Evaluation of an International Series of Teak Provenance Trials

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EVALUATION OF AN INTERNATIONAL SERIES OF TEAK PROVENANCE TRIALS

by

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and E. B. Lauridsen

DANIDA FOREST SEED CENTRE

Titel
Evaluation of an international series of teak provenance trials

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Cover photo
Cover photo shows seven-year-old teak in provenance trial IP 001 Huey Som Poi, Thailand. Two modes of branching: left "light scatter", right "regular" with persistent axis.

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Acknowledgement

In the long process of preparing the present paper it is evident that many people in different contexts have been involved. This is appreciated when we consider all the operations connected with the conduct of international provenance trials ranging from collections, distribution, field trial establishment and management, assessment and evaluation, to which may be added the adaption and/or development of methodologies.

Thus we are under obligation to a great many individuals, institutes and organizations for technical, organizational and financial contribution to the study of teak's genetic potential. It is regrettably not possible to mention all the persons or organizations to whom we owe our thanks during the 15 years that have passed since collections were started.

However, we would like to pay a special tribute to the hosts of the trials. Without the cooperation of forest departments and forest research personnel in running the experiments and participating in the assessments, the evaluation would not have been possible.

Among the different institutes supporting the assessment and evaluation we are specially indebted to the Arboretum in Hørsholm, Denmark, for generously placing staff-members at our disposal particularly in the field of statistical analysis and interprcuJ.tion of data.

Finally we gratefully acknowdedge the painstaking and laborious job made by our secretaries at the Seed Centre in transforming the handwritten manuscript with tables, figures etc. into the present paper.

H. Keiding Humlebæk
December 1986

Abstract

Teak provenance trials have been subject to assessment over a wide range of site conditions in the period 1981-83. The experiments are internationally coordinated through the DANIDA Forest Seed Centre, Denmark, as part of the action programme formulated by the FAO Panel of Experts on Forest Gene Resources in 1969, and were initiated in the early 1970's.

A total of 21 teak provenance trials have been assessed at ages varying from 9-10 years.

The development of an assessment procedure suited for the special features of broadleaved species is described and discussed in details covering purpose, scope and methodology of evaluation.

Traits for the assessment and subsequent evaluation are confined mainly to chararters related to and are restricted in number to about 8. Scoring systems are widely applied.

The data handling from field recording to processing by the computer is briefly described and illustrated.

The statistical analyses of the material are carried out and discussed at two levels, namely:

a) Individual experiments
b) Across experiments

Severe imbalance in provenance representation across sites limits possibilities for provenance x site interaction studies. Nevertheless, an attempt is made to delineate a number of plantation/breeding zones and to demonstrate average performance of whole provenance regions within each of these.

Individual provenance recommendations are only possible for specific experimental sites.

1. Introduction

A series of internationally coordinated provenance trials of the broadleaved species: teak, Tectona grandis, have been subject to evaluation for a number of quantitative and qualitative characters during the period 1981-83. The incitement to organize a world-wide testing of seed sources from the natural habitats and some "landraces" of the species, has its origin in the action programme formulated by the FAO Panel of Experts on Forest Gene Resources in 1969, in which teak, among other species, was given top priority for provenance investigations. Collection and distribution of provenance samples were carried out in 1971-73 and, in the years following the collections, trials were established throughout the tropical zone on a variety of site conditions. Details of seed collections are given in chapter 2. In order to give an impression of the material involved in the investigations a summary is presented below:

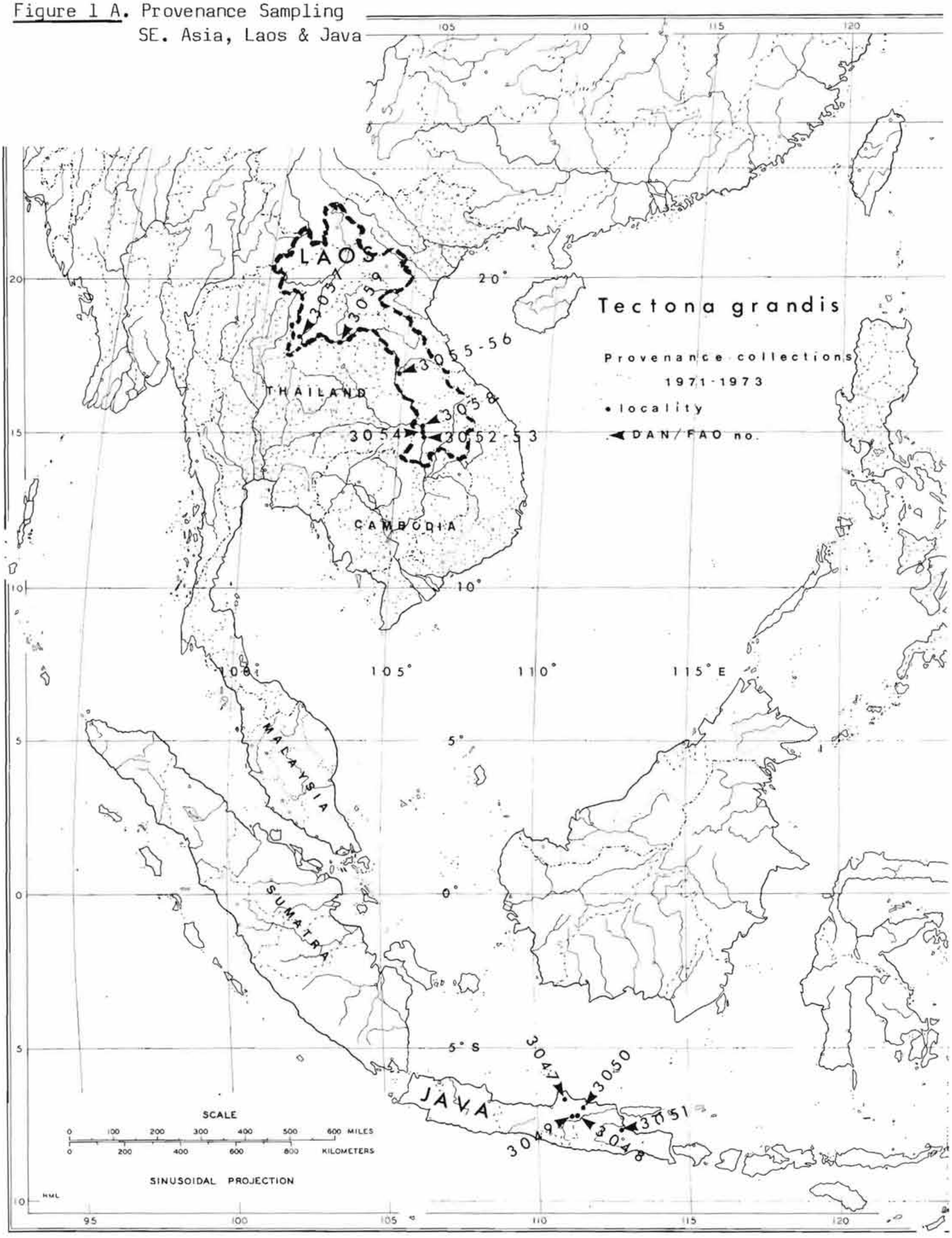
No. of provo collected	No. of trials established	No. of trials evaluated	% of trials evaluated
75	48	21	44

Due to the scope of the assessment scheme and the characteristics of broadleaved species the following two aspects of the evaluation had to be specially developed:

1. Methods of assessment and recording of multiple characters.
2. Methods of handling data and interpretation of the observations.

In the following the procedures applied for these two aspects of the provenance investigations will be described. They will be illustrated by results from the analysis of individual experiments as well as an overall analysis across sites.

Figure 1 A. Provenance Sampling
SE. Asia, Laos & Java



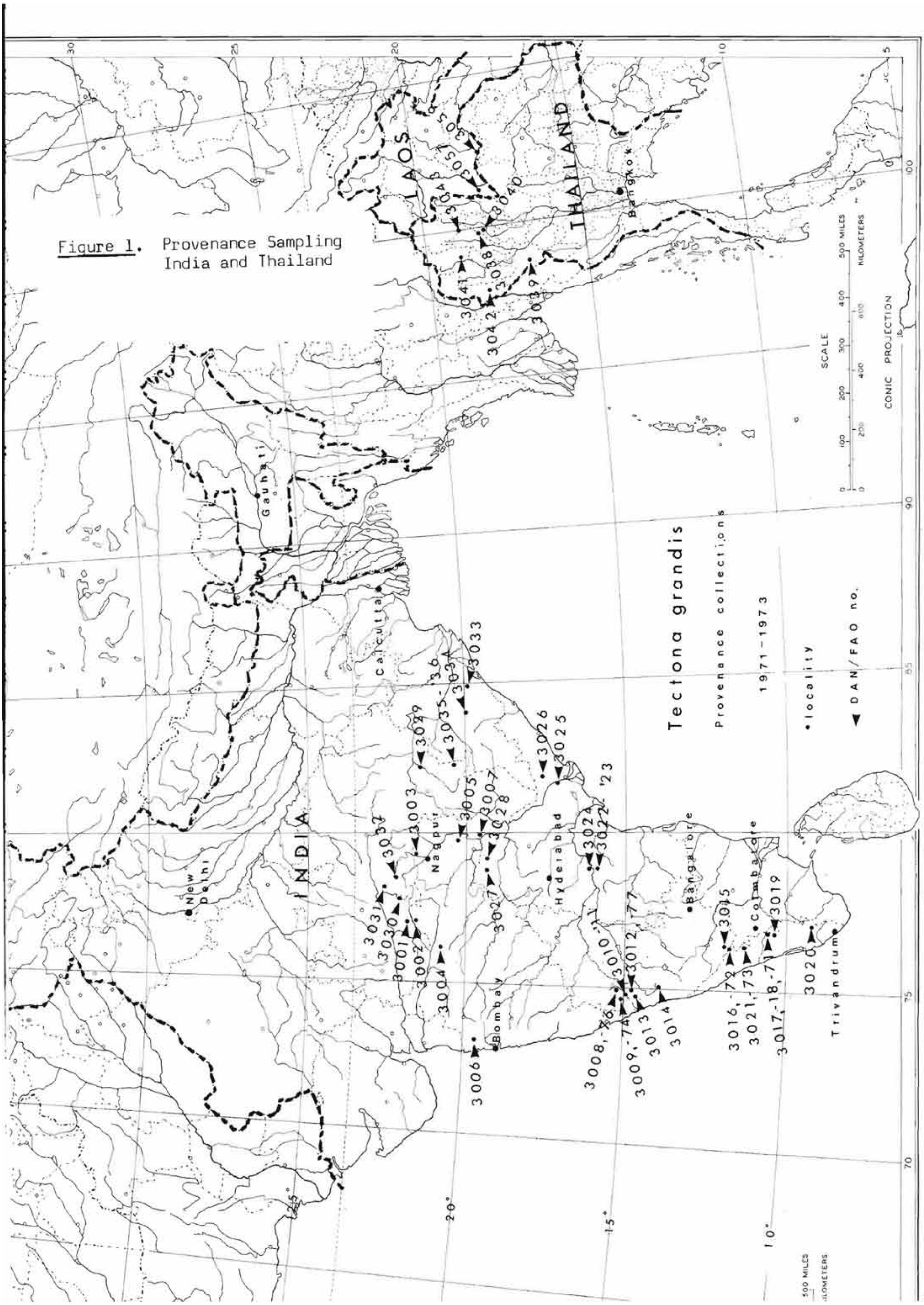


Figure 1. Provenance Sampling India and Thailand

Figure 2. Provenance sampling African Landraces

Fig. 3: Teak provenance trials evaluated 1982-84.

2. Seed collection anti distribution

2.1. Seed collection

The aim of the collections was to obtain as broad a representation from the whole range of distribution as possible, covering the more typical and distinctly different types of environments. In the concept of provenance this is the first stage in which the magnitude and pattern of variation between populations within a species may be estimated and regions of provenances identified.

The scope of collections was determined by the wide interest throughout the tropics in growing teak as a plantation species and in connection with gene resource conservation to obtain an estimate of gen-ecological variation between populations.

The natural distribution of teak covers a wide area geographically, ranging from the Indian sub-continent in the West through Burma, Thailand and Laos touching Cambodia to the East and naturalized on Java as the southernmost occurrence. Teak grows naturally mainly in the mixed, deciduous forests of the monsoon belt with a distinct seasonal climate (wet and dry seasons). Apart from Java its latitudinal limits are roughly 9^0 - 25^0 North, but it is found on a wide range of rainfall regimes (600- 3000 mm annually), varying soil types, topography and tree associations. Thus a number of different habitat correlated populations can be distinguished both on morphological characterstics and adaptability.

In addition to sampling from the natural distribution of teak, collections were also obtained from domesticated populations or socalled "landraces" outside the range as for instance in West- and East Africa. Such local populations or provenances may be of considerable interest for studies of patterns of adaptation and changes in genetic composition.

Three principal sources have been subject to collection as follows:

a) Indigenous, natural teak.
b) Plantations deriving from natural teak in the same area.
c) "Landraces" or local sources, outside the natural range.

Exploration in respect of preparatory investigations of occurrences, sites, assoriations with other species, climatic and environmental data were carried out by studying available literature and seeking advice from local authorities. An important guide for deciding where and what to collect was found in the classification of teak-growing forests in India from Champion & Seth: "A revised survey of the forest types of India", 1964.

According to this classification the following 5 types of natural teak forests are distinguished on the basis of 7 factors (rainfall, soil, biotic factors, percentage of teak, associated species, ground cover and regeneration) and are listed below in order of increasing rainfall regimes:

	Annual Rainfall
i. Very dry teak forest	600 -900 mm
ii. Dry teak forest	900 -1300 mm
iii. Semi-moist teak forest	1300-1600 mm
iv. Moist teak forest	1600-2500 mm
v. Very moist teak forest	> 2500 mm

Similar classifications were not available for the occurrences in the Burma, Thailand, Laos complex although different types of forests are described for Burma (Troup, 1928) and may be distinguished in Thailand (Apichart, 1981). The teak forests on Java constitute a separate group being naturalised teak of probably South Indian origin with more than 400 years of domestication.

During 1971-72, a total of 64 provenance samples were collected for international trials, of which a little more than half came from India. By the excellent cooperation of the Indian Forest Service and Forest Research Institute the Seed Centre managed to collect from 35 different localities distributed over the five different forest types containing teak. Samples from Indonesia, Thailand, Laos and parts of India were collected by the Teak Improvement Centre in Thailand. Other samples have been obtained directly from forest departments in Ghana, Ivory Coast, Togo, Cameroun and Tanzania. Without this support the comprehensive collection would not have been possible. Still a full representation both from the natural habitat and of landraces has not yet been achieved. The full list of provenance samples used in the experiment is shown in appendix A.

The regulations for provenance sampling concerning minimum number of trees and distance between parent trees, as prescribed by IUFRO, (Lines, 1965) were followed as far as possible. Seed from individual trees were mixed. Stands were described according to a standard collection sheet (Keiding 1973).

It was estimated on the basis of enquiries prior to collections that about 20 kg of seed (fruits) would be required from each locality, an estimate that proved to be a little on the low side.

The locations of the collections are shown on maps figure 1. South East Asia and figure 2. Africa.

The method of collection was in all cases picking the seed from the ground.

2.2. Seed distribution

All seed from the collections was sent to the Danish Forest Service Seed Extraction Station in Humlebaek for storage, registration and subsequent dispatch.

The distribution of seed began in 1972 and the first field trials were established in 1973 followed in 1974 with the majority of trials. Internationally coordinated trials continued to be laid out in 1975 and 1976 at a slower rate. By 1977, a total of 75 provenances were under test on over 50 sites in 16 countries (Keiding, 1977).

The background for distribution of provenance samples was the response to an invitation to join the internationally coordinated trials. No limitations were set for the number of provenances that could be included in the trials provided there was sufficient in stock. However, recipients of seed were asked to include 1-4 standard provenances in each trial. A few guidelines for experimental lay-outs were also given, recommending simple designs as randomized complete blocks with 3-4 replications, plot size of 36 to 49 trees and planting distances of 3 x 3 m. In case it was desired to test more than 15 provenances lattice designs were suggested (Circular letter No.2, 1971).

In the absence of facilities for testing actual germination capacity, the quantity of seed dispatched to individual trials was based on cutting tests and the number of seeds (fruits) per kilo. Combined with the unknown extent of dormancy and varying skill in nursery operations the result in some cases was too few seedlings for the planned trials initially and supplementary seed samples had to be provided where possible.

In retrospect a better balance should have been attempted between local requests and the overall requirements for testing provenance/site interaction. See later under the discussion in section 4.4: Overall analyses across sites. Of the 48 originally established trials, 21 were assessed according to the procedure described in this paper. Of these, 18 trials have been subject to analysis and evaluation. Their distribution is shown on the map in fig. 3. Provenance representation on the 18 trials is shown on Table 1.

3. Selection of traits and their assessment

In order to decide which characters to include in a provenance evaluation scheme as the present, both theoretical and practical aspects of provenance testing have to be considered. That the species in question is broadleaved gives ground for special considerations.

Table 1:

Provenance representation on trial sites.
Provenances subdivided into broad provenance regions and trials into trial-regions

PNG = Papua New Guinea
THA = Thailand
IND = India
MEX = Mexico
BRA = Brazil
NIG = Nigeria
GHA = Ghana
IVC = Ivory Coast

Provenance Regions	Trial Regions / Prov. Nos.	1 SOUTH-EAST ASIA				2 CENTRAL AMERICA				3 BRAZIL + W. AFRICA Moist				4 W. AFRICA: Dry + Semi-moist					
	Trial Nos.	PNG	THA		IND	MEX	ST. CROIX			BRA		NIG		GHA	IVC	NIG		GHA	NIG
		32	38	01	16	22	45	46	47	03	0[illegible]	24	26	08	18	28	29	09	30
A	SC 3002			x															
INDIA:	3003							x											
	3005							x											
	3007		x																
Dry Interior	3008			x				x											
	3015					x													
	3022													x			x	x	x
	3023					x													
	3032				x														
B1	3010							x											
INDIA:	3012							x											
	3013			x				x											
	3016	x	x					x							x	x			
Moist West Coast	3017	x				x	x		x										
	3018		x								x					x			
	3019	x	x																
	3020	x	x		x	x				x	x								
	3021	x	x				x		x	x	x	x	x	x		x		x	
	3071					x													
B2	3026															x			
INDIA:	3033	x	x									x	x			x			
	3034		x							x	x				x				
	3035				x						x								
Semi-moist	3036		x		x														
East Coast	SN 0001				x														
H1	SC 3038		x		x										x		x		
THAILAND	3039	x	x	x	x					x		x				x	x		x
	3040				x		x			x	x				x		x		x
	3041		x	x	x	x		x			x								
	3042		x					x								x	x		x
	3043		x	x	x	x										x	x		x
	SN 0133		x	x															
H2	SC 3053		x																
LAOS	3054					x									x				
	3055		x											x				x	
	3056		x								x			x			x	x	
	3057		x																
	3058					x													
	3059					x					x			x				x	
	3060					x					x								
	3061					x									x				
D	SC 3047	x	x											x		x	x	x	x
INDONESIA	3048	x	x											x		x	x	x	x
	3049		x	x			x		x	x	x	x	x	x		x	x	x	
	3050	x	x											x			x	x	x
	3051		x														x		
	SLTG 14	x																	
	SLTG 24	x																	
E	SC 3037		x		x	x									x				
AFRICAN	3044					x	x		x	x	x			x			x	x	x
	3062					x													
	3063					x									x				
Land-races	3064					x													
	3065					x									x				
	3066					x													
	3067					x									x				
	SG 01													x				x	
	03													x				x	
	04													x				x	
	SN 119											x	x			x	x		x
	SNTB 73														x				
R	SN 78					x													
LATIN AMERICAN	79					x													
	80					x													
	81					x													
Land-races	82					x													
	83					x													
	SAB						x		x										

As the stated object of provenance research with the DANIDA Forest Seed Centre is "to assist tropical countries to select the most appropriate seed sources of important species for establishing plantations under local conditions of climate, soil and for providing a basis for further improvement" (Anon., 1986), then it is implied that choice of characters would primarily be those which are of interest from a utilization point of view. In principle the number and nature of these characters should be adequate for a proper investigation of variability within and between provenances and consequently form a basis for selection of seed sources.

The practical aspects concern the available resources in techniques, time and personnel to assess the trials and for the development of a procedure which is applicable to many experiments at different site conditions. This means actually the establishment of a standard method which may be used by different people and with varying intensity. Ideally a system of that nature should possess:

a) clear and unequivocal definition of terms and description of characters/ classes,
b) flexibility in application, and
c) simplicity in operation and recording.

With these high and to some extent incompatible goals in mind, procedures for the assessment of teak were started in 1981.

However, the assessments of teak were faced with the problem that qualitative characters such as branching habit, persistence and straightness of stem etc., have been undertaken before. Not knowing the patterns and scope of variation of individual characters we had to work out scoring systems and classifications based on observations and guesses combined with trial runs of the system.

3.2. Selection of characters

The assessment comprises 8 characters, which are either measured or scored, and a number of additional descriptions (labels) connected with individual characters:

Characters measured:	1. Height
	2. Diameter
Characters scored:	3. Straightness/Crookedness
	4. Persistence of axis
	5. Branch size
	6. Mode of branching
	7. Flowering
	8. Health

Additional descriptions (labels) attached to characters:

Characters	Label
Diameter	9. Survival
	10. Non-descriptive trees
	11. Plus-tree candidates
Health	12. Attack by insects and/or fungi/ bacteria
Persistence	13. Broken axis: two categories
Straightness	14. Basal sweep
Branch size	15. Epicorrnics
Mode of branching	16. 3 categories of branches influencing branching
Flowering	17. Atypical floweringfrom side-branch

For measuring **growth** we need **diameter** and **height**.

Regarding the quality of the tree, it is generally accepted that a long, straight bole with small knots is desirable from a utilization point of view. Therefore, we include straightness/crookedness, persistence of axis and branch-size in the evaluation. For the judgement of straightness we consider primarily the severeness of bends and secondly their number for the whole length of unbroken axis in each scoring. In other words we do not make separate scorings for sections of the axis. The reason for doing this is that the tendency to crooked or straight growth is best displayed in the upper part of the stem while in the lower part bends may be more or less overgrown, although still present in the interior portion of the stem. As a consequence of the lesser weight given to the lower part of the stem, straightness is not scored for persistence classes 1-3, i.e. where the axis does not persist further than to half the tree height. In our experience nearly all trees with stems or axis shorter than half the tree height are straight or non-descriptive (multiple stems). In all other cases bends visible at the lower half of the unbroken axis indicate usually a severe tendency to crookedness. In scoring straightness a tree has to be observed from two standpoints at right angles to each other.

Mode of branching is connected with quality of a tree in cases where it may be the cause of damage (windbreak) or give access to rot or disease. Forking is a typical example giving a weak joint where the two branches separate. With other types or modes of branching the connection is less obvious. When it nevertheless was decided to include different types of branching in the assessment, the reason was that branching habits might be a means to characterize provenances. From observations it was found that 5 modes of branching could be identified. The types are illustrated in fig. 5., under the description of scorings (sect. 3.3). The scale of scoring of the different types from 1-5, reflecting a valuation of the classes, was later shown to give problems in the analysis, due to uneven distribution to classes and due to classes in certain instances being identical to persistence classes.

