenditure will produce enormously greater returns in due course.

13. Undiscounted seed procurement costs are assumed to be as follows:

Year		Total cost ($)	Cost to Case Study country ($)	Scale
0	Explore, collect seed	80,000	4,000	research
1	Explore, collect seed	80,000		quantities
2	Collect & distribute seed	120,000		
12	Collect seed for planting SPAs	180,000	9,000	semi-bulk
13	Collect seed for planting SPAs	200,000	10,000	quantities

14. It is assumed trhat provenance trials will eventually be used for wood production as well as for generating information. Likewise, the seed production areas will produce wood as well as seed. Both, therefore, can be considered as being substitutes for normal plantations of equivalent area. For this reason the full establishment costs have not been used, only the **additional** costs entailed in the establishment and management of these special plantations to the high standards needed. These **additional** costs are estimated at 50% of the normal costs of establishing commercial plantations.

15. The establishment of commercial plantations of superior provenances (from year 27 of the project) is assumed to cost the same as the establishment of the non-superior local or »standard« provenance. No additional cost is involved at this stage. In fact costs could be somewhat reduced if e.g. faster early growth reduces the number of weedings (see main text p.16).

16. Improved returns resulting from use of superior provenances have been calculated for five percentages of improvement, 2.5%, 5%, 10%, 15% and 20%. These percentages refer to improvements in the **monetary value** of the crop, which may include components for gross volume yield, timber and pulp quality, resistance to pests and diseases.

17. Returns will be received from year 43 of the project onwards, that is from commercial plantations planted from year 27 onwards and clearfelled for pulp at age 16. No thinning and therefore no intermediate yields are planned.

18. Money yield expected from local or »standard« unimproved provenances if $7,200/ha from year 43 (MAI 15^3 x rotation 16 years x ce $\$30/m^3$).

19. Additional money yield expected from improved provenances at rotation age is:

% improvement	2.5	5	10	15	20
Additional money yield/ha	180	360	720	1,080	1,440
Additional money yield ($'000) from harvesting 1000 ha/yr.	180	360	720	1,080	1,440

20. No account is taken of any genetic improvement obtainable from the careful management (including early and heavy thinning) of seed production areas, because this would apply as much to SPAs of the local or »standard« provenance as to those of superior provenances.