Thus "light scatter" and "light forking" would only occur in persistence class 5, "spreading, regular branching" only in class 6, while "double limbs" and "pronounced scatter" might occur in 3 and 2 different persistence classes respectively. The effect of this was firstly that a meaningful average for branching habit could not be obtained and secondly that mode of branching would not add new information to the index system applied to the quality characters (see later).

However, the registration of different modes of branching has disclosed some provenance dependency and thereby helped to identify provenances.

Flowering in teak is considered an important factor in determining quality of a tree by its connection with persistence of axis and branching habit (Gram & Syrach Larsen, 1958).

Flowering is in almost all trees initiated in the terminal bud of the axis. The big inflorescence, when it dies after one growth season, disrupts the continuous growth of the axis and causes normally two opposite branches to take over and the branching-out to start. Therefore the first occurrence of flowering in relation to age and height of the trees is important to register, in order to investigate its future effect on other qualities such as persistence and branching habit. There are strong indications of flowering having a high heritability and that selection, although unintentionally, has led to early (in age) flowering populations or landraces, where teak has grown as an exotic (West Africa, Trinidad). It should be noted that emphasis has been laid on observing initiation of flowering rather than on abundance, and therefore the scoring of this character is particularly relevant in younger stands where the trees pass into the mature stage.

Health, as will be noted, is recorded in 3 classes only. For a simple survey of the state of health we have found it appropriate to distinguish between the following 3 categories of tree:

a. those which were attacked by both insects and fungi/bacteria,
b. those attacked by either insects or fungi /bacteria, and
c. those which were free of disease.

The aim of applying such a simplified registration of health is to obtain a general impression of healthiness of the provenances on different sites irrespective of the agents causing the pests or disease. Thus in principle only the symptoms and the number of trees affected were registered but not the degree of damage made to individual trees. The latter, it was realized, would require more time and specialised knowledge than we were able to provide for the present assessment scheme.

However, efforts should be made to complement these preliminary investigations with more in-depth studies of how pests and diseases effect individual trees, how they occur on sites and in regions and how provenances vary in susceptility to them.

A comparison of provenances for state of health on many sites is complicated by the fact that different agents on different sites are responsible for the varying effects. For instance in parts of Thailand the beehole borer is doing severe damage while defoliators are of minor importance and root disease does not occur. In India the defoliators are widespread and affect the growth of teak while beehole borers are absent, at least from the provenance trials. In West Africa a root disease may do damage or kill trees and in Brazil a bark disease occurs which has not been observed elsewhere.

Thus the present recording of health merely informs us about which provenances in general are healthy or sick while subsequent and detailed investigations should reveal more specifically which provenances are susceptible to certain diseases or pests, to which extent they harm the trees and what role the site conditions are playing.

It may be asked why **wood quality** has not been included in the assessment of teak. Teakwood is generally of high quality and in respect of density not much provenance variation has yet been observed (Smeathers, 1951; Purkayastha *et al.* 1975). The most sought after characteristics of teawood are connected with the colour of the heart wood and formation or deformation of black streaks. Neither of these are possible to investigate by simple means such as taking out smaller wood cores, but would in more advanced stages of breeding certainly be factors to consider.

3.2.1 Field recording

This is carried out on data recording forms, of which a specimen is shown in appendix B.

The form contains a section for basic information about the experiment and its material, consisting of the first 6 main headings (from the left) with 10 sub-headings. Further, a section for the actual data of the 8 characters measured or scored, plus one column in reserve. Within the column of each character there is a sub-division into two columns headed by 'D' for data and 'L' for label respectively. The 'label' column is used for the additional descriptions. As all headings are given in full text, the forms may be used without prior knowledge of the coding system, which is applied in the transfer of data to the computer (see fig. 6). An indication of the coding system may be seen under each character name, e.g. 9-2, 21-D etc.

One recording form may register 30 individual trees. In order to use the recording form correctly and uniformly, explanatory notes were worked out (Keiding, 1981). The notes contain detailed information about terms, prefixes, classifications and descriptions. Basically the terms and the coding system are the same as those used at the tree breeding section of the Arboretum, Hørsholm, and the data is stored in and retrieved from that system. New terms and descriptive methods have naturally been made to suit the special features of teak.

Although such explanatory notes are essential for a uniform assessment over many sites and with different persons involved, they have to be complemented by exercises in the field. Whenever new officers were engaged in the assessments, time was taken to explain the application of the system and in particular the scorings and classifications while the comprehension of the system was checked from time to time during the field recording.

Manpower and time required for carrying out assessments of teak are as follow's:

Height + diameter	2 persons (+ 1 person in difficult terrain)
Scoring	1 person
Recording	1 person

i.e. 4-5 persons. A team of this size can conveniently complete 12 plots each of 25 trees, in a 7-hour working day. Thus a trial comprising 10 provenances in 5 replicates can be assessed in approximately 4 days, to which must be added time for supplementary descriptions.

3.2.2 Scorings

Obviously scorings may be considered from a number of view points and as most of the assessment consists of scorings of different characters, it may be of interest to discuss the systems in different contexts, e.g. recording capture of variation, genetic information and implications for statistical handling.

As stated earlier the choice of characters to be assessed depended on their assumed importance for utilization in matters of production and quality. The ideal tree from this point of view is considered to be a healthy, vigorous tree with a straight, cylindrical and clean bole, a stem persisting to the top of the crown and a spreading branching with branch angles around 90^0, to mention the visual characters only. In adopting the ideal tree-image a more or less diliberate valuation of classes is taking place. This is reflected in the marks allocated to the different classes, the highest score being given to the best class approaching the ideal. However, in the analyses presented later in this paper it is the distribution or frequencies of trees in different classes which have been subject to analyses, while the scores have merely been used as designations or codes for individual classes. A better founded evaluation is obtained when economic values are attached to characters and classes as demonstrated in the final presentation of results.

Some other aspects of the scoring and its applicability should be considered.

i. Age, or rather height and development of the trees are decisive for the scoring of a number of characters, e.g. stem straightness, branching, flowering and health conditions. An assessment as proposed above and in the following would need, as a lower limit, an average tree height of about 5 meters. An upper limit will no doubt also exist but about this we are less certain.
ii. Individual characters need different considerations and number of classes will vary accordingly. For instance stem straightness has been allocated 5 classes while flowering has only been given 3.

iii. A scoring system should be applied to one character only. For example "persistence" and "straightness" are kept separate in the assessment of stem-form.

iv. The identification of classes and thereby their numbers within each scoring system should be based on previous observations of the variability. As indicated under point ii, the number of classes depends on the individual character, its pattern of variation and the information required. When applying only 3 classes for scoring of flowering the reason is that we only require to know whether flowering has started or not and, if begun, whether it was recent (few) or of older date (many).

v. A pre-requisite for carrying out most of the scorings is that these take place in the leafless season.

3.2.3 Supplementary descriptions of characters

In the course of the assessments we often come across characteristics which are connected with individual characters but occur independently of classes. In order to catch these supplementary descriptions of characters without resorting to classifications, the concept of "labels" has been introduced. The object of the label system is to refine the distinction between provenances in supplement to the results from the scorings and to specify information about the state of the experiment such as site variation and unmeasured trees.

In a way the label-system may be considered as a formalised or standardised notebook.

To illustrate the application of labels, the scoring of persistence in teak, for instance, may be supplemented with the information that the interruption of continuous growth was caused by an accidental break (label A) or that the persistence included a "kink" or a "near-break" (label K). Dead, missing or non-measurable trees are recorded in connection with measuring diameter/height and informs directly about survival. With the position control of individual trees it may also give indications of site variation (labels: - and 0).

As the information from labels differ in nature and purpose, the handling of them is complex and, at the time of writing, no attempt has been made to include labels in the analyses.

The labels used in the assessments are listed at the end of chapter 3.3, table 6, in which individual label codes are indicated as well as the characters to which they are allocated.

3.3 Description of scorings and labels

Stemform

Persistence of axis: 6 classes

The total height of the tree is divided visually into 4 equal portions. The length of unbroken axis is scored according to the quarterly section to which it can be followed. In addition two classes, one at the beginning and one at the end of the scale, are recorded. See table 2 and fig. 5:

Table 2: Classes of persistence, teak

	Score
Double or multiple stem from ground level	1
Axis (single stem) branches out in the lowest quarter of tree	2
Axis branches out in 2nd quarter of tree	3
Axis branches out in 3rd quarter of tree	4
Axis branches out in 4th quarter of tree	5
Complete persistence	6

Straightness of stem: 5 classes

Straightness is only recorded for persistence classes 4-6, because judgement of bends on that relatively small portion of stem in classes 1-3 is considered irrelevant.

Table 3: Classes of straightness, teak

	Score
Crooked - more than 3 serious bends	1
Crooked 1-2 serious bends	2
Slightly crooked, many bends	3
Slightly crooked, few bends	4
Straight	5

A bend is defined as the distance between two tops of a stem, as indicated in fig. 4:

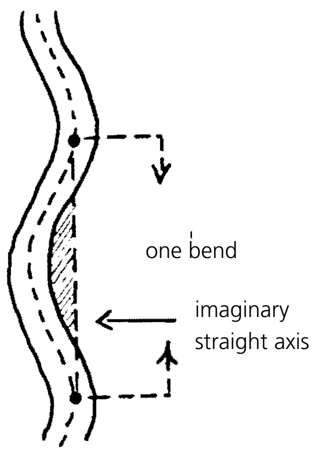


Figure 4:

A bend is considered serious if the side of the stem curves outside a straight line (imaginary axis) drawn through the length of a bend or if bends can be recognized at breast height.

Branching habit

Branch size (thickness): 5 classes

The classification of branch "coarseness" is a relative measure of branch size in proportion to the stem at the foot of the branches.

Table 4: Classes of branch size

	Score
Very heavy: branches from ½ - ¾ of stem	1
Heavy: branches about ½ of stem	2
Medium: branches between ½ and ¼ of stem	3
Light: branches around ¼ of stem	4
Very light: branches less than ¼ of stem	5

Branch size may be a little difficulty to classify as branches within a tree vary in size. Therefore the scoring must be based on a general impression (average size) of the branch thickness.

Mode of Branching: 5 classes

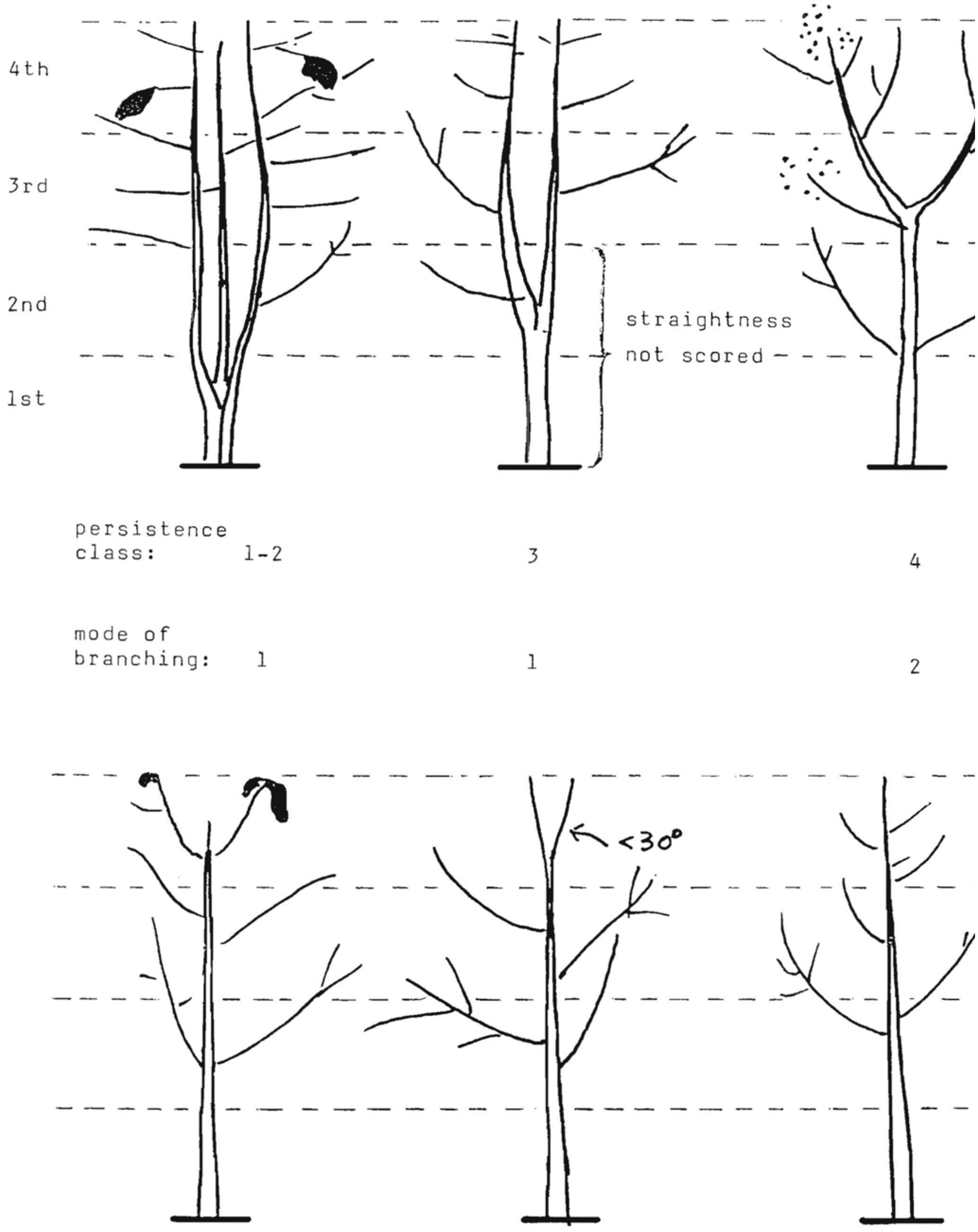
For the application of this scoring system certain conditions are required: trees must a) be leafless or almost leafless and b) have reached an eaverage height of 8-10 meters.

The different modes of branching are illustrated in figure 5. They are named and classified as shown in the figure and in Table 5:

Table 5: Classes of branching modes

	Score
Double limbs	1
Scattered branching pronounced	2
Light forking	3
Scattered branching - light	4
Regular, spreading branching	5

Figure 5: Scoring of persistence and mode of branching



To help to distinguish between the five different types some additional description is given below:

Forking:	branch angle between the two limbs $< 30^0$, branches of equal or almost equal size.
Scatter:	branch angle between two or more leaders $>30^0$
Light:	scatter or forking occurs in the quarter of the tree corresponding to persistence class 5.
Pronounced/ heavy:	scatter or forking takes place in one of the 3 lowest quarters of the tree corresponding to persistence classes 1-4 (both inclusive)

The individual classes may be described further by three different labels R, M and X, (see table 6) in order to cover variations independent of classes which do not justify special classification. See under the heading "Supplementary descriptions of characters".

Flowering: 3 classes

	Score
Many: 3 - more inflorescences	1
Few: 1 - 2 inflorescences	2
Nil: no inflorescence	3

State of health

Only a simple recording has been used for the present evaluation:

	Score
Affected by both pests and diseases	1
Affected by either insects or fungi/ bacteria label	2 +
Free of attacks - healthy	3

Note: For class 2 a lable indicating insects (G) or fungi/bacteria (C) may be added.

Table 6: Labels

Character		Score
Height or diameter:	-	Tree is dead
	o	Tree present but not measured -too small
	E	Replacement
	+	Plus tree candidate
State of health: (class 2 only)	G	Attacked by insects
	C	Attacked by fungi/bacteria
Persistence:	K	Kink or broken axis, cause unknown
	A	Broken axis, clearly accidental break
Straightness:	B	B Basal sweep
Branch size:	E	Presence of epicormic branches
Mode of branching:	R	Repeated forking
	M	Individual, bigger branches with narrow branch angles, easily recognizable from the main portion of branches.
	X	Several large branches rising from almost the same point. Axis still remaining.
Flowering:	A	Flowering from side branches. An atypical flowering habit.

4. ANALYSIS OF OBSERVATIONS

4.1. Data handling

Experience from many places has shown that the following stages of evaluation: field recording, data handling, statistical analysis and interpretation constitute a rather lengthy and demanding process which requires organisation as well as skill. In many cases these stages develop into bottlenecks which may postpone important decisions for years. In our case the development of the system has taken 18 months.

An outline of the procedure used at the DANIDA Forest Seed Centre is shown in figure 6 (page 22). Two outputs to hosts of the individual experiments are indicated; the left one in the figure concerning the actual experiment and the right one, whole series of experiments of which the local one is a member among others.

4.2. Statistical analyses of individual experiments

The aim of these analyses has been:

a) To quantify the reliability of each experiment
b) To give genetic estimates of provenances for each character
c) To give a survey of the aggregate genetic value of provenances concerning health, growth and quality.

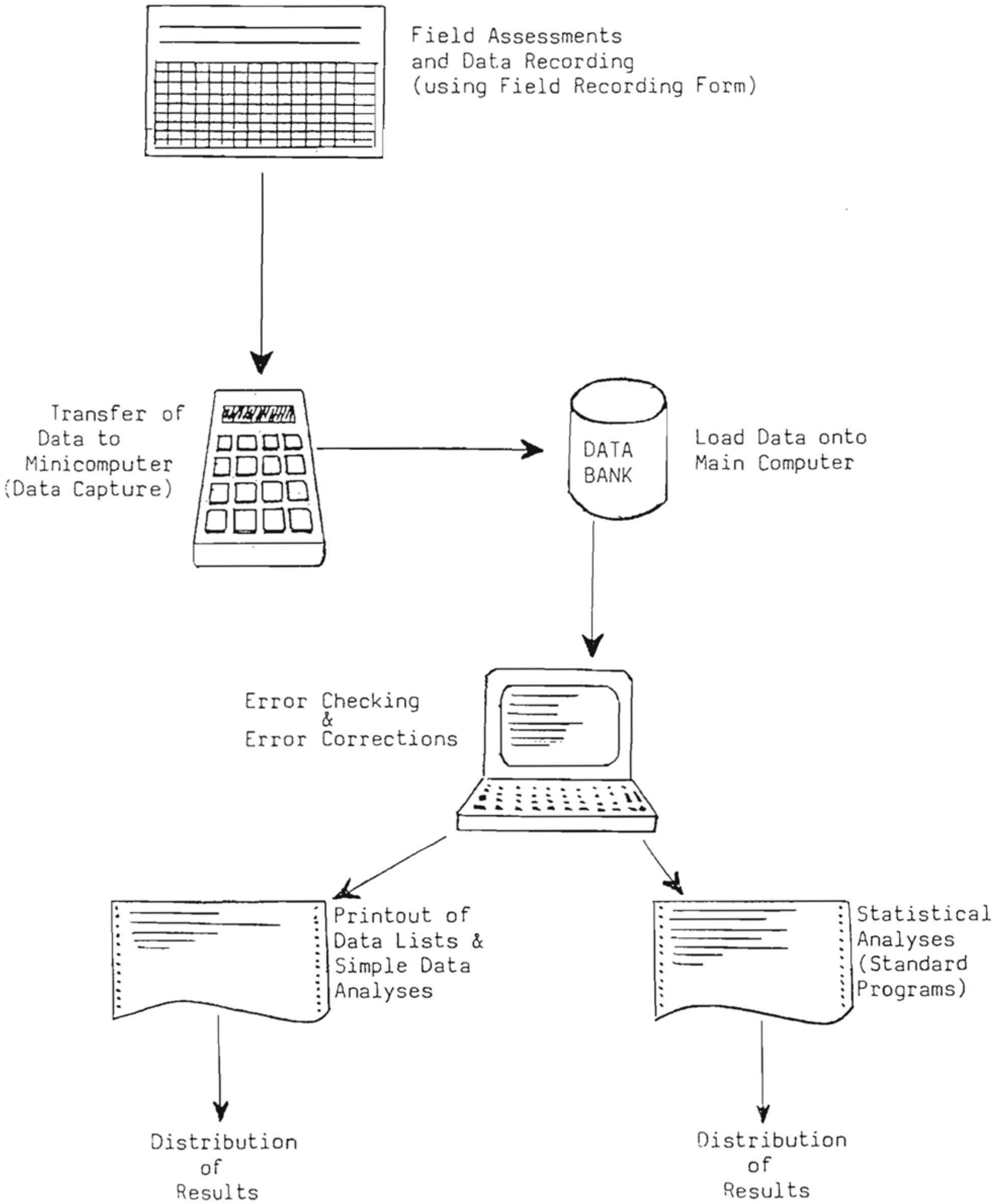
The tool with which to obtain this is primarily the 2-way analysis of variance of plot-means.

4.2.1 Type of characters and transformations
The characters defined in Chapter 3 can be classified into 3 groups:

a) Quantitative or metric characters
b) Semi-quantitative characters (scorings)
c) Qualitative or discrete characters, in this case threshold characters (scorings).

a) Quantitative or metric characters
Examples are diameter and height. Provided a sufficient number of trees have survived in a plot, plot means are calculated. These mean values are computed in a number of alternative ways, one of which is the simple arithmetic mean. For diameter, a basal area weighted mean is calculated as well.

Fig.6: Outline of data processing system at DFSC



b) Semi-quantitative characters

Trees have for certain characters been referred to classes whose values, from 1-6 for example, increase at a linear rate. This situation is an in-between stage, between the true quantitative "metric" characters and the simple either/or scoring of the qualitative (discrete) characters. As a consequence of this, two alternative analyses have been performed, one based on simple arithmetric means of the scorings and the other based on an arc-sin transformation of the proportion of the best one or two classes.

c) Qualitative or discrete characters

Here the atypical example is survival. The difficulty is that proportions follow the binomial distribution, i.e. the variance is dependant of the survival level. The analysis of variance requires the same variance for all observations - in our case plot-means. The arc sin transformation is applied to obtain this through the whole range of proportions from 0-1.

4.2.2. The two-way analysis of variance

The two-way analysis of variance of plot means has been performed for each character at each site, according to the usual model:

$$Y_{ij} = \mu + \alpha_i + \beta_j + \epsilon_{ij}$$

where:

Y_{ij} = plot mean
μ = overall mean
α_i = provenance effect
β_j = replication effect
ϵ_{ij} = random error

Variance components have been estimated and F-tests as well as heritability of the provenance means have been calculated. An example from experiment IP016, India, is shown in table 7.

Table 7: Two-way analysis of variance and heritability for straightness - arc sin transformation of proportion of best two classes.

Source of variation	Sums of squares	d.f.	Mean squares	E(ms)	F-ratio
Provenances	0.75192	10	0.07519	$\sigma^2 + 4\sigma^2$ prov	4.36***
Replications	0.16393	3	0.05464	$\sigma^2 + 11\sigma^2$ repl	3.17*
Error	0.51711	30	0.01724	σ^2	

$$h^2 = \frac{VG}{\text{prov.mean } V_G + V_E} = \frac{\sigma^2 \text{ prov.}}{\sigma^2 \text{ prov} + \frac{\sigma^2}{r}}$$

(Burley & Wood, 1976)

where:
r =number of replications

σ^2 prov. is the variance component for provenance.

h^2 for experiment IP016 is then: **0.77**

In this particular case the experiment has balanced, but very often we run into situations where one or several plots are missing. If there are several missing plots, we have to rely on advanced computer programmes such as the SAS package of statistical programmes and use procedures such as GLM and VARCOMP to obtain F-tests and epected mean squares (Barr et al. 1979, Freund and Littel, 1981). In these cases provenances have different provenance-mean heritabilities due to different values of r.