Appendix 2

A. DISCOUNTED ADDITIONAL COSTS OF PROVENANCE RESEARCH (US$)

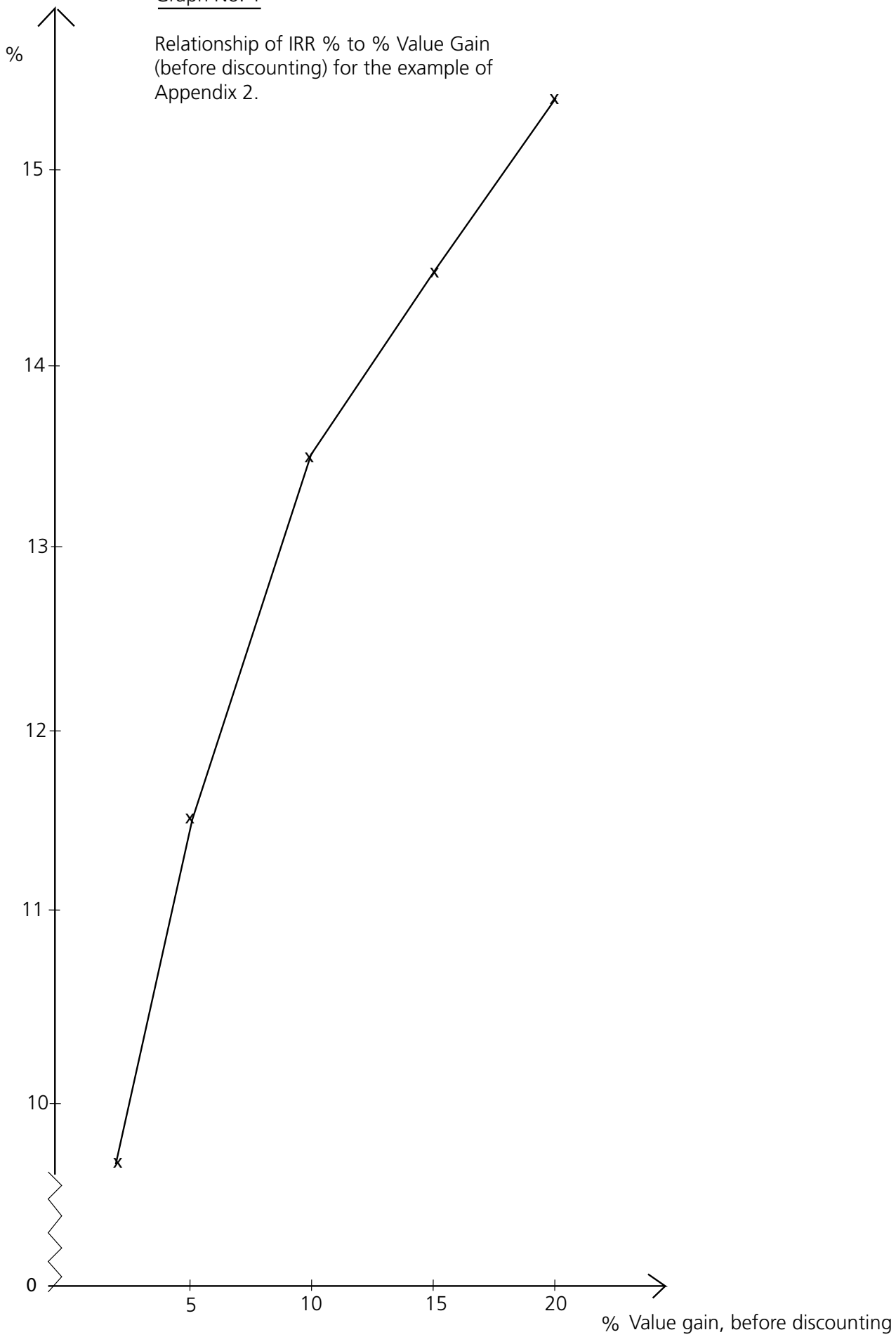
	Discount Rate		0%		2%		4%		6%		8%		10%	
Year	Operation	Basic cost/ha	Total basic cost		Multi-plier	Discounted cost	Multiplier	Discounted cost	Multiplier	Discounted cost	Multiplier	Discounted cost	Multiplier	Discounted cost
	1. Seed procurement for provenance trials													
0	Explore, collect seed		4,000		1.0	4,000	1.0	4,000	1.0	4,000	1.0	4,000	1.0	4,000
1	Explore, collect seed		4,000		0.980	3,920	0,962	3,850	0.943	3,770	0.926	3,700	0.909	3,640
2	Collect, distribute seed		6,000		0.961	5,770	0.925	5,550	0.890	5,340	0.857	5,140	0.826	4,960
	Total		14,000			13,690		13,400		13,110		12,840		12,600
	2. Establishment of trials (2,5 ha per site x 6 sties = 15 ha)													
3	Nursery, site prep., plant	320	4,800		0.942	4,520	0.889	4,270	0.84	4,030	0.794	3,810	0.751	3,600
4	Weed	100	1,500		0.924	1,390	0.854	1,280	0.792	1,190	0.735	1,100	0.683	1,020
5	Weed	60	900		0.906	820	0.822	740	0.747	670	0.681	610	0.621	560
6	Protection	20	300		0.924	280	0.854	260	0.792	240	0.735	220	0.683	200
5-11	Annual protection	20	2,100		0.924		0.854		0.792		0.735		0.683	
				(excluding	x 6.472	1,790	x 6.002	1,540	x 5,582	1,330	x 5,206	1,150	x 4,868	1,000
11	Assessment/evaluation	200	1,600	2 row surround on every plot	0.804	1,290	0.65	1,040	0.527	840	0.429	690,000	0.35	560