4.2.3 Genetic estimates of provenances

The next problem is to derive, for each character, genetic estimates of the provenances in the experiment. If the experiment is balanced, the simple provenance-mean is interpreted as a phenotypic expression of that particular provenance, amongst a "population" of other provenances represented in the environment of the field test. As with individuals within populations, the reliability of the phenotypic observation as an expression of the genotype is expressed by the heritability (Falconer, 1960). See figure 7 and table 8.

Fig. 7: The meaning of provenance-mean heritability

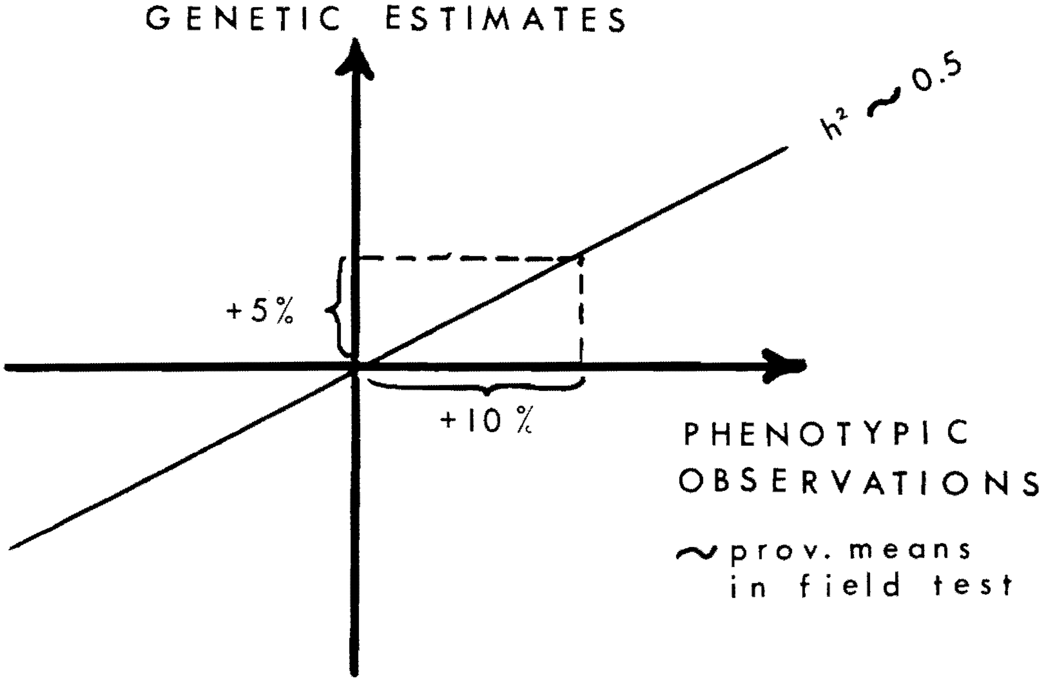


Table 8: List of phenotypic observations and genetic estimates

Prov. i	Phenotypic observation prov.means⁺⁾ Pi	h²	Genetic estimate⁺⁾ Gi
1	+ 10%	0.5	+ 5%
2	0		0
3	- 15		- 8
4	+ 4		+ 2
.	.		.
.	.	v	.
Average	0		0

* expessed by deviations from the experimental mean.

As can be seen from table 8 all phenotypic observations, as well as genotypic estimates, are transformed to deviations from the grand mean or "population" mean. By the outlined method we can obtain h^2 between 0 and 1. Low h^2 coincides with lack of significance in the F-test of provenance means. We have carried out the calculations in all cases where $h^2 > 0$, thereby breaking down the awkward separation of "significant" from "non-significant" cases. Even a "bad" experiment has some information worthwhile gathering.

If the eperiment is imbalanced, we cannot use simple mean values any longer for estimates of phenotypic values as the variation between the replications give bias to the simple provenance average. The GLM procedure computes an adjusted mean (LS-mean) which solves this problem (Freund and Littel, 1981).

In the imbalanced case we, furthermore, have different provenance-mean h^2. If a provenance is represented only in some of the replications, that particular provenance mean, calculated with an adjustment by the LS-mean procedure, is estimated with reduced precision. That means that the environmental effect (VE) is larger, and therefore the provenance mean heritability, for that particular provenance is lower according to the general formula.

$$h^2 = \frac{V_G}{V_G + V_E}$$

V_E is - in this case - calculated as the square of the standard deviation of the actual LS-mean.

4.2.4 Correlation between characters

Correlation between characters is important to consider in any selection. Correlation can be studied at different levels, e.g. at the level of individual trees or provenance-means. In the simple job of provenance evaluation and selection, correlations at the level of provenance means are most important. Simple correlations between characters can be computed on provenance mean values (phenotypic values) and we denote such correlations: **phenotypic correlations**. To which extent such correlations reflect genetics at the provenance level depends on the reliability of the phenotypic provenance means, i.e. the provenance-mean h^2. If these are all high for the recorded characters as in the example from trial IP 038 in Thailand, we have found the following estimates based on provenance-means of phenotypic correlations:

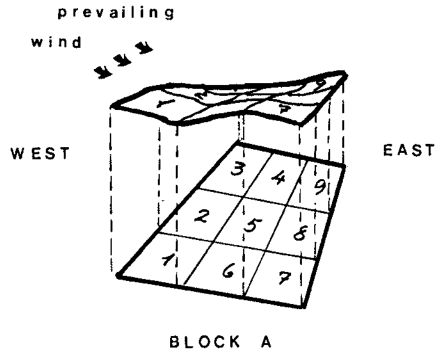
Table 9: Example of phenotypic correlations between 4 quality characters

	Straightness $h^2 \sim 0.41^+$	Persistence $h^2 \sim 0.51^+$	Branch Size $h^2 \sim 0.68^{+++}$	Lack of Flowering $h^2 \sim 0.84^{++}$
Straightness	1.00	-0.09	-0.26	0.13
Persistence		1.00	-0.11	0.02
Branch size			1.00	0.40^+
Lack of Flowering				1.00

4.2.5 Adjustments for uneven environments within blocks.

One of the important contributions to the exprimental error of field experiments laid out as randomized block experiments is uneven blocks. That is the unavoidable environmental heterogenity within each of the replicated blocks. Sometimes, this heterogenity is systematic, where for instance some sort of general trend affect a cross section as shown in figure 8:

Fig.8: Example of systematic heterogenity within B replicated block.



In such cases we use the plot position within blocks as covariable in an analysis of covariance (ANOCOV) and test the significance of such effects. when ANOCOV is applied, adjusted provenance-means are tested and obtained by the SAS-procedure GLM with LS-mean statements. In the analysis of each experiment a whole array of ANOCOV-models as well as the simple 2-way ANOVA model have been attempted and the most appropriate model is selected. A number of criteria are used in the selection of models, such as:

low error variance,
high between-provenance variance component,
simplicity,
a certain balance in consumption of degrees of freedom for tracing genetic versus environmental effects.

It often happened that an ANOCOV-model was able to make a better separation of provenances than the simple 2-way ANOVA. A special paper about these adjustments is under preparation.

4.3. Analyses of multiple traits within individual experiments.

As already described previously, quite a number of characters have been recorded. Therefore, it is desirable to "boil down" the large number of observations to simple terms.

4.3.1. Three separate indices for health, growth and quality

Our first approach has been to construct 3 separate indices, one for health, another for growth and a third for quality. The separate characters behind these headings are listed in table 10.

The term "index" has been used in the classical meaning and is referred to as the Smith-Hazel Index (Lin 1978). In our first approach we have not found it appropriate to calculate the full index, as this requires good estimates of genetic parameters in the actual field tests, and this requirement is seldom fulfilled for all characters. What we have actually done is to calculate the aggregate genetic value for each provenance :

$$H_i = \sum_j a_j g_{ij}$$

where:

H_i = aggregate genotypic value for provenance i

a_j = economic weight of trait j, $\sum_j a_j g_{ij} = 1$

g_{ij} = Genetic estimate of provenance i for trait j, $\Sigma_i g_{ij} = 0$

This is an approximation to the complete index w which is reasonably simple to construct.

Table 10: Grouping of recorded characters and composition of economic weights and aggregate genetic values.

GROUP/ HEADING	Observations			Economic weights		Derived aggregate genetic value
	Original Character	Scale of record.	Plot Statistics	Propor-tions	Scaled to unity (a_j)	$H_i = \sum a_j g_{ij}$
1 **HEALTH**	General Health	1-3	Proportion of healthy trees	1	0.33	→
	Survival	1,2	Proportion of surviving trees	2	o.67	→ ↓
Total	Health			3	1.00	$H_{i(health)}$
2 **GROWTH**	Diameter	cm	Basal area weighted average diameter	1	1.00	→ $H_{i(growth)}$
	or alternatively:					
	Diameter Plot area	cm m^2	Basal area per ha.	1/2*)	0.50*)	→ $H_{i(growth)}$
3 **QUALITY**	Persist-ence	1-6	Proportion of best class	2	0.33	→
	Straight-ness	1-5	Proportion of best two classes	1	0.17	→
	Branch size	1-5	- " -	1	0.17	→
	Flowering	1-3	Proportion of non-flowering trees	2	0.33	→ ↓
Total	Quality			6	1.00	$H_{i(quality)}$

For all characters going into the Index: the higher the plot-statistics, the higher the value.

*) A 5% increase in diameter corresponds to a 10% increase in basal area/ha. Therefore we must reduce the weight of the latter with 50%.

4.3.2 Economic weights

The economic weighting is an attempt to catalogue the value of one unit of character A in comparison with one unit of character B.

For the 4 quality characters we have more or less arbitrarily judged a 10% increase of proportion of "straight trees" to be of the same economic importance as a 10% increase in the proportion of "finebranched trees". The character persistence has been judged to be twice as important as straightness, i.e. a 10% increase in proportion of "persistent trees" has been assigned the same value as a 20% increase in proportion of straight trees.

By demanding that economic weights within each index sum up to 1.00, we obtain the advantage that all indices are scaled equally, i.e. an index value of + 5 means a genetic determined 5% higher value than the experimental average which is set to zero.

Certain precautions should be kept in mind when interpreting these rather simplified indices. In **Appendix C** a worked example of the whole procedure is given for a typical field experiment.

Lack of much variation between provenances in certain experiments is very often due to variable site conditions within experimental areas (height error variance -> low provenance-mean heritability). In the final summary table in appendix C, the actual heritability of each character is stated as well as the experimental average.

Another feature of for instance the quality index is that the different characters can substitute each other, so a given index-value can be obtained by different character combinations.

If we compare the two provenances in Exp. IP 001, 3043 and SN 133, they sum up to aggregate genetic values of + 6 and + 7% respectively. These indices have been obtained in the following way.

Table 11: Example of character substitution within a 4-character Index.

Prov	**Genetic Estimates for**				**Aggr. Genetic Value** $H_i = \sum_j a_j g_{ij}$
	Straight-ness	Persistence	Branch Size	Lack of Flowering	
3043	+ 5	+ 10	- 2	+ 7	6.16
SNO 133	+ 17	+ 7	+ 4	+ 2	6.50
Economic weight a	0.167	0.333	0.167	0.333	

4.3.3 Provenance performance within indvidual experiments.
The actual performance of the tested provenances on the different sites is tabulated in Appendix D, table 1, 2 and 3. These 3 tables present health, growth and quality respectively and the unit is the index, i.e. the aggregate genetic value in percent deviation from the local experimental average.

In appendix D, fig 2-19 individual histograms for each experiment is presented. One of these histograms is presented in fig. 9. In these histograms it is possible to obtain a visual impression of the characteristic pattern of each tested provenance concerning health, growth and quality. In each figure a box presents appropriate key statistics about the experiment, i.e. averages and heritabilities for each trait which is contributing to the 3 indices.

4.4. Overall analyses across sites

Although local experiments may be useful for local choice of provenances, some sort of broader scope is needed.

The aim of overall analyses across sites is to develop provenance recommendations in different plantation zones. The actual plan of the investigation across sites is presented in fig. 10.

4.4.1 Description of method and its application
According to the flowchart in fig. 10, the first step ① is to group provenances into broad provenance regions. These groups are already indicated in the list of provenance collection sites in appendix A and shown on the map, figure II.

As indicated, we have used the term "provenance region" for quite extensive areas. This is considered in accordance with the official definition of provenance regions as stated by OECD, 1974: the area or group of areas subject to sufficiently uniform ecological conditions on which are found stands showing similar phenotypic or genetic characters.

The ecological conditions we have used are mainly annual rainfall in association with broad geographic regions.

The reason why we prefer to delineate so large areas as provenance regions is that the provenance representation on sites is very "thin" and imbalanced (table 1) and therefore we are only able to develop general recommendations concerning whole provenance regions in equally broad plantation zones.

The delineation is attempted in steps as illustrated in fig.10: steps - ② -> ③ -> ④ -> ⑤ -> ⑥ . The first step is to group trial sites to trial regions ② and then question whether provenance x site interactions occur ③.

From Table 1 it is painfully evident that provenance representation on the evaluated trial sites is very incomplete. As provenances as well as trials are

Appendix D, fig. 2

IP 001, HUEY SOM POI, Thailand

Lat. 18° 40' N. Long. 99° 55' E. Elev. 350 m. Annual rainfall: 1400 mm. 8 provenances tested

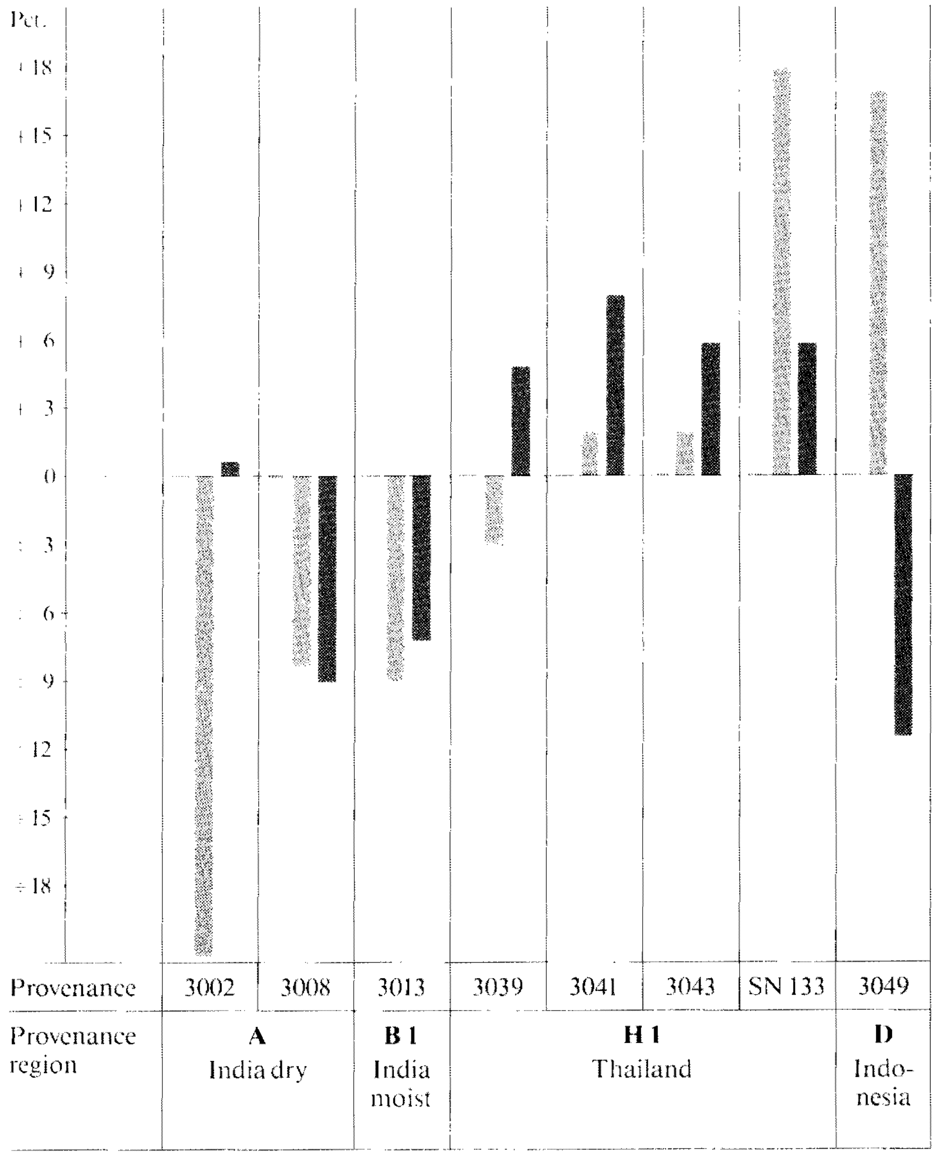


Figure 9.

Example of graphical presentation of provenance performance within an individual experiment.

Group	Indiv. Traits		Exp. mean	h²
Health	SURV.	(%)	87	.81
	HEALTH	(%)	18	.82
Growth ▒	DBH	cm	13.2	.94
Quality ■	STR.	(%)	8	.87
	PERS.	(%)	50	.80
	BR. SZ.	(%)	16	.48
	L. FL.	(%)	91	.84

stratified into 2 levels, interactions too can be studied at more than one level. The study of provenance x site interactions has been limited to natural populations or populations with a long adaptable history. Excluded from the study are therefore African and Latin American landraces, whereas the Indonesian populations are included due to their presumed long history of adaptation on Java.

The study of provenance x site interaction has furthermore been limited to growth. This character is the most basic and most susceptible to environments, provided survival and health is satisfactory and this is generally the case with the evaluated experiments.

A number of ANOVA models were attempted for diameter growth. Basic unit was provenance-mean at each site. The problem of different validity of each experiment due to uneven provenance-mean heritabilities were solved by using these as weight factors.

Fig. 10: Plan of overall investigations across sites.

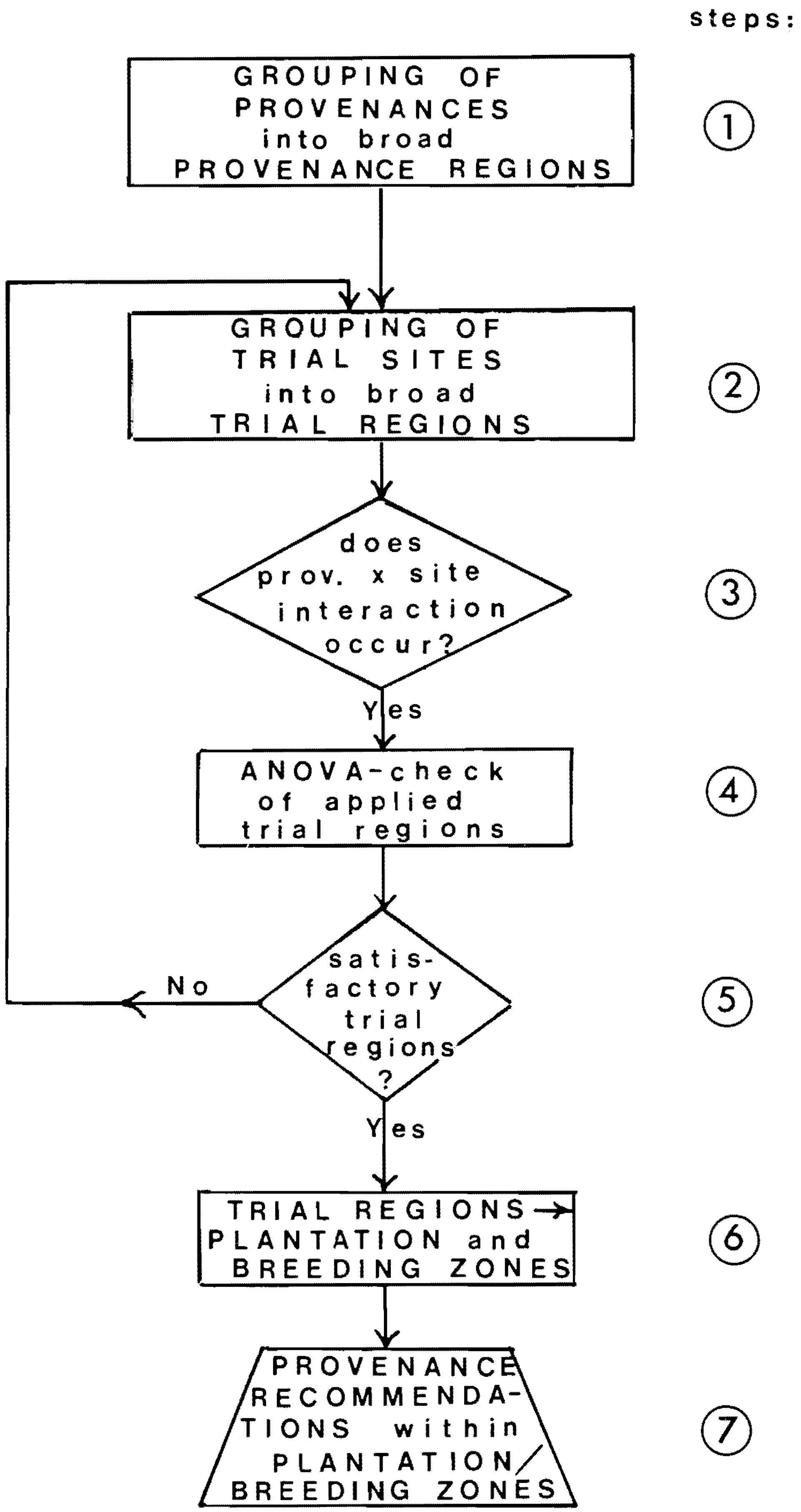
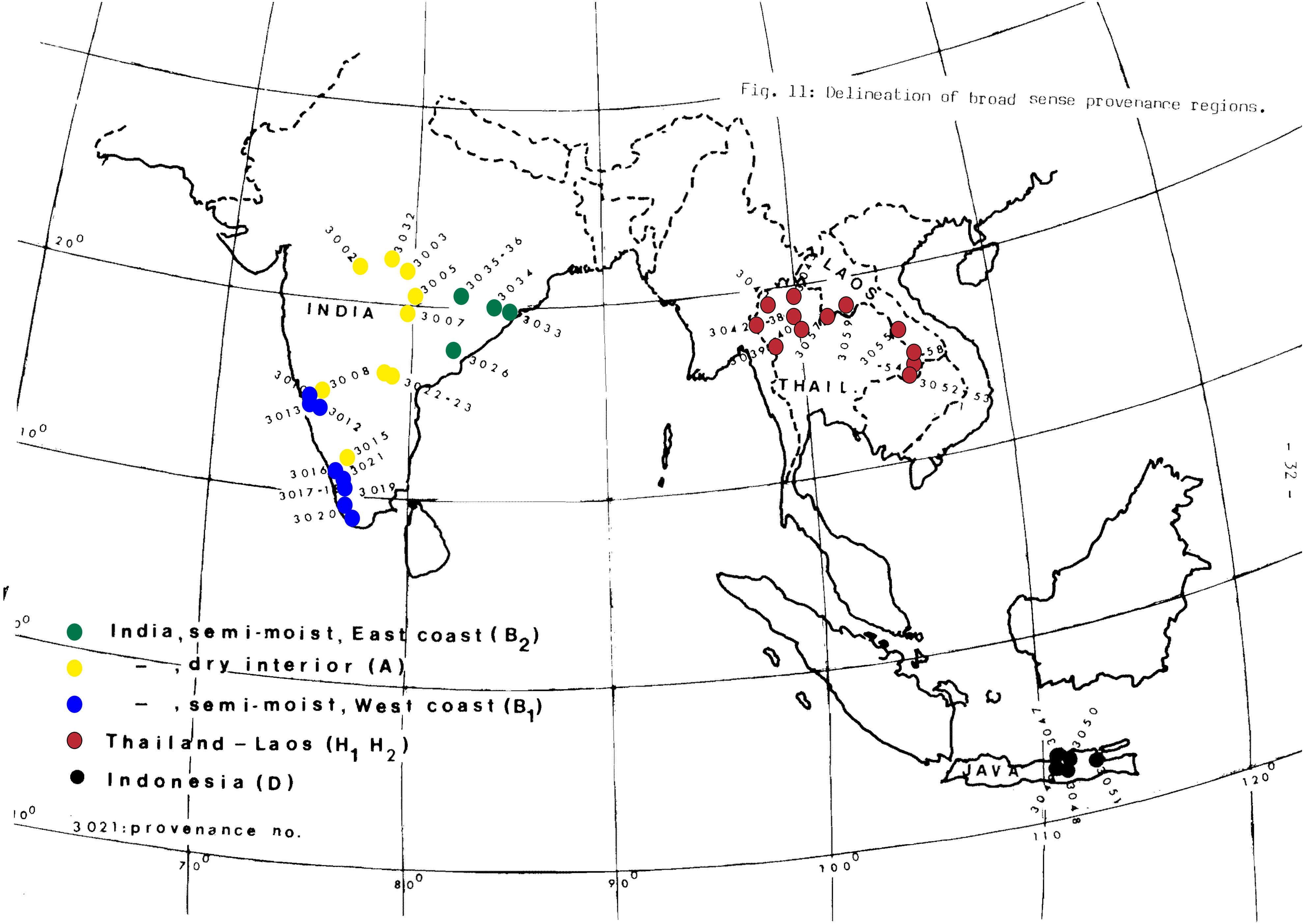


Fig. 11: Delineation of broad sense provenance regions.



Analysis No.1, step '3': **Problem**: Do interactions occur?

ANOVA-model.

$D_{j(i), l(k)} = m + a_i + b_{j(i)} + c_k + d_{l(k)} + f_{ik} + l_{j(i), l(k)}$

where:

$D_{j(i), l(k)}$ = Diameter of prov. j within prov.-reg. i on trial l within trial reg. k

m = Overall mean
a_i = Effect of provenance region i
$b_{j(i)}$ = Effect of provenance j within provenance region i
c_k = Effect of trial region k
$d_{l(k)}$ = Effect of trial l within trial region k
f_{ik} = interaction between prov.reg. i and trial reg. k
$l_{j(i), l(k)}$ = random error

This analysis yielded a highly significant provenance-region x trial-region interaction. See Appendix E.

Analysis no. 2, step '4' : **Problem:** A critical look at the applied trial regions.

Within each of the 6 trial regions and for all trials pooled together:

ANOVA-MODEL

$D_{ik} = m + a_i + c_k + e_{ik}$

Where:
D_{ik} = Diameter of prov reg. i in trial k
a_i = Effect of provenance region i
c_k = Effect of trial k
e_{ik} = Random error, including prov. x site interaction

Concerning the error variance Within individual trial regions the following estimates came out.

Within trial-region error variance:

Trial Region	SS	d.f	MS
1	45.75	44	1.0400
2	17.48	20	0.8742
3	6.967	12	0.5806
4	0.3804	2	0.1902
5	4.310	19	0.2268
6	11.22	12	0.9346
Sum	86.107	109	0.7900[x)]

x) Pooled estimate within all 6 trial regions

This pooled estimate of within-trial region error variance can be compared with the error-variance in the analysis across all sites (ignoring trial regions).

The actual estimates came out as follows:

	Pooled within trial region	One overall trial region
d.f.	109	125
MS	0.7900	0.9622

As can be seen, our error variance, much of which is composed of provenance x site interaction, is reduced by the applied sub-division into trial regions. The individual ANOVA's are presented in appendix E, tables E2-E3. By studying the ranking of provenance-regions in trial regions, trial regions 3 and 4 could be pooled together as well as trial regions 5 and 6, ending up with 4 reasonably homogenous trial regions:

Former No.	Final No	Trial-Region	No. of Trials
1	'1'	South-East Asia	4
2	'2'	Central America	4
3	'3'	Brazil and West	4
4		Africa - moist	
5	'4'	West Africa intermediate +	6
6		dry	

Average genetic estimates of provenance-regions in the proposed 4 trial regions are shown on fig. 12.

This rather primitive trial and error method is applied because the "thin" provenance representation is insufficient to other more objective multivariate classification methods which have been applied at other series of provenance experiments (Wellendorf, Werner and Roulund 1986).

4.4.2 Proposed plantation zones and provenance performances

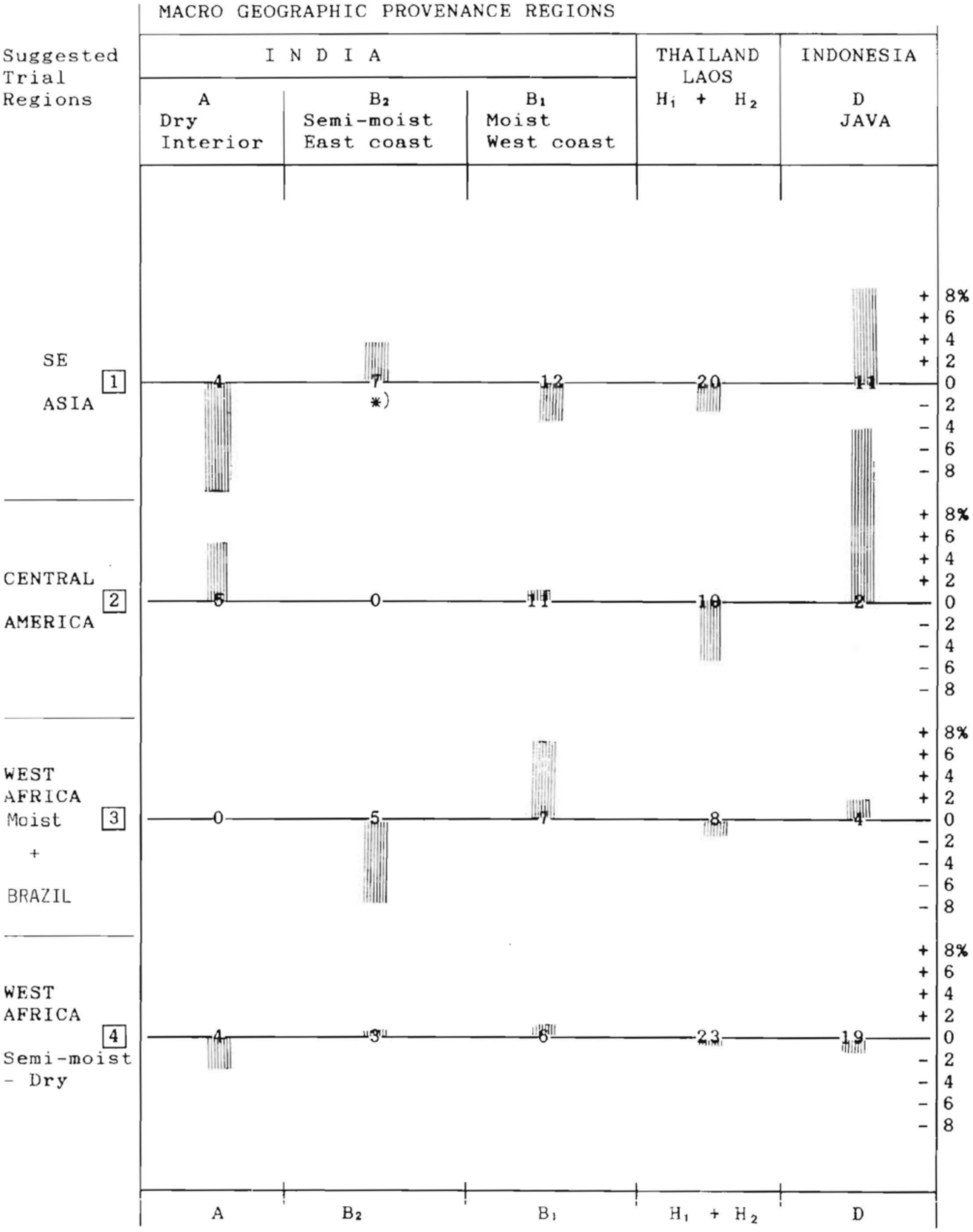
The aim of the overall analyses across sites was to give provenance recommendations in specified plantation zones.

According to the investigation lined up in fig. 10 we have detected severe provenance x site interactions for diameter growth and 4 trial regions are identified. In other words each of these trial regions has a characteristic variation pattern between provenance-regions concerning growth (figure 12). A practical result of this is, that provenance recommendations must be different in these trial regions.

Consequently, the trial regions may be considered as initial plantation zones concerning choice of provenances for plantation establishment and as initial breeding zones concerning choice of provenance for further breeding.

The average performance of provenance regions within these 4 plantation/breeding zones is presented in figures. 13-16.

Figure 12: Average genetic estimates of diameter growth for provenance-regions in the proposed 4 trial regions



*) No. of observations

Figure 13: Average performance of provenance regions for health, growth and quality in trial region **1**, **South East Asia** (Thailand, India, A. P. and Papua New Guinea) represented by 4 trials.

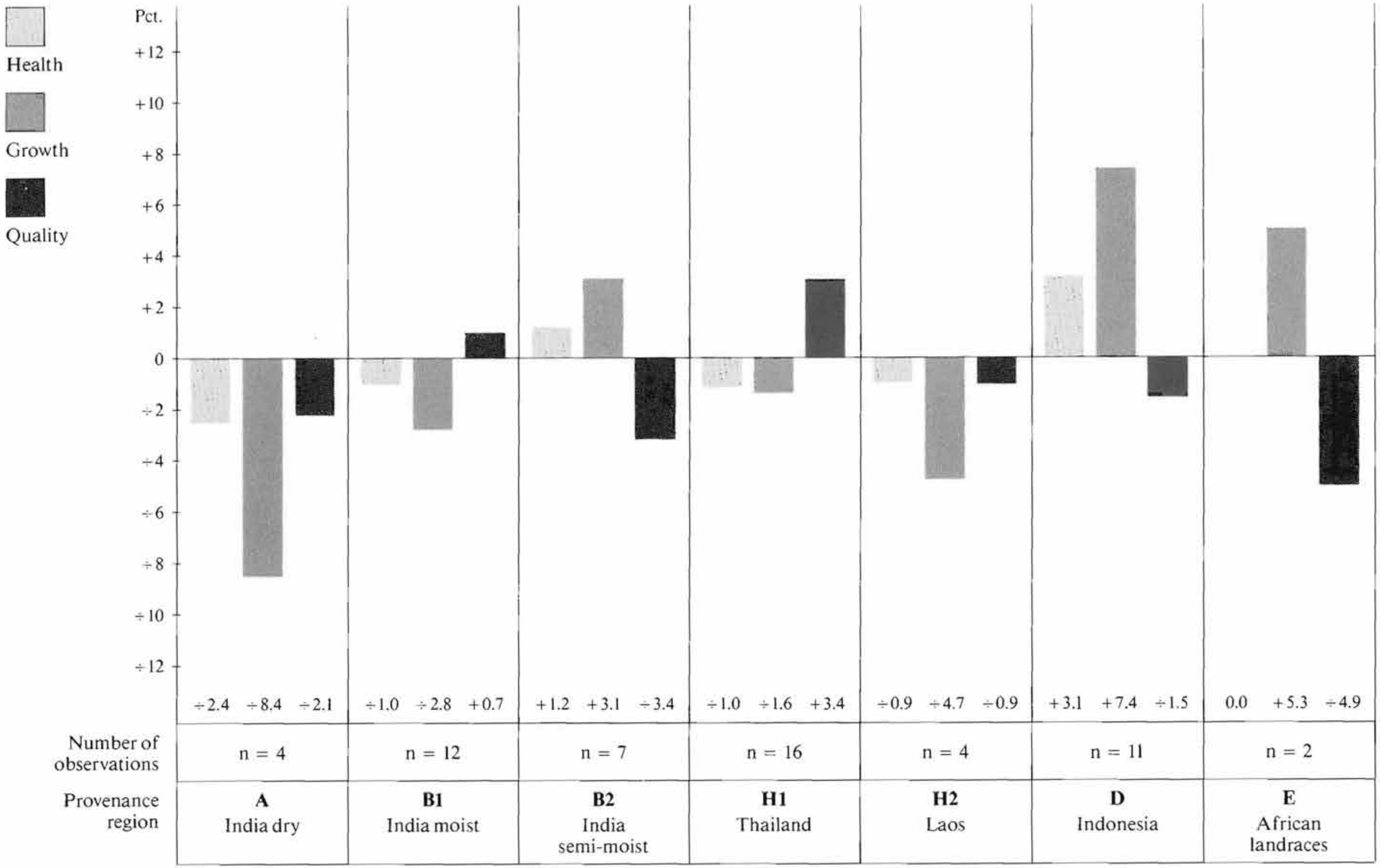


Figure 14: Average performance of provenance regions for health, growth and quality in trial region **2**, **Central America** (Mexico, Puerto Rico) represented by 4 trials.

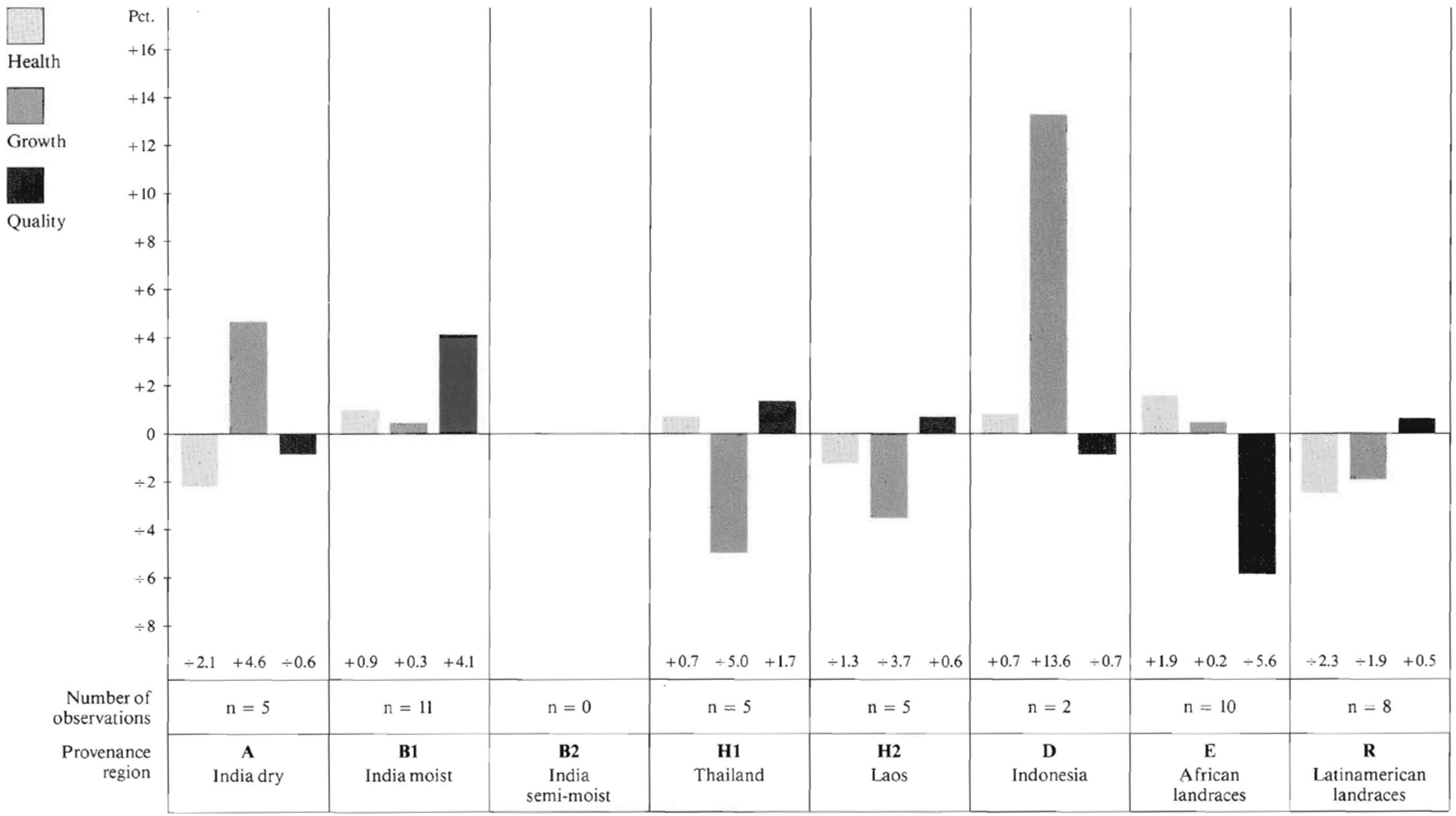


Figure 15: Average performance of provenance regions for health, growth and quality in trial region

3 , **West Africa, moist + Brazil**

(Nigeria South, Brazil-Aracruz) represented by 4 trials.

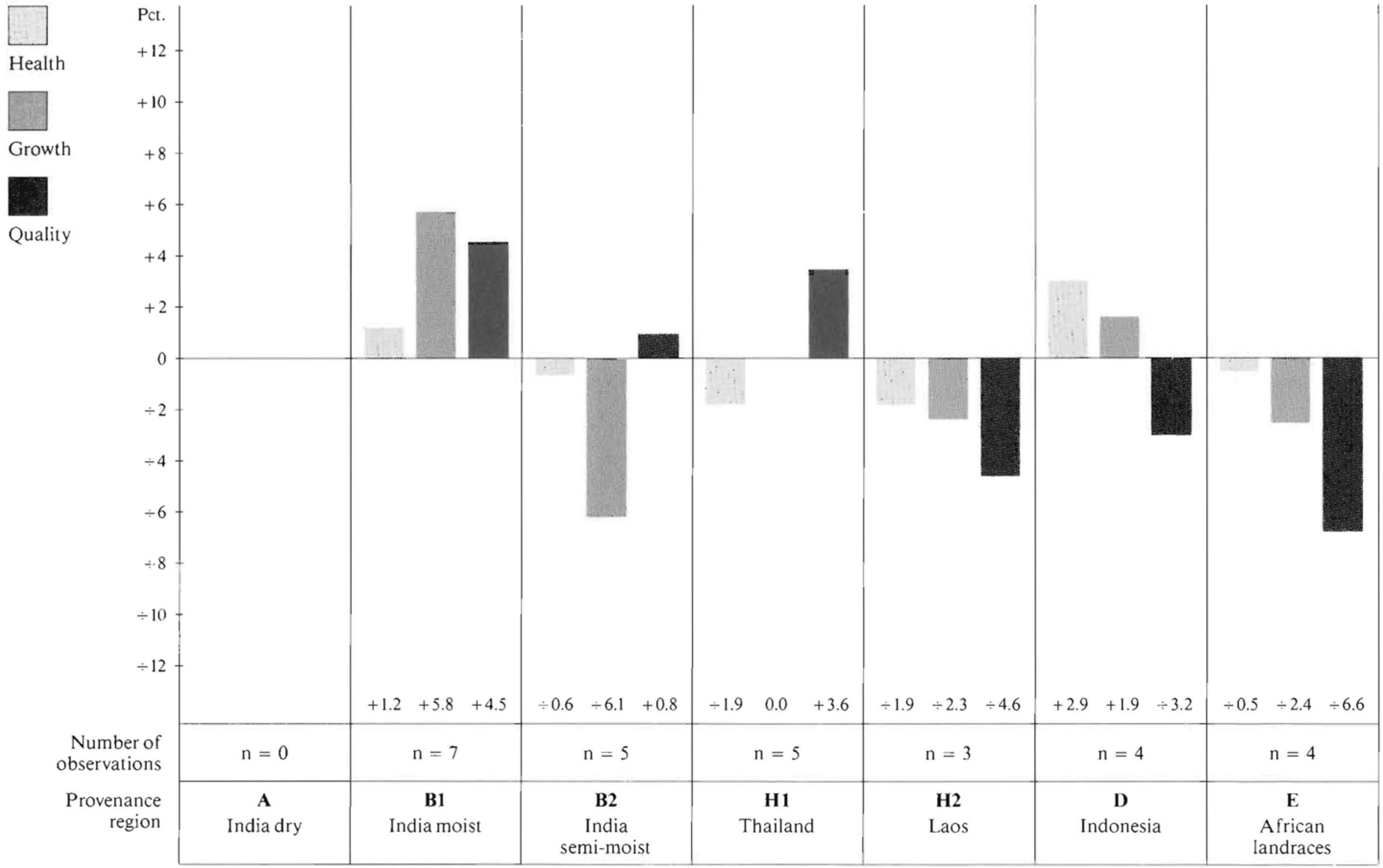
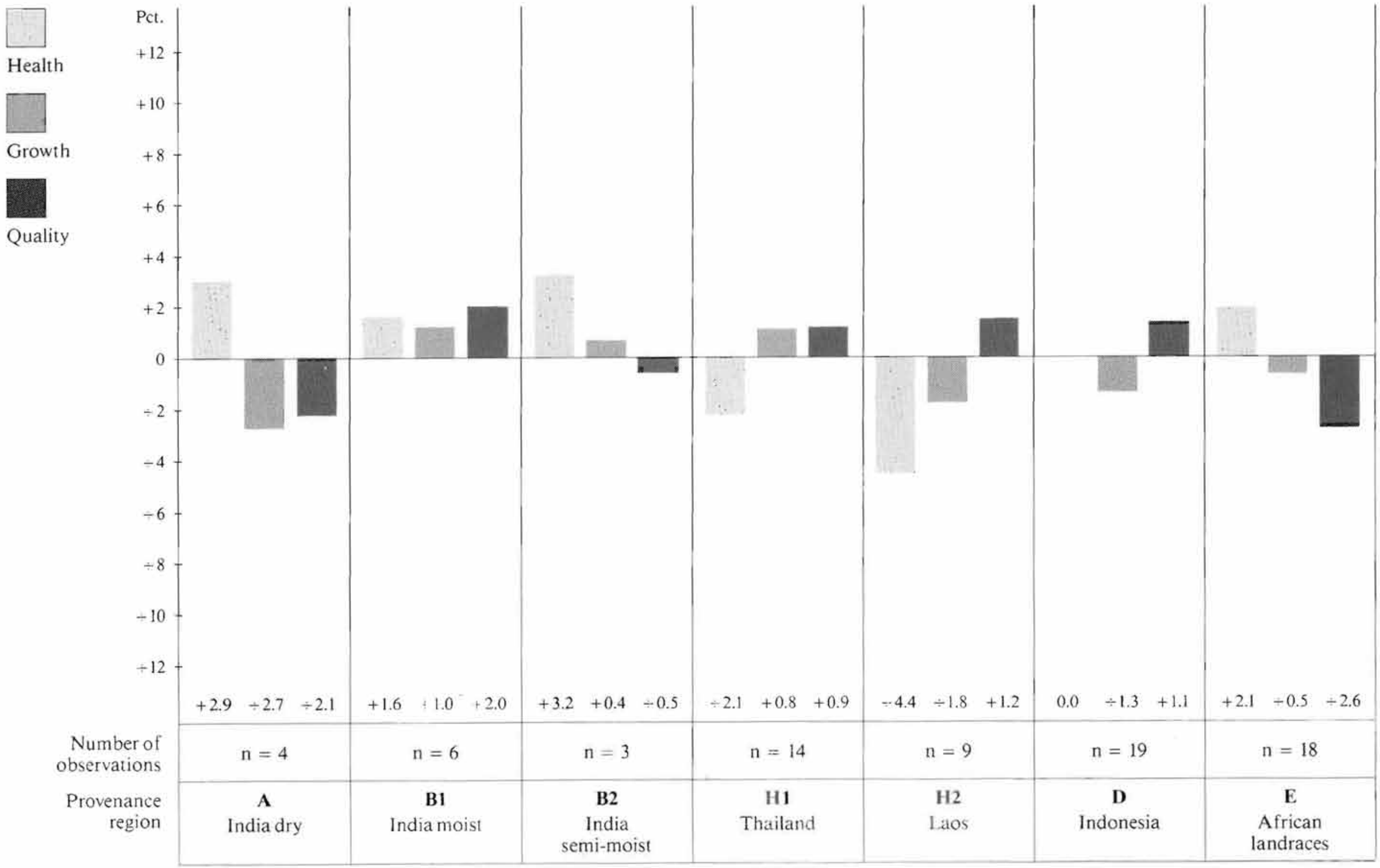


Figure 16: Average performance of provenance regions for health, growth and quality in plantation zone

4 , West Africa, semi-moist - dry

(Ghana, Ivory Coast, Nigeria) represented by 4 trials.