	Total		11,200			10,090		9,130		8,300		7,580		6,940
	3. Seed procurement for seed stands													
12	Seed collection		9,000		0.788	7,090	0.625	5,630	0.788	4,470	0.397	3,570	0.319	2,870
13	Seed collection		10,000		0.773	7,730	0.601	6,010	0.773	4,690	0.368	3,680	0.29	2,900
	Total		19,000			14,820		11,640		9,160		7,250		5,770
	4. Establishment of seed stands (10 ha per provenance x 3 provenances = 30 ha)													
14	Nursery, site prep., plant	320	9,600		0.758	7,280	0.577	5,540	0.758	4,240	0.34	3,260	0.263	2,520
15	Weed	100	3,000		0.743	2,230	0.555	1,670	0.743	1,250	0.315	950	0.239	720
16	Weed	60	1,800		0.728	1,310	0.534	960	0.728	710	0.292	530	0.218	390
17	Protection	20	600,000		0.743	450	0.555	330	0.743	250	0.315	190	0.239	140
6-41	Annual protection	20	15,600		0.743		0.555		0.743		0.315		0.239	
					x 20.121	8,970	x 15,983	5,320	x 20.123	3,250	x 10,810	2,040	x 9,151	1,310
	Total		30,600			20,240		13,820		9,700		6,970		5,080
	5. Establishment of commercial stands													
26-41	Annual seed collection from seed stands. No increased cost over collection of iúnimproved commercial seed													
27-42	Annual planting. No increased cost over use of unimproved commercial seed													
	Total discounted costs		74,800			58,840		47,990		40,270		34,640		30,390
			0%			2%		4%		6%		8%		10%
	Discount Rate		0%		2%		4%		6%		8%		10%	

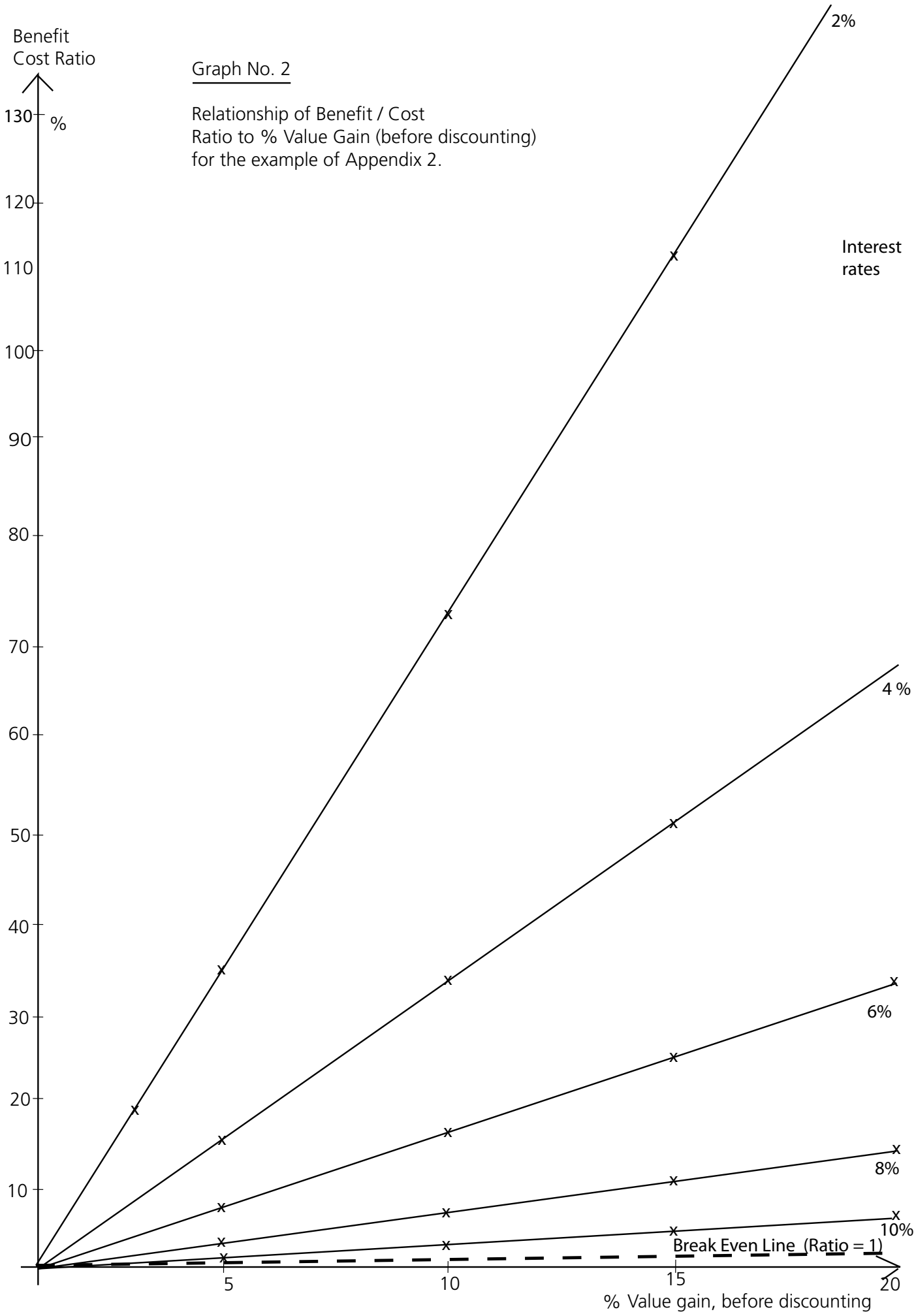
Year	Operation	Basic cost/ha	Total basic cost	Multi-plier	Discounted cost	Multiplier	Discounted cost	Multiplier	Discounted cost	Multiplier	Discounted cost	Multiplier	Discounted cost
	1. Value improvement from improved provenance 2.5%												
43	Clearfelling	180	180,000	0.427	76.9	0.185	33.3	0.082	14.8	0.0365	6.6	0.0166	3.0
44-58	Annual clearfelling	180/yr	2,700	0.427		0.185		0.082		0.0365		0.0166	
				x 12.849	987.6	x 11.118	370.2	x 8.559	143.7	x 8.559	56.5	x 7.606	22.7
	Total (year 58)		2,880		1.064.5		403.5		158.5		63.2		25.7
	Less discounted costs		74.8		58.8		48		40.3		34.6		30.4
	Discounted profit = NPV		2,805.2		1,005.7		355.5		118.2		28.5		4.7
	Benefit/cost ratio		38,5		18.1		8.4		3.9		1.8		0.9
	2. Value improvement from improved provenance 5%												
	Total (year 58)		5,760		2,129		807		317		126.2		51.4
	Less discounted costs		74.8		68.8		48		40.3		34.6		30.4
	Discounted profit = NPV		5,685.2		2,070.2		759		276.7		91.6		21.0
	Benefit/cost ratio		77,0		36.2		16.8		7.9		3.6		1.7
	3. Value improvement from improved provenance 10%												
	Total (year 58)		11,520		4,258		1,614		634		252.4		102.8
	Less discounted costs		74.8		58.8		48		40.3		34.6		30.4
	Discounted profit = NPV		11,445.2		4,199.2		1,566		593.7		217.8		72.4
	Benefit/cost ratio		154,0		72.4		33.6		15.7		7.3		3.4
	4. Value improvement from improved provenance 15%												
	Total (year 58)		17,280		6,387		2,421		951		378.6		154.2
	Less discounted costs		74.8		58.8		48		40.3		34.6		30.4
	Discounted profit = NPV		17,205.2		6,328.2		2,373		910.7		344.0		123.8
	Benefit/cost ratio		231,0		108.6		50.4		23.6		10.9		5.1
	5. Value improvement from improved provenance 20%												
	Total (year 58)		23,040		8.516		3,228		1,268		504.8		205.6
	Less discounted costs		74,800		58.8		48		40.3		34.6		30.4
	Discounted profit = NPV		22,965.2		8,457		3.18		1,227.7		470.2		175.2
	Benefit/cost ratio		308.0		144.8		67.2		31.4		14.6		6.8