5. Recommendations

5.1. General procedure

In specific cases, i.e. choice of provenance in a specified area, the following procedure is recommended:

a) allocate your area to one (or two) of the 4 plantation/breeding zones.
b) find out, if one or more of the analyzed provenance trials is located in your neighbourhood.

Based on these two pieces of information, a general and a specific, it should be possible to make your specific choice of provenances, dependant of your own judgement of importance of health, growth and quality. Your choice should, of course, also be based on other sources of information, if available, for instance, already established plantations of known origin and possible local networks of provenance tests. Of course all this is not a guarantee that your favourite is the ultimate "right" choice. An array of possible errors or deficiencies are listed below:

i) Environments may vary within our very "thin" network of trials.
ii) Our evaluation is performed at a rather early stage - 10 years of a, say, 60 year rotation.
iii) There is still an appreciable amount of genetic variation within certain provenance regions.
iv) No samples from one of the major teak sources, Burma, are represented in the trials.
v) Seed may not be available from the desired sources.

On the other hand, the recommendations are the best available at the present stage. They may constitute a qualified guess as an alternative to seed supply from random local sources.

5.2. A case study for West Africa

Distribution of international provenance trials of teak in West Africa covers the countries of Ghana, Ivory Coast and Nigeria, which in respect of climatic conditions represent more or less the countries boardering the Gulf of Guinea from Sierra Leone in the West to Cameroun in the East. Characteristic for these countries is the change in rainfall regimes from high rainfall areas (> 2000 mm) along the coast to low rainfall areas (< 800 mm) in land boardering the desert. The pattern of precipitation is associated with the length of the dry season, which varies from 0-7 months of the year - also an important factor for growing teak.

The traditional zones for establishment of teak plantations are the moist high forest areas and the semi-moist Guinea zone extending with so-called kurmis into dryer conditions of the Sudanian zone i.e. quite a variety of site conditions.

On the basis of the analysis of the provenance trials it has been possible to distinguish between two major plantation zones:

③ West Africa moist + Brazil (fig. 15)
④ West Africa semi-moist dry (fig. 16)

In order to be more specific in the choice of provenances in a certain area for large-scale planting and breeding purposes the procedure outlined in section 5.1. may be illustrated with the following example:

Target: Improvement of material for planting in a rainfall regime of 1000-1600 mm annually.

Plantation zone:③

Nearest international provenance trial: IP 028, GAMBARI, Nigeria

A visual impression of provenance region performance and a general conclusion about choice of region can be seen from fig.16.

Assuming that equal weights are given to the 3 character groups: health, growth and quality the following criteria may be used for selection:

a) Best combined performance (above line) of provenance region in the plantation zone.
b) Exceptionally good performance in one character group i.e. either health, growth or quality.
c) Number of provenances (n) within the provenance region.

In plantation zone ④ under consideration, variation between provenance regions seems as a whole to be rather moderate.

Provenance region B1: India, moist west coast is, however, the only one above average in all 3 "characters".

We find better performances in health for both provenance regions,
A: India, dry interior and B2: India, semi-moist, east coast, but growth and quality are less, and mostly below average.

It is interesting to note that African landraces (E) perform well in health but not in growth and quality, when considered for the whole of the plantation zone.

The cautious conclusions that may be drawn from the performance of provenance regions in this broadly defined plantation zone ④ illustrated in figure16, would be that material from provenance region B1: India, moist west coast should be exploited further. This applies both to the testing and selection of specific provenances within the region B1 (see later) for different sites and their role as base for breeding populations. Adaptability may need special attention when introducing the sources from high rainfall areas to dryer areas of the zone. However, in several trials on drier sites elsewhere provenances from moist south-west India have survived and grown surprisingly well.

Due to the good health performance of the local race, which reflects high adaptability, it should be used as a second breeding population.

Selection of provenances within region

Plantation zone ④ is a very broad zone comprising a variety of site conditions. The average performances of provenance regions may therefore disguise considerable variation between provenances within regions.

Individual experiments offer a means to disclose the magnitude of this variation and to be more specific in the choice of provenance. Ref. section 5.1.b.

Experiment IP 028, GAMBARI is chosen for such an investigation.

Following the same procedure as outlined above for plantation zones and provenance regions (figure 16) the choice of individual provenances may be carried out using appendix D, figure 12.

Of the 3 provenances from provenance B1 present in the Gambari experiment, 3021, NILAMBUR, India, Kerala would be the first choice, due to its combined performance.

In terms of providing a breeding base, provenance 3033, BERBERA, India, Orissa may be included.

The local provenance SN 119 seems at this locality to equal 3021 and should be used continuously in the breeding programme, and for large-scale plantation establishment.

It should be emphasized that this selection may be adjusted by examining:

a) The table of key statistics in fig. 12 showing experimental mean, heritability and weight for individual traits, which the background for constructing the histograms = mean of character groups.
b) Other trials in the same plantation zone growing at similar climatic conditions and containing the same provenance(s) as in Gambari.

Referring to a) and experiment IP 028, Gambari, the quality performance is determined by the characters straightness and persistence only, missing the important characteristic of lack of flowering. This means "quality" is evaluated on lesser evidence than desired.

With reference to b) experiments IP 008 and IP 009 in Ghana (appendix D, figures 5 and 6) are located at almost the same latitude as IP 028, have rather similar rainfall regimes and contain both provenance 3021. Further the quality performance is determined by all 4 individual traits.

Both experiments confirm the choice of provenance 3021, and in case of experiment IP 009, with special emphasis on quality.

5.2.1 Supplementary remarks to case study West Africa

In the preceeding section one situation out of several has been chosen deliberately in order to demonstrate application and limitation of the available data. The principles and method may be used for other situations in West Africa as well as for other plantation zones (other continents), but each "case" where comparison with individual trials is possible should be considered separately.

We have considered such recommendations to be outside the scope of the present paper because this would make it far too bulky and unmanageable. It should also be noted that the presentation of data and graphs is based on one set of economic weights. If these are not considered valid in specific cases, new calculations and evaluations of "quality" and "health" will have to be worked out.

However, in both circumstances the authors are prepared to discuss and take part in the interpretation of results from individual experiments as well as the calculations connected with change of economic weights.

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List of Appendices

Table A-1: List of provenance collection sites

No. Designation	Provenance	Latitude	Longitude	Elevation m	Annual Rainfall mm	Provenance Region
		N	E			
3002	Kolkaz, Maharashtra	21° 30'	77° 15'	496	1638	
03	Nagpur, "	21° 18'	79° 34'	400	1270	
05	Lohara, "	19° 55'	79° 20'	200	1143	INDIA
07	Allapally Plains, "	19° 23'	80° 07'	160	1524	
08	Haliyal, Karnataka	15° 21'	74° 52'	610	1398	DRY
15	Antersante, "	12° 01'	76° 17'	762	890	
22	Bairluty 1, A.P.	15° 51'	78° 45'	305	1016	INTERIOR
23	Bairluty 2, "	15° 62'	78° 45'	305	1016	
32	Jhirpa, M.P.	22° 36'	78° 28'	396	1016	A
3010	Dandeli, Bl.II,Karnataka	15° 10'	74° 35'	573	2032	
12	Kolikeri, "	15° 01'	74° 49'	579	1778-2032	INDIA
13	Arbail, "	14° 50'	74° 41'	69	2565	
16	Masale Valley, "	11° 55'	76° 10'	823	1270	MOIST
17	Mount Stuart I,T.N.	10° 30'	76° 47'	671	2032	
18	" " 2 "	10° 30'	76° 47'	640	2032	WEST
19	Ulandy, "	10° 23'	76° 50'	732	2032	
20	Konni, Kerala	9° 03'	76° 41'	61	2540	COAST
21	Nilambur, "	11° 21'	76° 21'	49	2565	
71	Mt. Stuart, T.N.	10° 30'	76° 47'	640	2032	B_4
3026	Maripakala, A.P.	17° 45'	82° 15'	407	1524	INDIA
33	Berbera, Orissa	19° 52'	85° 05'	100	1200-1500	SEMI-
34	Purunakote, "	20°	84°	133	1200-1500	MOIST
35	Munda Reserve For.	20° 22'	82° 45'	300	1200-1500	EAST
36	Bakbahal, Orissa	20° 27'	82° 47'	315	1200-1500	COAST
SN 001	Local source, A.P.	-	-	-		B_2
3038	Ban Cham Pui	18° 29'	99° 49'	520	1200	
39	Ban Maekut Luang	16° 49'	98° 36'	220	1644	
40	Ban Pha Lai	18° 13'	99° 59'	200	1100	
41	Ban Mae Pam	19° 02'	99° 02'	450	1200	THAILAND
42	Ban Huey Luang	18° 14'	97° 56'	220	1282	
43	Ban Doi Thon	19° 03'	99° 59'	562	1200	H_1
SN 0133	Mae Huat, Selected Seed Stands	18° 45'	99° 59'	300	1200	

continued/...

No. Designation	Provenance	Latitude	Longitude	Elevation m	Annual Rainfall mm	Provenance Region
		N	E			
SC 3053	Pakse South I	15°04'	105°53'	170	1925	LAOS
54	" " II	15°07'	105°51'	120	1925	
55	Savannakhet I	16°33'	104°45'	100	1309	H_2
56	" " II	16°33'	104°45'	100	?	
57	Pak Lay East	18°13'	101°25'	150	1200	
58	Chumpi	15°16'	105°49'	50-100	1925	
59	Vientiane Town	17°56'	102°37'	50-100	1569	
60	Khong Island	14°10'	105°50'	50-100	1925	
61	Pak Lai Main Forest	18°10'	101°15'	20	1200	
		S	E			
SC 3047	Bangsri, Pati	6°30'	110°48'	75-100	3900	INDONESIAN
48	Nanas, Blora	6°57'	111°30'	250-280	1700	+
49	Ngliron, Ngliron	7°12'	111°22'	150	1200	PAPUA
50	Temandsang	7°12'	111°22'	104	1200	NEW GUINEA
51	Beran, Saradan	7°35'	112°45'	60	1830	
SLTG 14	Papua New Guinea, landrace					D
SLTG 24	" " " , "					
		N	W			
SC 3037	Bouake, Ivory Coast	7°48'	5°07'	310	1200	
44	Jema, Ghana	7°50'	1°50'	267		
			E			AFRICAN
62	Yoh, Palime, Togo	6°50'	0°35'	350	1700	
63	Tové, Togo	6°40'	0°40'	200	1300	LANDRACES
64	Atakpame, Togo	7°30'	1°15'	200	1450	
		S				
65	Bigwa, Tanzania	6°50'	38°39'	580	-	
66	Kihuwi, "	5°12'	38°39'	260	-	
		N	W			
67	Bambuku, Cameroun	4°26'	9°16'	210	1900	
SG 01	Landrace, Ghana*	7°50'	1°50'	-	1100-1600	
03	" "	7°50'	1°50'	-	"	E
04	" "	7°50'	1°50'	-	"	
		N	E			
SN 119	Landrace, Nigeria*	7°10'	3°52'	-	1300-1500	
		N	W			
SNTB 73	Landrace, Ivory Coast*	7°48'	5°07'	-	-	
SN 78	Landrace, Mexico*	18°26'	90°43'		900-1300	
79	" "	"	"		"	LATIN
80	" "	"	"		"	AMERICAN
81	" "	"	"		"	
82	" "	"	"		"	LANDRACES
83	" "	"	"		"	
SAB	" , Puerto Rico*	18°00'	65°50'		2000	R

* = geographical locations approximate

Table A-2: Location of Evaluated Trials

Trial No.	Country	Site Name	Latitude	Longitude	Annual Rainfall	Elev-ation
001	Thailand	Huey Som Poi	N 18° 40'	E 99° 55'	1400	350
003	Brazil	Aracruz	S 19° 46'	W 40° 16'	1400	50
005	"	"	"	"	"	"
008	Ghana	Pra Anum	N 06° 15'	W 01° 15'	1650	100
009	"	Tain	N 07° 30'	W 02° 30'	1140	100
016	India	Maredumilli	N 17° 36'	E 81° 43'	1470	500
018	Ivory Coast	Tenė	N 06° 05'	W 05° 05'	1300	250
022	Mexico	El Tormento	N 18° 26'	W 90° 43'	900-1300	100
024	Nigeria	Bende	N 05° 30'	E 07° 38	2150-2540	400
026	"	Sapoba	N 06° 01'	E 05° 46'	2500	100
028	"	Gambari	N 07° 12'	E 03° 53'	1260	400
029	"	Nimbia	N 08° 30'	E 09° 30'	1750	600
030	"	Afaka	N 10° 37'	E 08° 17'	1290	600
032	Papua New Guinea	Ederu	S 09° 04'	E 147° 06'	2000	50
038	Thailand	Pah Nok Krau	N 16° 45'	E 102° 00'	1300	300
045	Puerto Rico	Rio Abajo	N 18° 22'	W 66° 44'	2400	330
046	" "	Tract 105	N 18° 15'	W 65° 55'	2100	325
047	" "	St. Croix	N 17° 45'	W 65° 50'	1500	250

Data Recording Form

Page: ______

Measurements and Scorings of Single Trees (Tectona grandis)

EDP Code	Trial Code	Trial Number	Date of Assessment			Plant Material			Position in Trial					Diam./Girth (1.3 m)		Axis Persist.		Bran. Mode		Stem Str.		Bran. Size		Flowering		State of Health		Height				
			Year	Month	Day	Category	Number	Year Planted	Block	Plot Coord. x	Plot Coord. y	Tree Coord. x	Tree Coord. y	15-2/9-2		21-D		70-C		20-C		25-C		43-A		80-A		Σ % 10-6	Distance 10-3			
														D	L	D	L	D	L	D	L	D	L	D	L	D	L	D	D			
13	F	IP																														

Appendix C : A worked example of calculation of aggregate genetic values.

Table C-1: Assumptions for the quality index IP 038 Thailand

25 provenances tested

Characters in the index	Unit	Exp.*) Mean	Prov-mean Herit-ability h^2	Economic weights	
				prop.	scaled to unity
Straightness	Proportion of class 4 and 5	0.15	.42	1	.167
Persistence	- " - class 6	0.30	.52	2	.333
Branch size	- " - " 4 and 5	0.05	.66	1	.167
Lack of flowering	- " - " 3	0.92	.85	2	.333
			Total	6	1.000

Phenotypic correlations of provenance means

Characters	Straight-ness	Persis-tence	Branch size	Flowering
Straightness	1.00	-0.06	0.08	0.09
Persistence		1.00	-0.16	0.01
Branch Size			1.00	0.20
Flowering				1.00

*) The ANOVA and heritability estimates are performed on ARC SIN transformed proportions, whereas the present calculations on provenance-means and genetic estimates and values are carried out on the re-transformed proportions.

Table C-2: IP 038. Calculations of aggregate genetic values for the 4 quality characters

	j = 1		j = 2		j = 3		j = 4			
prov i	Straightness (class 4 & 5)	a_1 = 0.167	Persistence (class 6)	a_2 = 0.333	Branch size (class 4 & 5)	a_3 = 0.167	Lack of flowering (class 3)	a_4 = 0.333	Aggregate Genetic Value	prov.
	Genetic est*) G_{i1} **)	Genetic val. $a_1 * G_{i1}$	Genetic est*) G_{i2} **)	Genetic val. $a_2 * G_{i2}$	Genetic est*) G_{i3} **)	Genetic val. $a_3 * G_{i3}$	Genetic est*) G_{i4} **)	Genetic val. $a_4 * G_{i4}$	$H_i = \sum_j a_j * G_{ij}$	
1	.0310	.005	- .0053	- .002	.0885	.015	- .0915	- .030	- .012	1
2	- .0493	- .008	- .0571	- .019	.0303	.005	.0539	.018	- .004	2
3	.0294	.005	- .0813	- .027	.0759	.013	.0805	.027	.017	3
4	- .0431	- .007	- .0358	- .012	.0217	.004	.0707	.024	.008	4
5	.0119	.002	- .0839	- .028	.0463	.008	.0711	.024	.005	5
6	.0333	.006	- .1075	- .036	- .0616	- .010	.0590	.020	- .021	6
7	.0046	.001	- .0199	- .007	- .0125	- .002	- .1530	- .051	- .059	7
8	.0201	.003	- .0166	- .006	- .0495	- .008	- .0734	- .024	- .035	8
9	- .0077	- .001	.0009	.000	.0318	.005	- .1451	- .048	- .044	9
10	.0009	.000	- .0274	- .009	- .0619	- .010	- .1602	- .053	- .073	10
11	.0445	.007	.0821	.027	- .0158	- .003	.0647	.022	.054	11
12	.0198	.003	.0639	.021	- .0573	- .010	.0429	.014	.029	12
13	.0212	.004	- .0239	- .008	- .0130	- .002	.0803	.027	.020	13
14	- .0216	- .004	.0664	.022	- .0420	- .007	.0711	.024	.035	14
15	.0506	.008	.0159	.005	.0671	.011	.0389	.013	.038	15
16	- .0340	- .006	.0826	.028	.0662	.011	.0749	.025	.058	16
17	- .0472	- .008	.0009	.000	- .0175	- .003	.0111	.004	- .007	17
18	.0268	.004	- .0431	- .014	.0301	.005	.0222	.007	.003	18
19	- .0042	- .001	.0125	.004	- .0217	- .004	.0283	.009	.009	19
20	- .0536	- .009	- .0038	- .001	.0252	.004	- .0878	- .029	- .035	20
21	- .0089	- .001	.0394	.013	- .0532	- .009	- .2449	- .082	- .079	21
22	- .0261	- .004	.0380	.013	- .0374	- .006	.0224	.007	.010	22
23	- .0383	- .006	- .0110	- .004	- .0380	- .006	.0264	.009	- .008	23
24	.0356	.006	.0404	.013	- .0074	- .001	.0619	.021	.039	24
25	.0049	.001	.0740	.025	.0048	.001	.0742	.025	.051	25
n	25		25		25		25		25	
mean	.0000		0.0000		0.0000		.0001		.0000	
s.d.	.0318		.0526		0.0460		.0938		.0382	
abs.mean	0.1507		0.3005		0.0801		.9179			
s.d.	0.0318		0.0526		.0460		.0938			

*) Calculated as described in Genetic estimates of provenances, see Chap. 4.2.3 - particularly fig.7 & table 8.

**) Deviation from grand mean.

Table C-3: IP 038 Thailand

Summary of the 3 indices for health, growth and quality.

Prov.		Aggregate Genetic Values		
		Health	Growth	Quality
1	3007	+ 7	0	- 1
2	3016	+ 3	+ 7	0
3	3018	+ 1	- 4	+ 2
4	3019	- 3	- 8	+ 1
5	3020	+ 3	+ 1	+ 1
6	3021	- 3	- 2	- 2
7	3033	+ 2	+ 1	- 6
8	3034	- 3	- 1	- 4
9	3036	+ 3	+ 5	- 4
10	3037	0	+ 3	- 7
11	3038	0	0	+ 5
12	3039	- 1	- 4	+ 3
13	3041	- 2	- 3	+ 2
14	3042	+ 1	+ 2	+ 4
15	3043	- 4	- 5	+ 4
16	3047	+ 6	+ 3	+ 6
17	3048	- 2	+ 4	- 1
18	3049	- 1	+ 7	0
19	3050	+ 2	+ 4	+ 1
20	3051	- 1	- 2	- 4
21	3053	+ 1	- 2	- 8
22	3055	- 1	- 2	+ 1
23	3056	- 3	+ 3	- 1
24	3057	- 1	- 9	+ 4
25	SNO 133	0	+ 3	+ 5
Averages		Survival(%) 72 Health(%) 99	DBH(cm) 12.7	Straightness(%) 15 Persistence(%) 30 Branch size(%) 5 Lack of flow.(%) 92
h²		Survival .42 Health .20	DBH .49	Straightness .42 Persistence .52 Branch size .66 Lack of flow. .85
Economic weights		Survival .67 Health .33 1.00	DBH 1.00	Straightness .17 Persistence .33 Branch size .17 Lack of flow. .33 1.00

Appendix D : Provenance performance within individual experiments

Table D-1: Health index values for all provenances at all sites.

TRIAL SITES

			1				2				3				4					
PROVNO	PREGION	INDEX	IP001	IP038	IP032	IP016	IP046	IP022	IP045	IP047	IP005	IP003	IP024	IP026	IP018	IP028	IP008	IP009	IP029	IP030
SC3002	A	HEALTH	-10	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3003	A	HEALTH	.	.	.	.	-6	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3005	A	HEALTH	.	.	.	.	-16	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3007	A	HEALTH	.	7	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3008	A	HEALTH	-9	.	.	.	6	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3015	A	HEALTH	.	.	.	.	.	-0	.	.	.	.	.	.	.	.	.	.	.	.
SC3022	A	HEALTH	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	1	-2	8
SC3025	A	HEALTH	.	.	.	.	.	5	.	.	.	.	.	.	.	.	.	.	.	.
SC3032	A	HEALTH	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3010	B1	HEALTH	.	.	.	.	7	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3012	B1	HEALTH	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3013	B1	HEALTH	-1	.	.	.	-2	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3016	B1	HEALTH	.	2	12	.	5	-0	.	.	.	.	.	.	-0	-3	.	.	.	.
SC3017	B1	HEALTH	.	.	-9	.	.	.	0	-5	.	.	.	.	.	.	.	.	.	.
SC3018	B1	HEALTH	.	0	.	.	.	.	.	.	5	.	.	.	.	1	.	.	.	.
SC3019	B1	HEALTH	.	-4	-26	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3020	B1	HEALTH	.	3	5	1	.	1	.	.	-0	2	.	.	.	.	.	.	.	.
SC3021	B1	HEALTH	.	-3	7	.	.	.	0	2	2	0	-0	0	.	5	7	-0	.	.
SC3071	B1	HEALTH	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.
SC3026	B2	HEALTH	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.	.
SC3033	B2	HEALTH	.	2	2	.	.	.	.	.	.	.	0	0	.	7	.	.	.	.
SC3034	B2	HEALTH	.	-3	.	.	.	.	.	.	1	-4	.	.	-0	.	.	.	.	.
SC3035	B2	HEALTH	.	.	.	-1	.	.	.	.	-1	.	.	.	.	.	.	.	.	.
SC3036	B2	HEALTH	.	2	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SW0001	B2	HEALTH	.	.	.	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3047	D	HEALTH	.	6	-4	.	.	.	.	.	.	.	.	.	.	-6	-1	2	5	-1
SC3048	D	HEALTH	.	-2	8	.	.	.	.	.	.	.	.	.	.	-7	4	-2	-3	1
SC3049	D	HEALTH	6	-1	.	.	.	.	0	1	5	6	1	0	.	-1	5	-2	0	.
SC3050	D	HEALTH	.	2	7	.	.	.	.	.	.	.	.	.	.	.	1	-0	2	-3
SC3051	D	HEALTH	.	-1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-0	.
SLT614	D	HEALTH	.	.	12	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SLT624	D	HEALTH	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3037	E	HEALTH	.	-0	.	0	.	5	.	.	.	.	.	.	[illegible]	.	.	.	.	.
SC3044	E	HEALTH	.	.	.	.	.	-4	0	0	0	0	.	.	.	.	4	-1	2	10
SC3062	E	HEALTH	.	.	.	.	.	9	.	.	.	.	.	.	.	.	.	.	.	.
SC3063	E	HEALTH	.	.	.	.	.	2	.	.	.	.	.	.	1	.	.	.	.	.
SC3064	E	HEALTH	.	.	.	.	.	9	.	.	.	.	.	.	.	.	.	.	.	.
SC3065	E	HEALTH	.	.	.	.	.	-7	.	.	.	.	.	.	-1	.	.	.	.	.
SC3066	E	HEALTH	.	.	.	.	.	4	.	.	.	.	.	.	.	.	.	.	.	.
SC3067	E	HEALTH	.	.	.	.	.	1	.	.	.	.	.	.	[illegible]	.	.	.	.	.
SG 01	E	HEALTH	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	5	.	.
SG 03	E	HEALTH	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-1	2	.	.
SG 04	E	HEALTH	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	-3	.	.
SW 119	E	HEALTH	.	.	.	.	.	.	.	.	.	.	-2	0	.	4	.	.	5	2
SWT873	E	HEALTH	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.	.	.
SC3038	H1	HEALTH	.	-0	.	-2	.	.	.	.	.	.	.	.	-1	.	.	.	-2	.
SC3039	H1	HEALTH	4	-1	-16	-1	.	.	.	.	.	-4	1	.	.	-7	.	.	-1	-8
SC3040	H1	HEALTH	.	.	.	1	.	.	0	.	-2	1	.	.	2	.	.	.	-7	-3
SC3041	H1	HEALTH	6	-2	.	-0	6	-0	.	.	-5	.	.	.	.	.	.	.	.	.
SC3042	H1	HEALTH	.	1	.	.	-2	.	.	.	.	.	.	.	.	4	.	.	7	-2
SC3043	H1	HEALTH	3	-4	.	-6	.	-0	.	.	.	.	.	.	.	-5	.	.	-3	-3
SW0133	H1	HEALTH	1	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3053	H2	HEALTH	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3054	H2	HEALTH	.	.	.	.	.	0	.	.	.	.	.	.	2	.	.	.	.	.
SC3055	H2	HEALTH	.	-1	.	.	.	.	.	.	.	.	.	.	.	.	-12	-1	.	.
SC3056	H2	HEALTH	.	-3	.	.	.	.	.	.	-8	.	.	.	.	.	-11	2	-4	.
SC3057	H2	HEALTH	.	-1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3058	H2	HEALTH	.	.	.	.	.	5	.	.	.	.	.	.	.	.	.	.	.	.
SC3059	H2	HEALTH	.	.	.	.	.	0	.	.	-2	.	.	.	.	.	-11	-2	.	.
SC3060	H2	HEALTH	.	.	.	.	.	-9	.	.	4	.	.	.	.	.	.	.	.	.
SC3061	H2	HEALTH	.	.	.	.	.	-3	.	.	.	.	.	.	-3	.	.	.	.	.
SW 78	R	HEALTH	.	.	.	.	.	-2	.	.	.	.	.	.	.	.	.	.	.	.
SW 79	R	HEALTH	.	.	.	.	.	-5	.	.	.	.	.	.	.	.	.	.	.	.
SW 80	R	HEALTH	.	.	.	.	.	-4	.	.	.	.	.	.	.	.	.	.	.	.
SW 81	R	HEALTH	.	.	.	.	.	-6	.	.	.	.	.	.	.	.	.	.	.	.
SW 82	R	HEALTH	.	.	.	.	.	-6	.	.	.	.	.	.	.	.	.	.	.	.
SW 83	R	HEALTH	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.
SW SA8	R	HEALTH	.	.	.	.	.	.	0	1	.	.	.	.	.	.	.	.	.	.

Table D-2: Productivity index values for all provenances at all sites

TRIAL SITES

			1				2				3				4					
PROVNO	PREGION	INDEX	IP001	IP038	IP032	IP016	IP046	IP022	IP045	IP047	IP005	IP033	IP024	IP026	IP018	IP028	IP008	IP019	IP029	IP030
SC3002	A	PRODUCT	-21	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3003	A	PRODUCT	.	.	.	.	-11	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3005	A	PRODUCT	.	.	.	.	4	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3007	A	PRODUCT	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3008	A	PRODUCT	-8	.	.	.	-4	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3015	A	PRODUCT	.	.	.	.	.	11	.	.	.	.	.	.	.	.	.	.	.	.
SC3022	A	PRODUCT	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-4	-0	0	-6
SC3023	A	PRODUCT	.	.	.	.	.	23	.	.	.	.	.	.	.	.	.	.	.	.
SC3032	A	PRODUCT	.	.	.	-8	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3010	B1	PRODUCT	.	.	.	.	0	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3012	B1	PRODUCT	.	.	.	.	-3	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3013	B1	PRODUCT	-8	.	.	.	13	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3016	B1	PRODUCT	.	13	4	.	0	6	.	.	.	.	.	.	0	-4	.	.	.	.
SC3017	B1	PRODUCT	.	.	-12	.	.	.	-1	2	.	.	.	.	.	.	.	.	.	.
SC3018	B1	PRODUCT	.	-1	.	.	.	.	.	.	10	.	.	.	.	-1	.	.	.	.
SC3019	B1	PRODUCT	.	-14	-26	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3020	B1	PRODUCT	.	1	1	7	.	-3	.	.	9	3	.	.	.	.	.	.	.	.
SC3021	B1	PRODUCT	.	-3	3	.	.	.	-14	0	10	-2	8	3	.	4	7	0	.	.
SC3071	B1	PRODUCT	.	.	.	.	.	4	.	.	.	.	.	.	.	.	.	.	.	.
SC3026	B2	PRODUCT	.	.	.	.	.	.	.	.	.	.	.	.	.	-0	.	.	.	.
SC3033	B2	PRODUCT	.	3	-7	.	.	.	.	.	.	.	-3	-1	.	2	.	.	.	.
SC3034	B2	PRODUCT	.	-0	.	.	.	.	.	.	-6	-4	.	.	-1	.	.	.	.	.
SC3035	B2	PRODUCT	.	.	.	-6	.	.	.	.	-17	.	.	.	.	.	.	.	.	.
SC3036	B2	PRODUCT	.	11	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SN0001	B2	PRODUCT	.	.	.	18	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3047	D	PRODUCT	.	11	-1	.	.	.	.	.	.	.	.	.	.	2	3	-0	-6	-29
SC3048	D	PRODUCT	.	2	2	.	.	.	.	.	.	.	.	.	.	-3	2	1	-2	-19
SC3049	D	PRODUCT	17	7	.	.	.	.	27	0	3	0	-4	0	.	-0	6	1	1	.
SC3050	D	PRODUCT	.	2	9	.	.	.	.	.	.	.	.	.	.	.	2	1	1	8
SC3051	D*	PRODUCT	.	-0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-1	.
SLT614	D	PRODUCT	.	.	23	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SLT624	D	PRODUCT	.	.	19	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3037	E	PRODUCT	.	2	.	9	.	-0	.	.	.	.	.	.	2	.	.	.	.	.
SC3044	E	PRODUCT	.	.	.	.	.	-9	10	0	2	-8	.	.	.	.	-5	-1	-1	-11
SC3062	E	PRODUCT	.	.	.	.	.	-1	.	.	.	.	.	.	.	.	.	.	.	.
SC3063	E	PRODUCT	.	.	.	.	.	-7	.	.	.	.	.	.	0	.	.	.	.	.
SC3064	E	PRODUCT	.	.	.	.	.	6	.	.	.	.	.	.	.	.	.	.	.	.
SC3065	E	PRODUCT	.	.	.	.	.	0	.	.	.	.	.	.	7	.	.	.	.	.
SC3066	E	PRODUCT	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.
SC3067	E	PRODUCT	.	.	.	.	.	0	.	.	.	.	.	.	0	.	.	.	.	.
SG 01	E	PRODUCT	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	-1	.	.
SG 03	E	PRODUCT	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-3	-0	.	.
SG 04	E	PRODUCT	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	-0	.	.
SM 119	E	PRODUCT	.	.	.	.	.	.	.	.	.	.	-1	-2	.	4	.	.	1	-1
SMT673	E	PRODUCT	.	.	.	.	.	.	.	.	.	.	.	.	9	.	.	.	.	.
SC3038	H1	PRODUCT	.	-1	.	-3	.	.	.	.	.	.	.	.	0	.	.	.	2	.
SC3039	H1	PRODUCT	-3	-9	-7	-3	.	.	.	.	.	-6	1	.	.	-2	.	.	-2	-10
SC3040	H1	PRODUCT	.	.	.	-9	.	.	-15	.	-2	0	.	.	-0	.	.	.	-2	-1
SC3041	H1	PRODUCT	2	-7	.	2	-8	-1	.	.	-1	.	.	.	.	.	.	.	.	.
SC3042	H1	PRODUCT	.	6	.	.	3	.	.	.	.	.	.	.	.	1	.	.	0	19
SC3043	H1	PRODUCT	2	-0	.	-10	.	-4	.	.	.	.	.	.	.	-2	.	.	-1	9
SN0133	H1	PRODUCT	18	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3053	H2	PRODUCT	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3054	H2	PRODUCT	.	.	.	.	.	-6	.	.	.	.	.	.	-5	.	.	.	.	.
SC3055	H2	PRODUCT	.	-7	.	.	.	.	.	.	.	.	.	.	.	.	-5	-1	.	.
SC3056	H2	PRODUCT	.	-5	.	.	.	.	.	.	1	.	.	.	.	.	-6	0	-0	.
SC3057	H2	PRODUCT	.	-10	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3058	H2	PRODUCT	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
SC3059	H2	PRODUCT	.	.	.	.	.	-6	.	.	-1	.	.	.	.	.	-0	-0	.	.
SC3060	H2	PRODUCT	.	.	.	.	.	0	.	.	-7	.	.	.	.	.	.	.	.	.
SC3061	H2	PRODUCT	.	.	.	.	.	-7	.	.	.	.	.	.	1	.	.	.	.	.
SM 78	R	PRODUCT	.	.	.	.	.	-0	.	.	.	.	.	.	.	.	.	.	.	.
SM 79	R	PRODUCT	.	.	.	.	.	14	.	.	.	.	.	.	.	.	.	.	.	.
SM 80	R	PRODUCT	.	.	.	.	.	-5	.	.	.	.	.	.	.	.	.	.	.	.
SM 81	R	PRODUCT	.	.	.	.	.	-8	.	.	.	.	.	.	.	.	.	.	.	.
SM 82	R	PRODUCT	.	.	.	.	.	-7	.	.	.	.	.	.	.	.	.	.	.	.
SM 83	R	PRODUCT	.	.	.	.	.	-0	.	.	.	.	.	.	.	.	.	.	.	.
SM 548	R	PRODUCT	.	.	.	.	.	.	-6	-3	.	.	.	.	.	.	.	.	.	.

Table D-3: Quality index values for all provenances at all sites

TRIAL SITES

PROVNO	REGION	INDEX	1 IP001	IP038	IP037	IP016	2 IP046	IP022	IP045	IP047	3 IP005	IP063	IP024	IP026	4 IP018	IP028	IP088	IP089	IP029	IP030
SC3002	A	QUALITY	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3005	A	QUALITY	.	.	.	.	-0	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3019	A	QUALITY	.	.	.	.	-0	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3006	A	QUALITY	.	-1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3006	A	QUALITY	-9	.	.	.	0	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3015	A	QUALITY	.	.	.	.	.	-2	.	.	.	.	.	.	.	.	.	.	.	.
SC3022	A	QUALITY	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-1	-6	-1	-1
SC3023	A	QUALITY	.	.	.	.	.	-1	.	.	.	.	.	.	.	.	.	.	.	.
SC3032	A	QUALITY	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3017	B1	QUALITY	.	.	.	.	-0	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3012	B1	QUALITY	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3013	B1	QUALITY	-6	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3016	B1	QUALITY	.	-0	-3	.	-0	-0	.	.	.	.	.	.	-3	-0	.	.	.	.
SC3017	B1	QUALITY	.	.	1	.	.	.	6	17	.	.	.	.	.	.	.	.	.	.
SC3018	B1	QUALITY	.	2	.	.	.	.	.	.	14	.	.	.	.	1	.	.	.	.
SC3019	B1	QUALITY	.	1	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3026	B1	QUALITY	.	1	1	4	.	-3	.	.	-2	0	.	.	.	.	.	.	.	.
SC3021	B1	QUALITY	.	-2	6	.	.	.	6	16	7	11	2	3	.	1	2	11	.	.
SC3071	B1	QUALITY	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.
SC302	B2	QUALITY	.	.	.	.	.	.	.	.	.	.	.	.	.	-1	.	.	.	.
SC3037	B2	QUALITY	.	-6	-0	.	.	.	.	.	.	.	2	-1	.	0	.	.	.	.
SC3034	B2	QUALITY	.	-3	.	.	.	.	.	.	4	-3	.	.	.	.	.	.	.	.
SC3039	B2	QUALITY	.	.	.	-3	.	.	.	.	2	.	.	.	.	.	.	.	.	.
SC303.	B2	QUALITY	.	-4	.	-0	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SW0007	B2	QUALITY	.	.	.	-2	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3041	D	QUALITY	.	6	-3	.	.	.	.	.	.	.	.	.	.	-1	-0	4	-5	11
SC3043	D	QUALITY	.	-1	-1	.	.	.	.	.	.	.	.	.	.	0	1	2	-3	-4
SC3048	D	QUALITY	-11	0	.	.	.	.	-3	2	-3	-5	-6	1	.	-0	4	2	5	.
SC3050	D	QUALITY	.	1	-6	.	.	.	.	.	.	.	.	.	.	.	1	3	1	2
SC3051	D	QUALITY	.	-4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-4	.
SLT61	D	QUALITY	.	.	-3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SLT674	D	QUALITY	.	.	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3037	E	QUALITY	.	-7	.	-3	.	-0	.	.	.	.	.	.	5	.	.	.	.	.
SC3044	E	QUALITY	.	.	.	.	.	-0	-15	-43	-11	-13	.	.	.	.	-2	-7	-11	-19
SC3062	E	QUALITY	.	.	.	.	.	-1	.	.	.	.	.	.	.	.	.	.	.	.
SC3063	E	QUALITY	.	.	.	.	.	-1	.	.	.	.	.	.	-1	.	.	.	.	.
SC3064	E	QUALITY	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
SC3065	E	QUALITY	.	.	.	.	.	0	.	.	.	.	.	.	2	.	.	.	.	.
SC3066	E	QUALITY	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.
SC306	E	QUALITY	.	.	.	.	.	1	.	.	.	.	.	.	-1	.	.	.	.	.
SG 01	E	QUALITY	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-3	-3	.	.
SG 02	E	QUALITY	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-1	-6	.	.
SG 07	E	QUALITY	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-2	-6	.	.
SM 119	E	QUALITY	.	.	.	.	.	.	.	.	.	.	0	-3	.	2	.	.	9	4
SMTB73	E	QUALITY	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.	.	.
SC3039	H1	QUALITY	.	5	.	3	.	.	.	.	.	.	.	.	7	.	.	.	6	.
SC3031	H1	QUALITY	5	3	-0	0	.	.	.	.	.	4	1	.	.	1	.	.	-2	5
SC3040	H1	QUALITY	.	.	.	3	.	.	7	.	3	5	.	.	1	.	.	.	5	1
SC3041	H1	QUALITY	8	2	.	-0	-0	1	.	.	6	.	.	.	.	.	.	.	.	.
SC3042	H1	QUALITY	.	4	.	.	-0	.	.	.	.	.	.	.	.	-1	.	.	-3	6
SC3043	H1	QUALITY	6	4	.	1	.	1	.	.	.	.	.	.	.	-1	.	.	-1	1
SM81	H1	QUALITY	6	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC305	H2	QUALITY	.	-8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC305	H2	QUALITY	.	.	.	.	.	1	.	.	.	.	.	.	3	.	.	.	.	.
SC305.	H2	QUALITY	.	1	.	.	.	.	.	.	.	.	.	.	.	.	-1	2	.	.
SC305	H2	QUALITY	.	-1	.	.	.	.	.	.	-5	.	.	.	.	.	2	0	2	.
SC305	H2	QUALITY	.	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
SC3058	H2	QUALITY	.	.	.	.	.	-0	.	.	.	.	.	.	.	.	.	.	.	.
SC305	H2	QUALITY	.	.	.	.	.	2	.	.	-5	.	.	.	.	.	0	2	.	.
SC306	H2	QUALITY	.	.	.	.	.	0	.	.	-3	.	.	.	.	.	.	.	.	.
SC306.	H2	QUALITY	.	.	.	.	.	1	.	.	.	.	.	.	7	.	.	.	.	.
SW 72	R	QUALITY	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
SW	R	QUALITY	.	.	.	.	.	-3	.	.	.	.	.	.	.	.	.	.	.	.
SW 8	R	QUALITY	.	.	.	.	.	0	.	.	.	.	.	.	.	.	.	.	.	.
SW 8	R	QUALITY	.	.	.	.	.	7	.	.	.	.	.	.	.	.	.	.	.	.
SW 8	R	QUALITY	.	.	.	.	.	0	.	.	.	.	.	.	.	.	.	.	.	.
SW 8.	R	QUALITY	.	.	.	.	.	-2	.	.	.	.	.	.	.	.	.	.	.	.
SW SA	R	QUALITY	.	.	.	.	.	.	-1	0	.	.	.	.	.	.	.	.	.	.

Appendix D
Figure 1

Figure 1: Legend to Symbols and Abbreviations on Individual Experiment Analysis presented as Appendix D Figures 2-19.

Example of Key Statistics

Group of Traits	Individual Traits	Experimental Averages	h^2 of Provenance Average	Economic Weights a_i	a_i
Health	Survival (%)	93	0.51	.67	
	Health (% healthy)	17	0.82	.33	1.00
Growth	Basal Area sq.m.			0.50	0.50
	D.B.H. cm.	13.2	0.90	1.00	1.00
Quality	Straightness (% straight)	6	0.87	.17	
	Persistence (% persistent)	50	0.79	.33	
	Branch Size (% fine branches)	16	0.17	.17	
	Lack of Flowering (% without flowers)	93	0.33	.33	1.00

The above economic weights are valid for all the figures in Appendix D.

In the above example, D.B.H. is quoted. In other cases, basal area is applied.

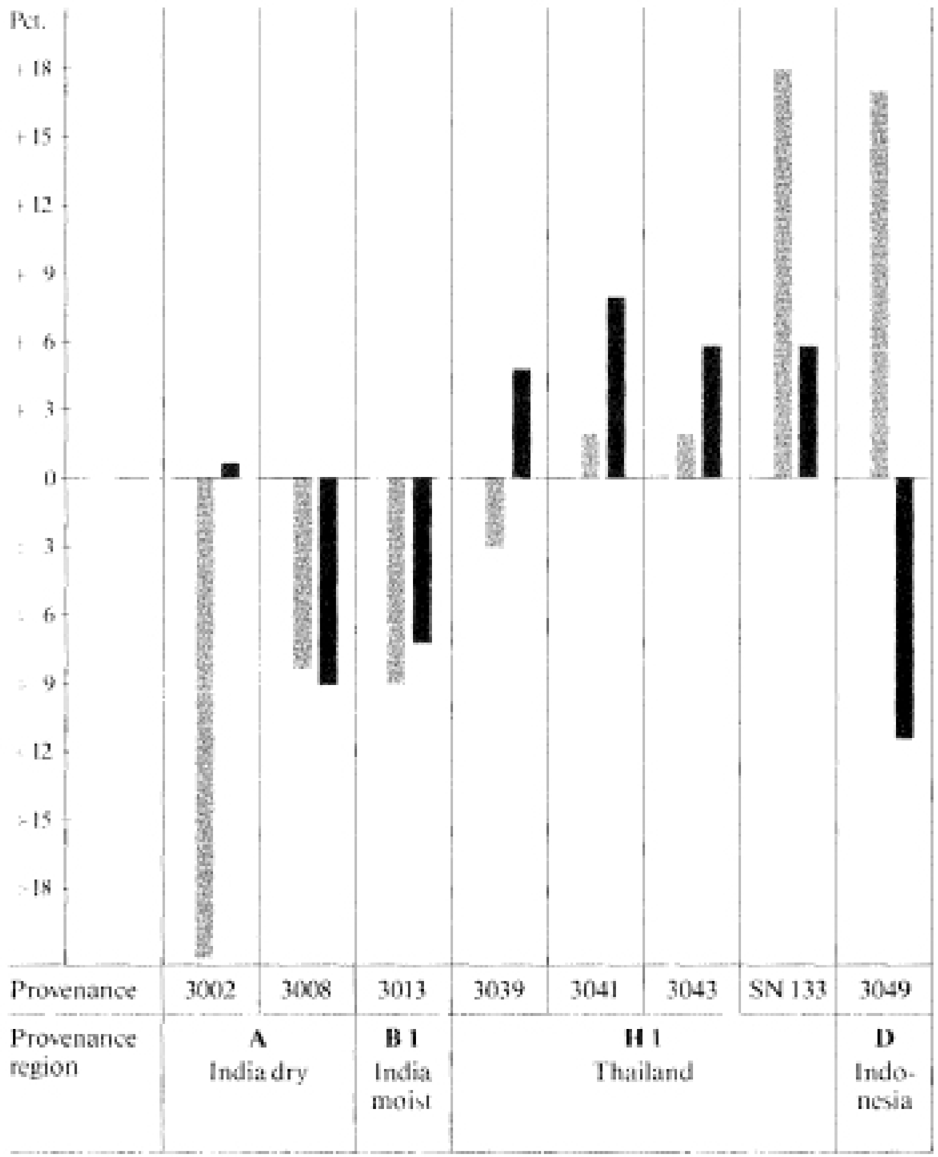
Where the grey columns are missing in the histograms, the deviation from the local experimental average is zero.