IRR

Graph No. 1

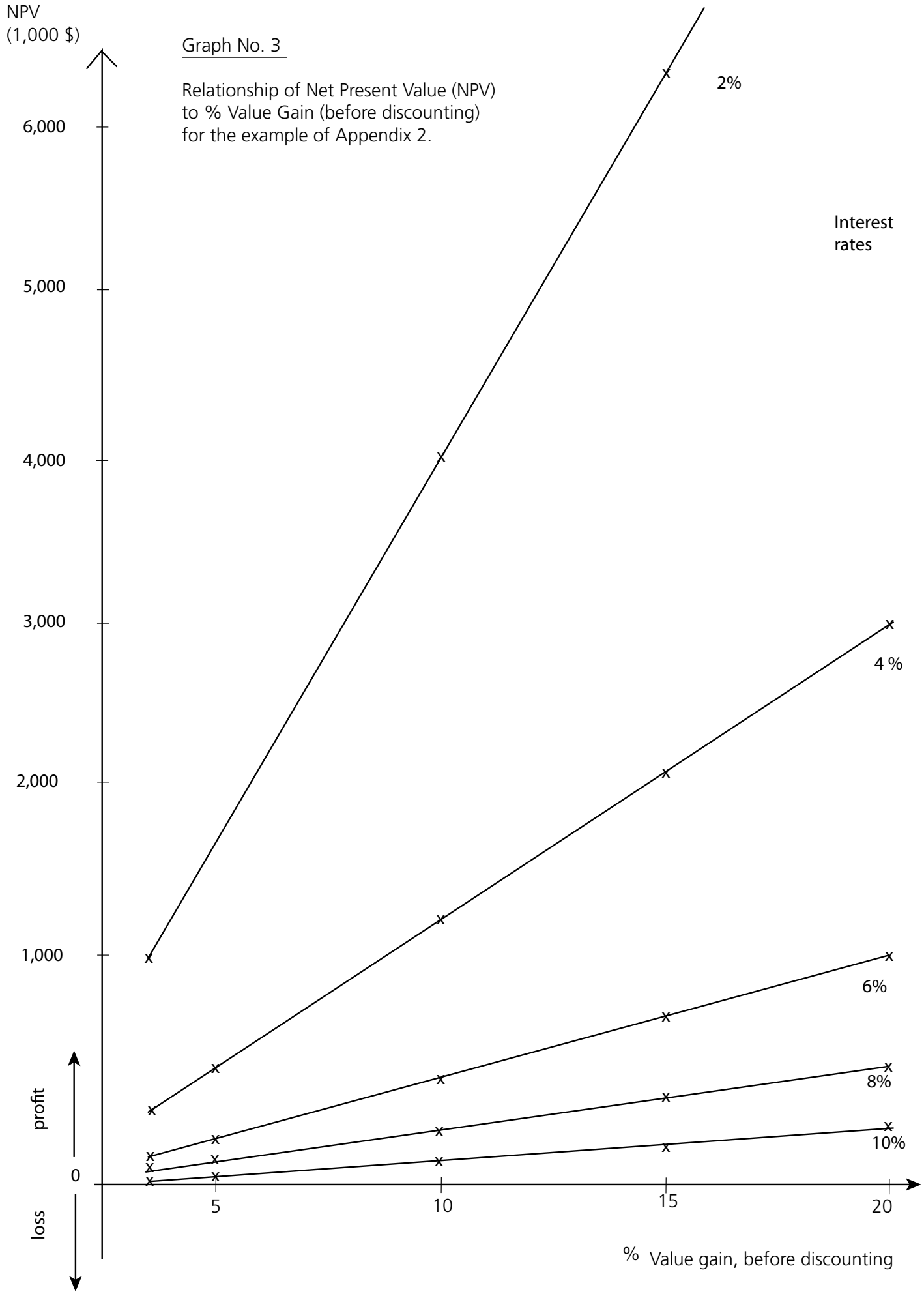
Relationship of IRR % to % Value Gain (before discounting) for the example of Appendix 2.





Graph No. 2

Relationship of Benefit / Cost
Ratio to % Value Gain (before discounting)
for the example of Appendix 2.


NPV
(1,000 $)
Graph No. 3
Relationship of Net Present Value (NPV)
to % Value Gain (before discounting)
for the example of Appendix 2.
6,000
5,000
4,000
3,000
2,000
1,000
0
profit
loss
2%
4 %
6%
8%
10%
Interest
rates
5
10
15
20
% Value gain, before discounting