Appendix D, fig. 2

IP 001, HUEY SOM POI, Thailand

Lat. 18° 40' N. Long. 99° 55' E. Elev. 350 m. Annual rainfall: 1400 mm. 8 provenances tested

Group	Indiv. Traits		Exp. mean	h^2
Health	SURV.	(%)	87	.81
	HEALTH	(%)	18	.82
Growth (grey)	DBH	cm	13.2	.94
Quality (black)	STR.	(%)	8	.87
	PERS.	(%)	50	.80
	BR. SZ.	(%)	16	.48
	L. FL.	(%)	91	.84

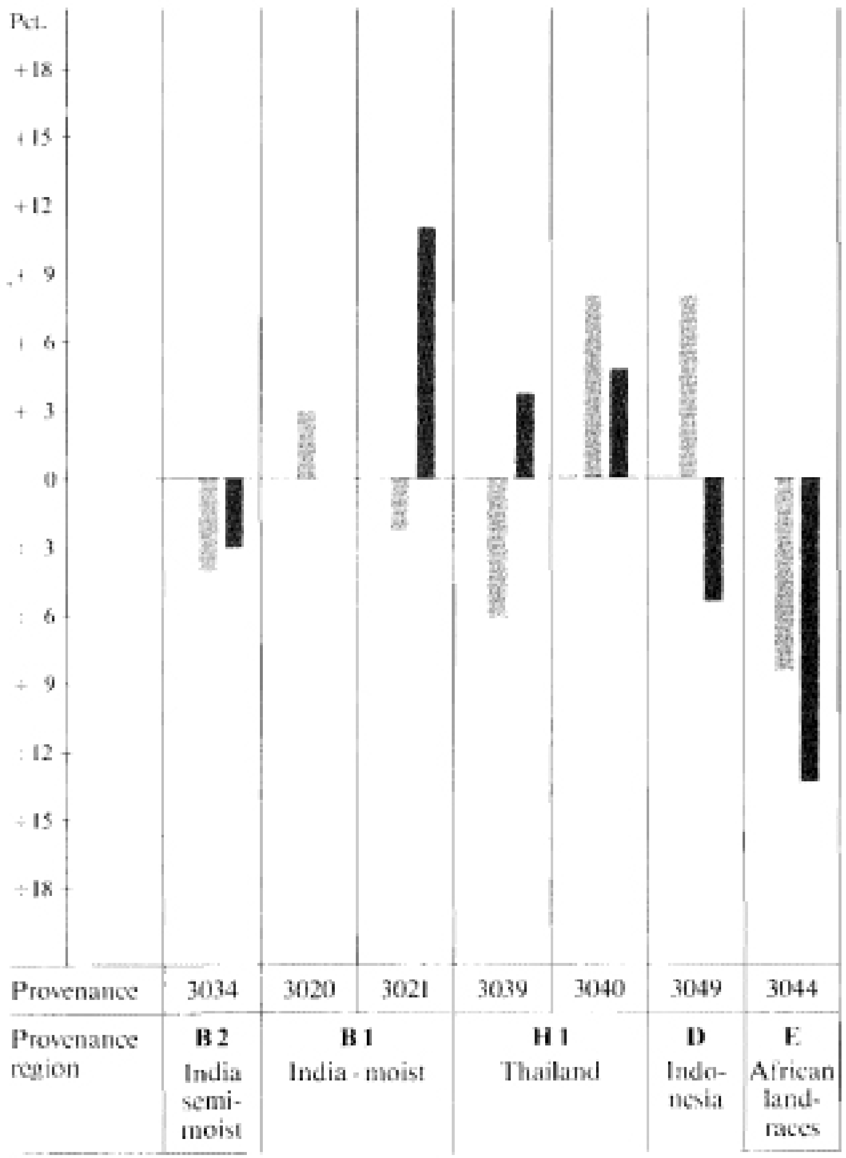


Appendix D, fig. 3

IP 003, ARACRUZ, Brasil

Lat. 19° 46' S. Long. 40° 16' W. Elev. 50 m. Annual rainfall: 1400 mm. 7 provenances tested

Group	Indiv. Traits		Exp. mean	h^2
Health	SURV.	(%)	86	.85
	HEALTH	(%)	93	.72
Growth	BA. AR	m^2	17.68	.80
Quality	STR.	(%)	19	.19
	PERS.	(%)	10	.89
	BR. SZ.	(%)	68	.79
	L. FL.	(%)	32	.94

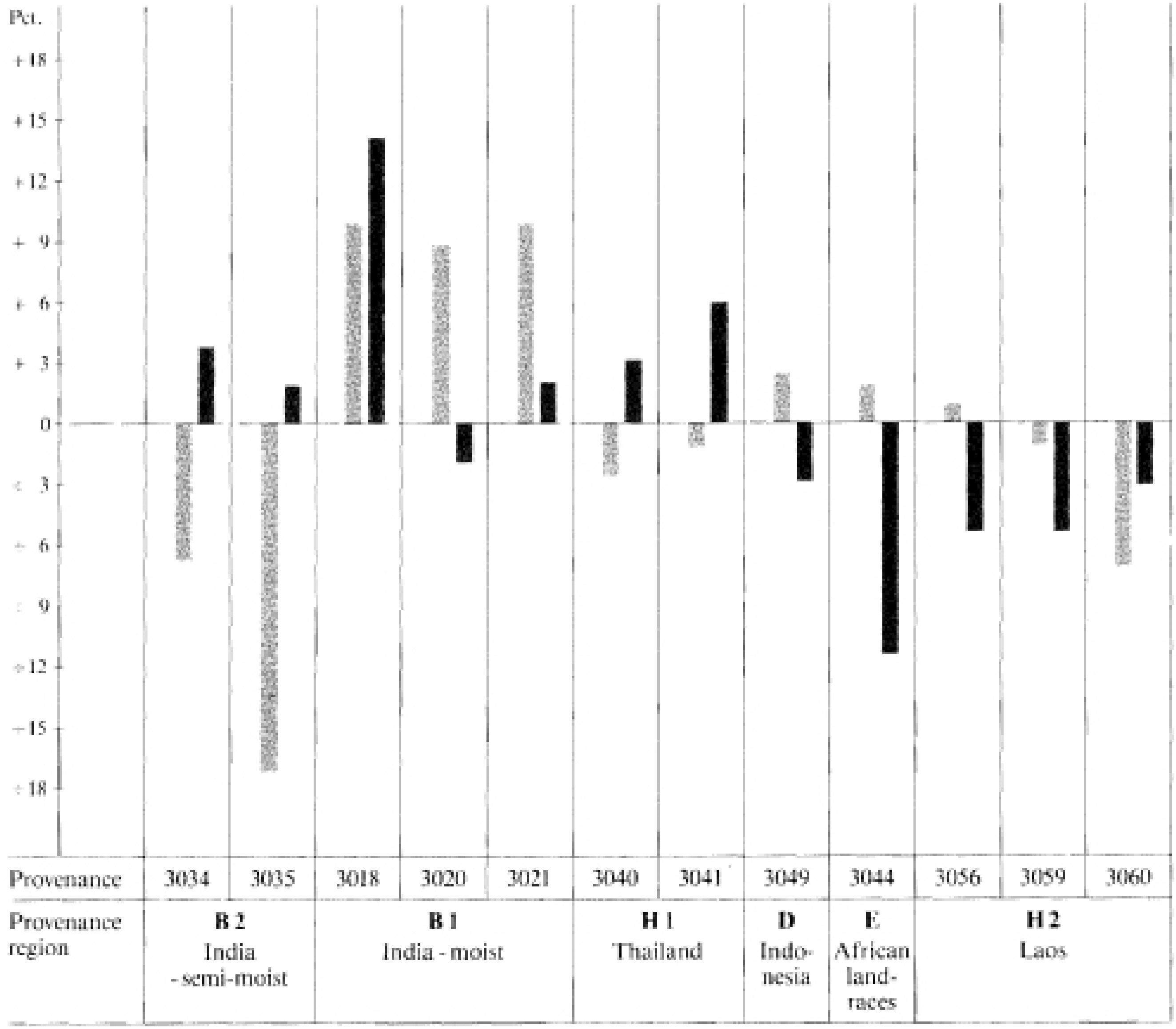


Appendix D, fig. 4

IP 005, ARACRUZ, Brasil

Lat. 19° 46' S. Long. 40° 16' W. Elev. 50 m. Annual rainfall: 1400 mm. 12 provenances tested

Group	Indiv. Traits		Exp. mean	h²
Health	SURV. HEALTH	(%) (%)	82 88	.50 .65
Growth ▒	DBH	cm	15.9	.83
Quality ■	STR. PERS. BR. SZ. L. FL.	(%) (%) (%) (%)	23 9 7 30	.54 .80 .31 .85

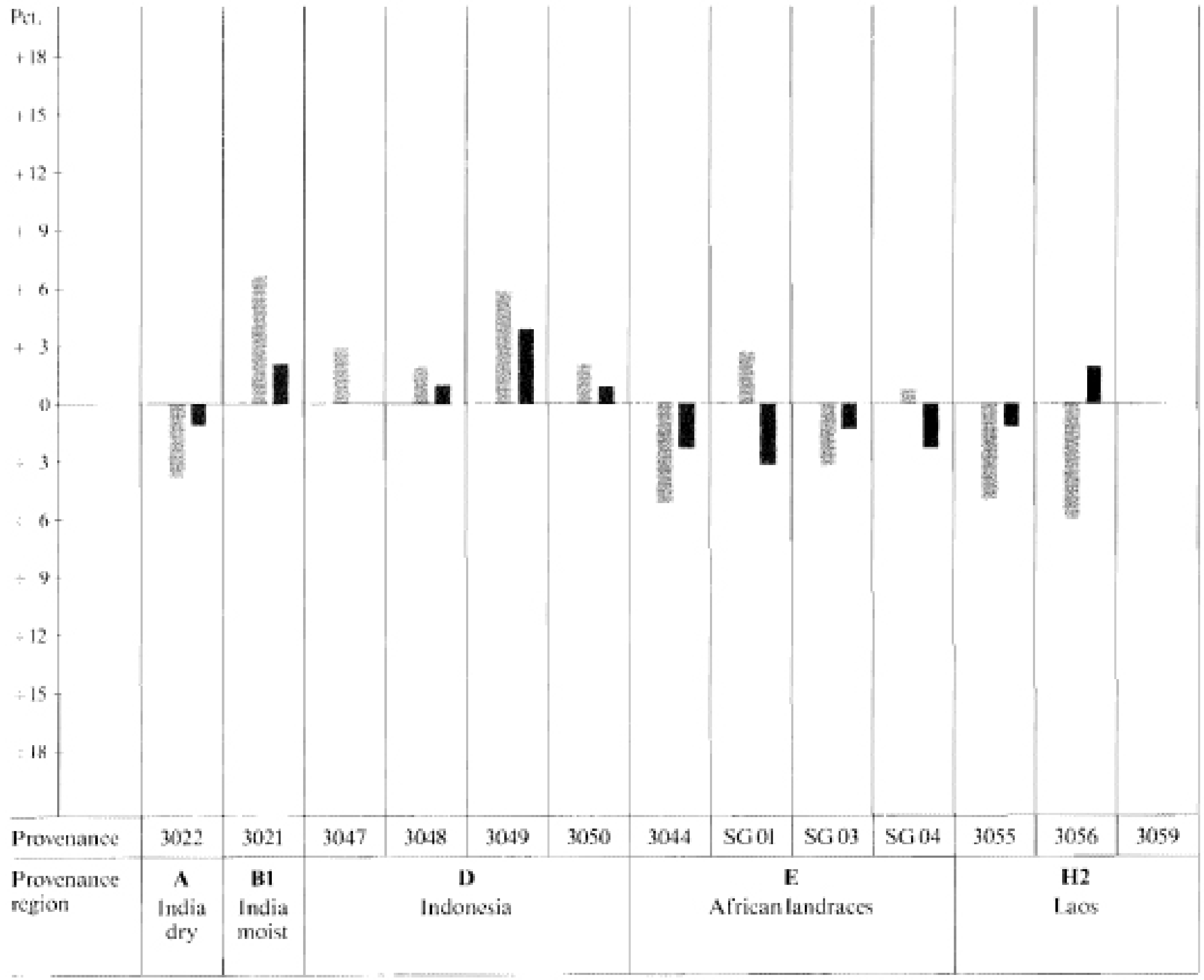


Appendix D, fig. 5

IP 008, PRA ANUM, Ghana

Lat. 6° 15' N. Long. 1° 15' W. Elev. 100 m. Annual rainfall: 1650 mm. 13 provenances tested

Group	Indiv. Traits		Exp. mean	h^2
Health	SURV.	(%)	85	.67
	HEALTH	(%)	87	.93
Growth	BA. AR	m^2	22.8	.76
Quality	STR.	(%)	28	.45
	PERS.	(%)	5	.44
	BR. SZ.	(%)	2	.30
	L. FL.	(%)	16	.49

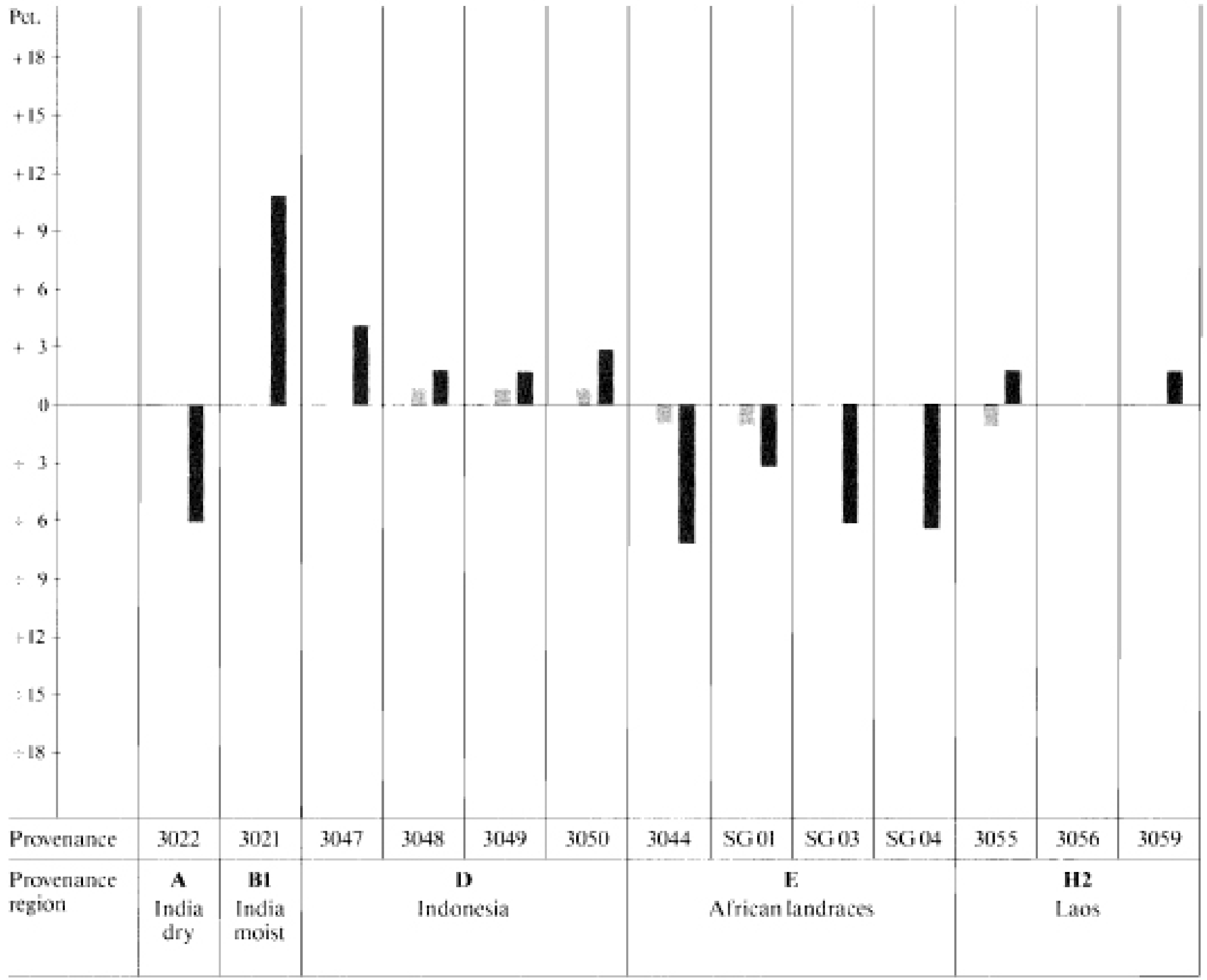


Appendix D, fig. 6

IP 009, TAIN, Ghana

Lat. 7° 30' N. Long. 2° 30' W. Elev. 100 m. Annual rainfall: 1140 mm. 13 provenances tested

Group	Indiv. Traits		Exp. mean	h²
Health	SURV.	(%)	88	.59
	HEALTH	(%)	81	.35
Growth	DBH	cm	15.1	.20
Quality	STR.	(%)	50	.62
	PERS.	(%)	7	.73
	BR. SZ.	(%)	11	.50
	L. FL.	(%)	10	.86

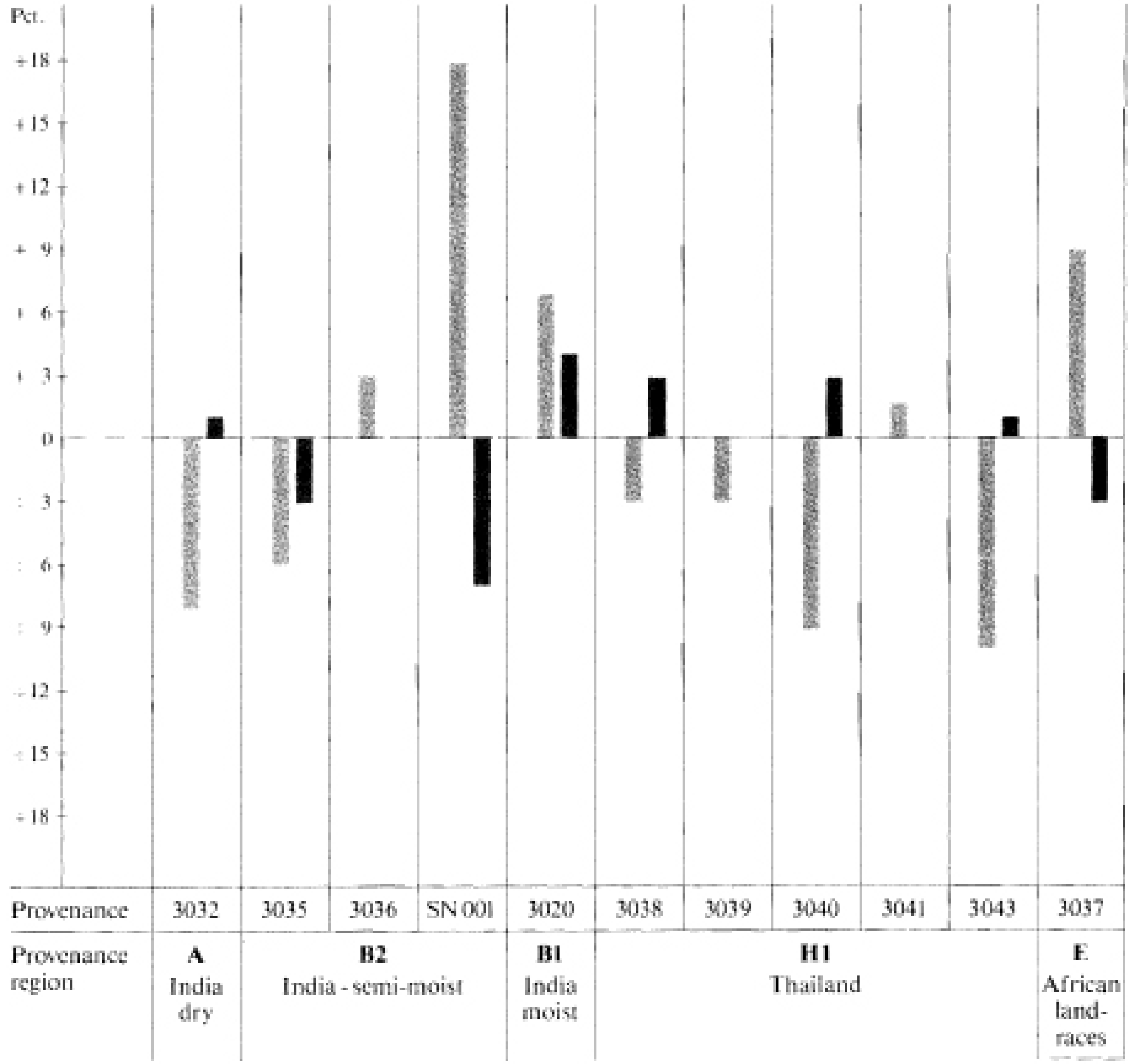


Appendix D, fig. 7

IP 016, MAREDUMILLI, India, A.P.

Lat. 17° 36' N. Long. 81° 43' E. Elev. 500 m. Annual rainfall: 1470 mm. 11 provenances tested

Group	Indiv. Traits		Exp. mean	h^2
Health	SURV.	(%)	90	.69
	HEALTH	(%)	94	.56
Growth	BA. AR	m^2	15.1	.86
Quality	STR.	(%)	21	.82
	PERS.	(%)	24	.40
	BR. SZ.	(%)	6	.48
	L. FL.	(%)	93	.72

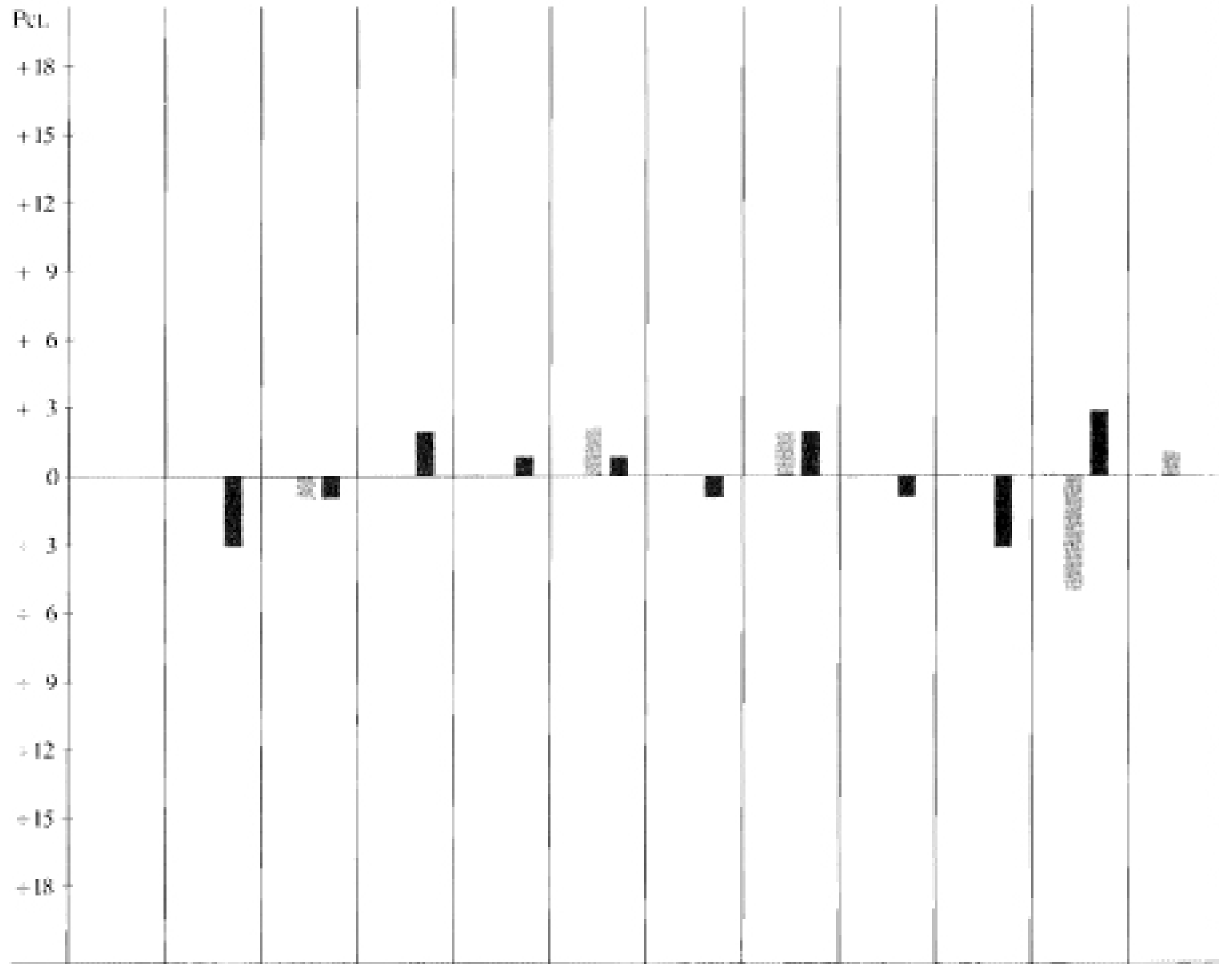


Appendix D, fig. 8

IP 018, LA TENÉ, Ivory Coast

Lat. 6° 05' N. Long. 5° 05' W. Elev. 250 m. Annual rainfall: 1300 mm. 11 provenances tested

Group	Indiv. Traits		Exp. mean	h²
Health	SURV. HEALTH	(%) (%)	85 90	.00 .52
Growth	DBH	cm	19.1	.41
Quality	STR. PERS. BR. SZ. L. FL.	(%) (%) (%) (%)	48 4 1 —	.88 .63 .00 —

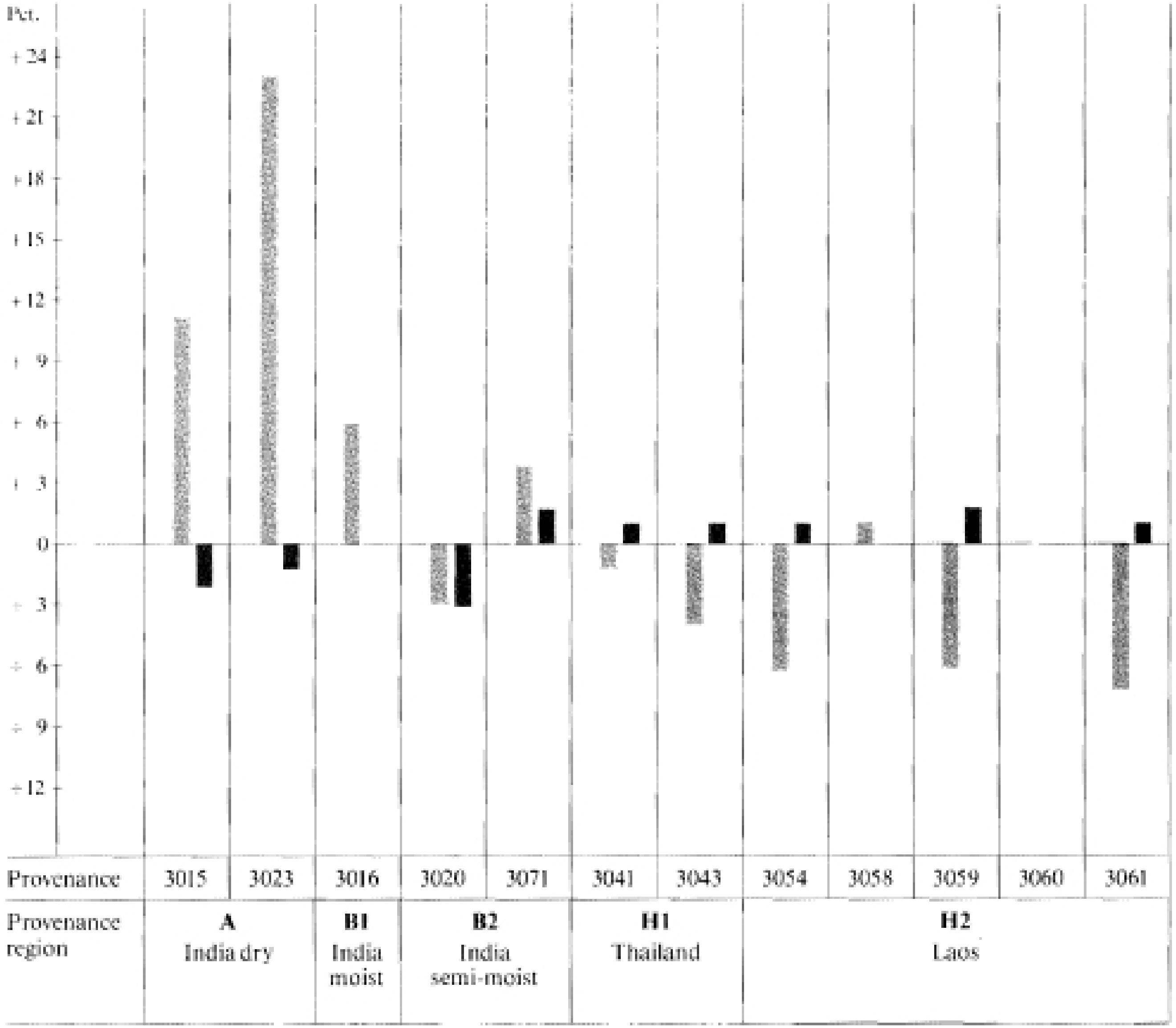


Provenance	3016	3034	3038	3040	3037	3063	3065	3067	TB 73	3054	3061
Provenance region	B1 India moist	B2 India semi-moist	H1 Thailand		E African landraces					H2 Laos	

Appendix D, fig. 9

IP 022, EL TORMENTO, Mexico

Lat. 18° 26' N. Long. 90° 43' W. Elev. 100 m. Annual rainfall: 1100 mm. 26 provenances tested



Group	Indiv. Traits		Exp. mean	h²
Health	SURV.	(%)	65	.44
	HEALTH	(%)	89	.17
Growth	DBH	cm	7.7	.37
Quality	STR.	(%)	93	.40
	PERS.	(%)	8	.14
	BR. SZ.	(%)	28	.11
	L. FL.	(%)	98	.41

Continued on next page

Appendix D, fig. 9

IP 022, EL TORMENTO, Mexico

Lat. 18° 26' N. Long. 90° 43' W. Elev. 100 m. Annual rainfall: 1100 mm. 26 provenances tested

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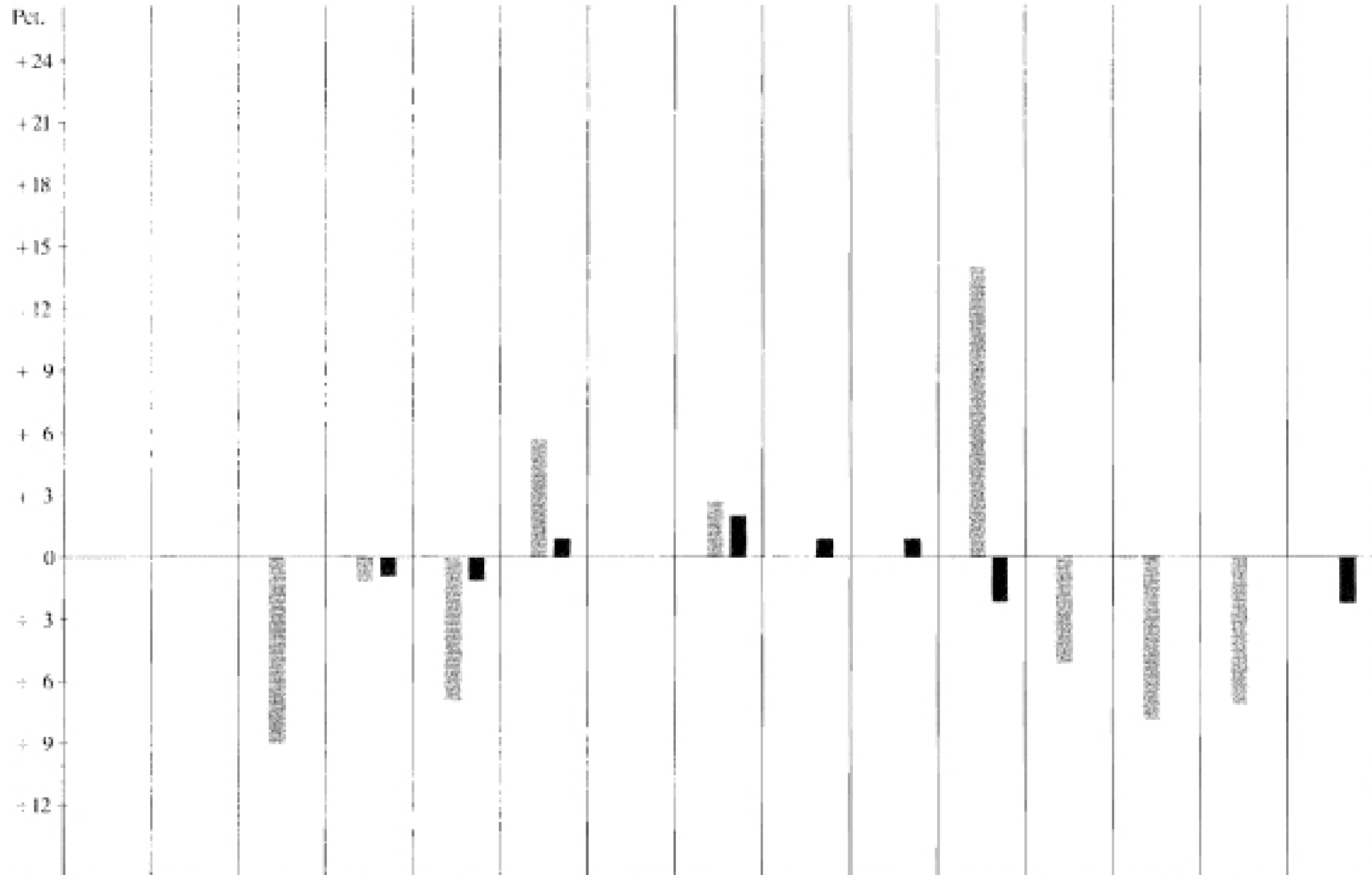


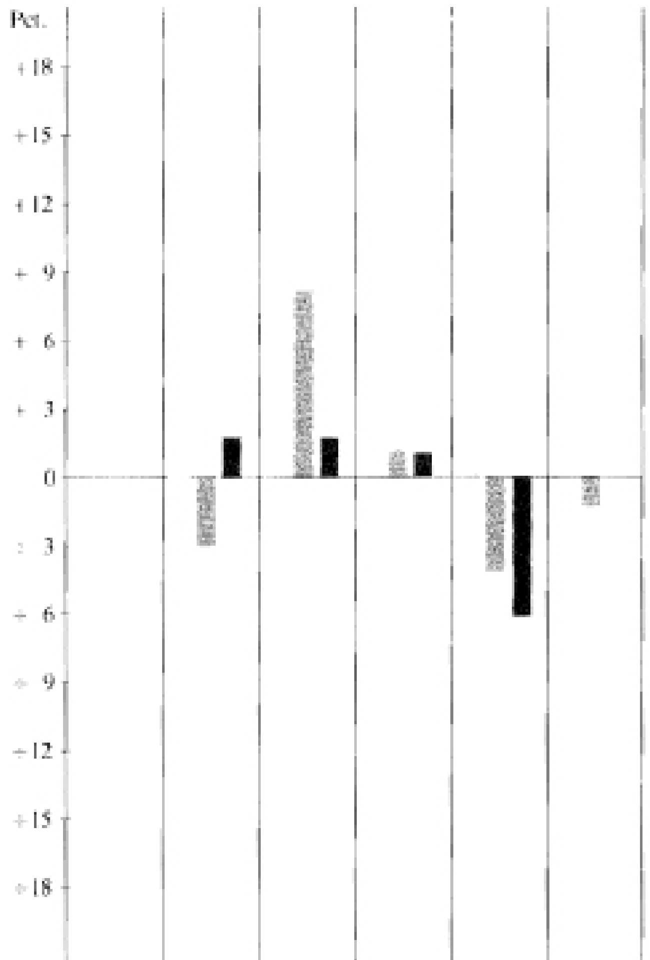
Provenance	3037	3044	3062	3063	3064	3065	3066	3067	SN 78	SN 79	SN 80	SN 81	SN 82	SN 83
Provenance region	E African Landraces								R Latin American Landraces					

Appendix D, fig. 10

IP 024, BENDE, Nigeria

Lat. 5° 30' N. Long. 7° 38' E. Elev. 400 m. Annual rainfall: 2300 mm. 5 provenances tested

Group	Indiv. Traits		Exp. mean	h²
Health	SURV.	(%)	40	.00
	HEALTH	(%)	55	.43
Growth ▒	DBH	cm	20.2	.82
Quality ■	STR.	(%)	31	.00
	PERS.	(%)	16	.67
	BR. SZ.	(%)	22	.65
	L. FL.	(%)	59	.00



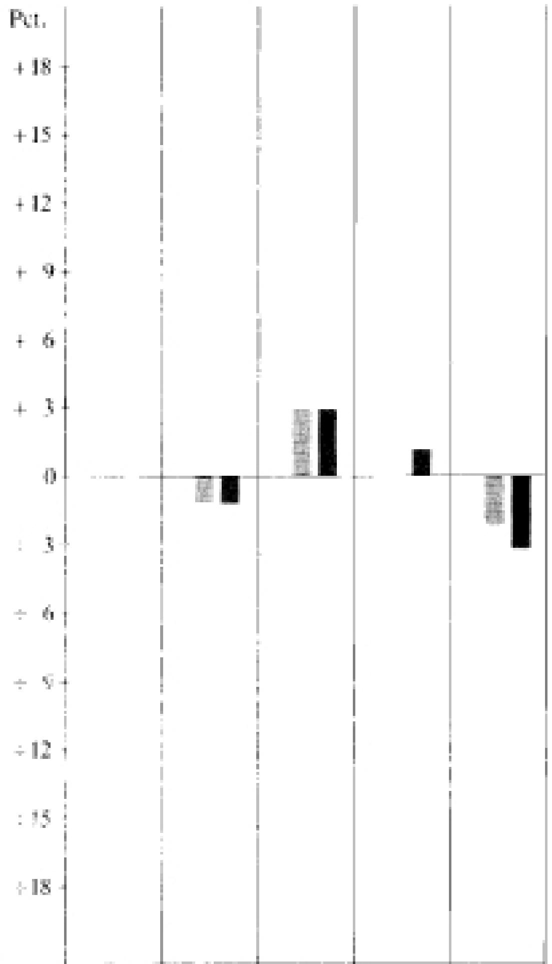
Provenance	3033	3021	3039	3049	SN 119
Provenance region	**B2** India semi-moist	**B1** India moist	**H1** Thai-land	**D** Indo-nesia	**E** African land-races

Appendix D, fig. 11

IP 026, SAPOBA, Nigeria

Lat. 6° 01' N. Long. 5° 46' E. Elev. 100 m. Annual rainfall: 2500 mm. 4 provenances tested

Group	Indiv. Traits		Exp. mean	h²
Health	SURV.	(%)	81	.00
	HEALTH	(%)	92	.00
Growth	BA, AR	m²	16.4	.30
Quality	STR.	(%)	19	.00
	PERS.	(%)	19	.00
	BR. SZ.	(%)	18	.43
	L. FL.	(%)	26	.54



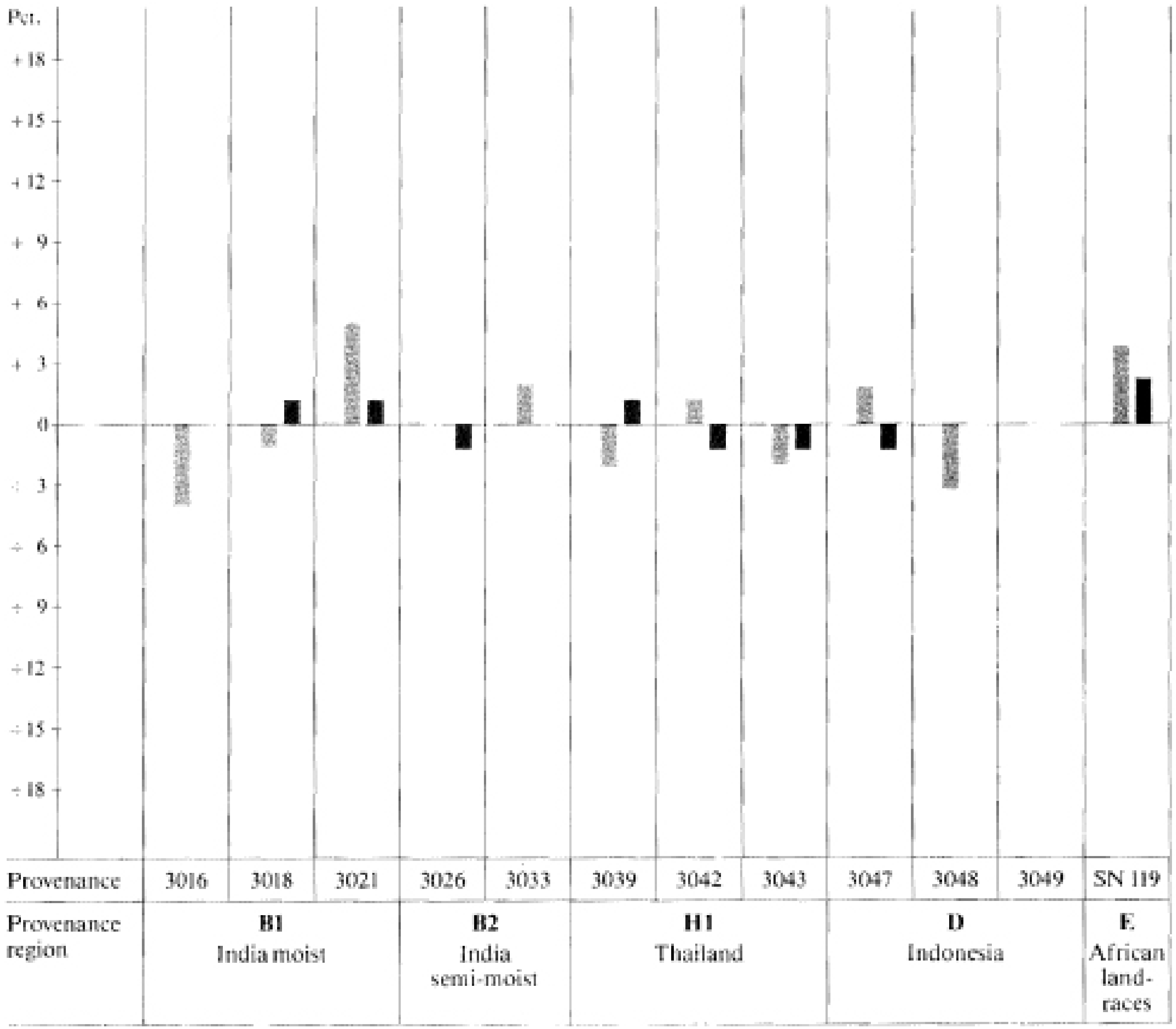
Provenance	3033	3021	3049	SN 119
Provenance region	**B2** India semi-moist	**B1** India moist	**D** Indo-nesia	**E** African land-races

Appendix D, fig. 12

IP 028, GAMBARI, Nigeria

Lat. 7° 12' N. Long. 3° 53' E. Elev. 400 m. Annual rainfall: 1260 mm. 12 provenances tested

Group	Indiv. Traits		Exp. mean	h²
Health	SURV.	(%)	79	.77
	HEALTH	(%)	82	.30
Growth	BA. AR	m²	26.7	.46
Quality	STR.	(%)	15	.73
	PERS.	(%)	9	.21
	BR. SZ.	(%)	—	—
	L. FL.	(%)	—	—

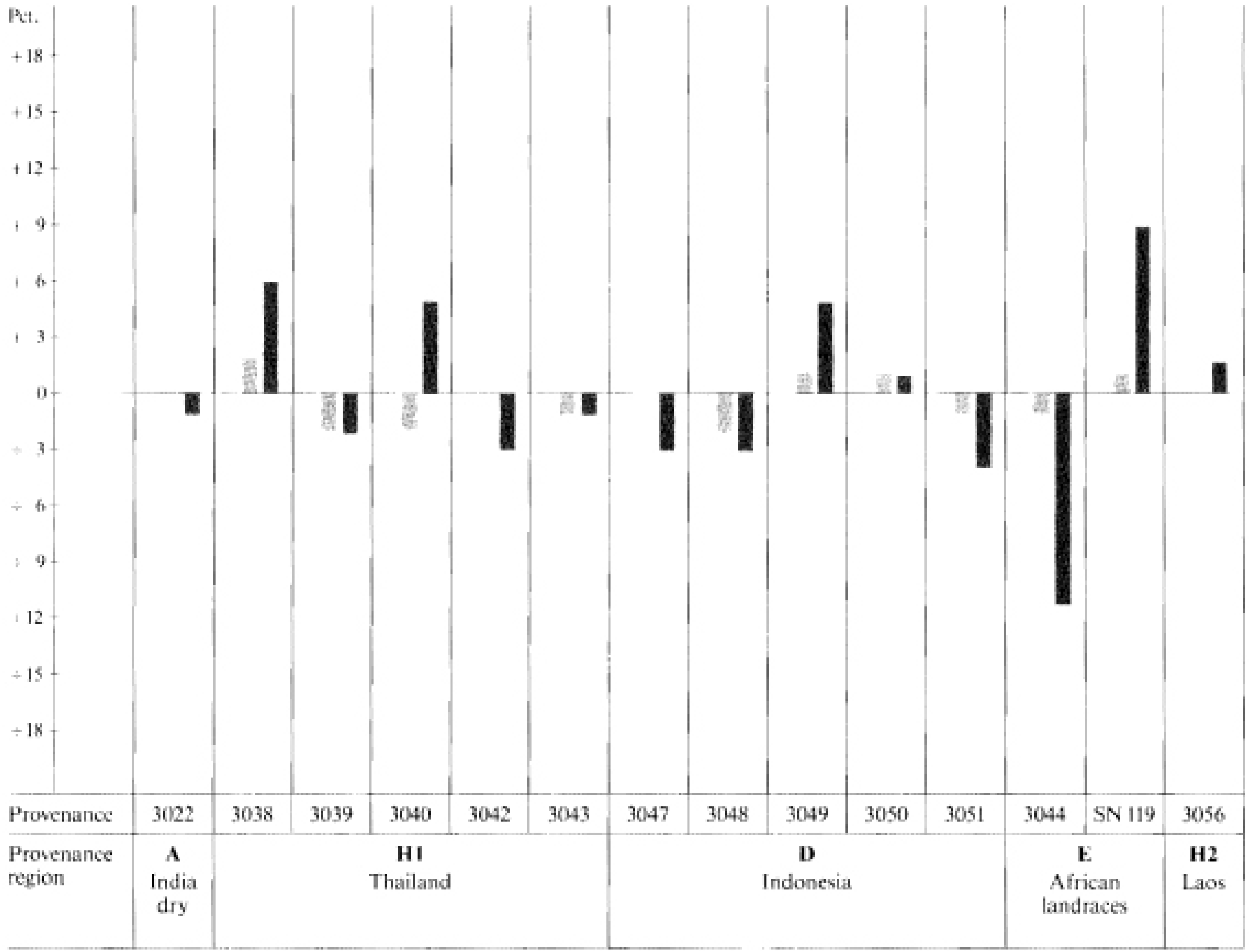


Appendix D, fig. 13

IP 029, NIMBIA, Nigeria

Lat. 8° 30' N. Long. 9° 30' E. Elev. 600 m. Annual rainfall: 1750 mm. 14 provenances tested

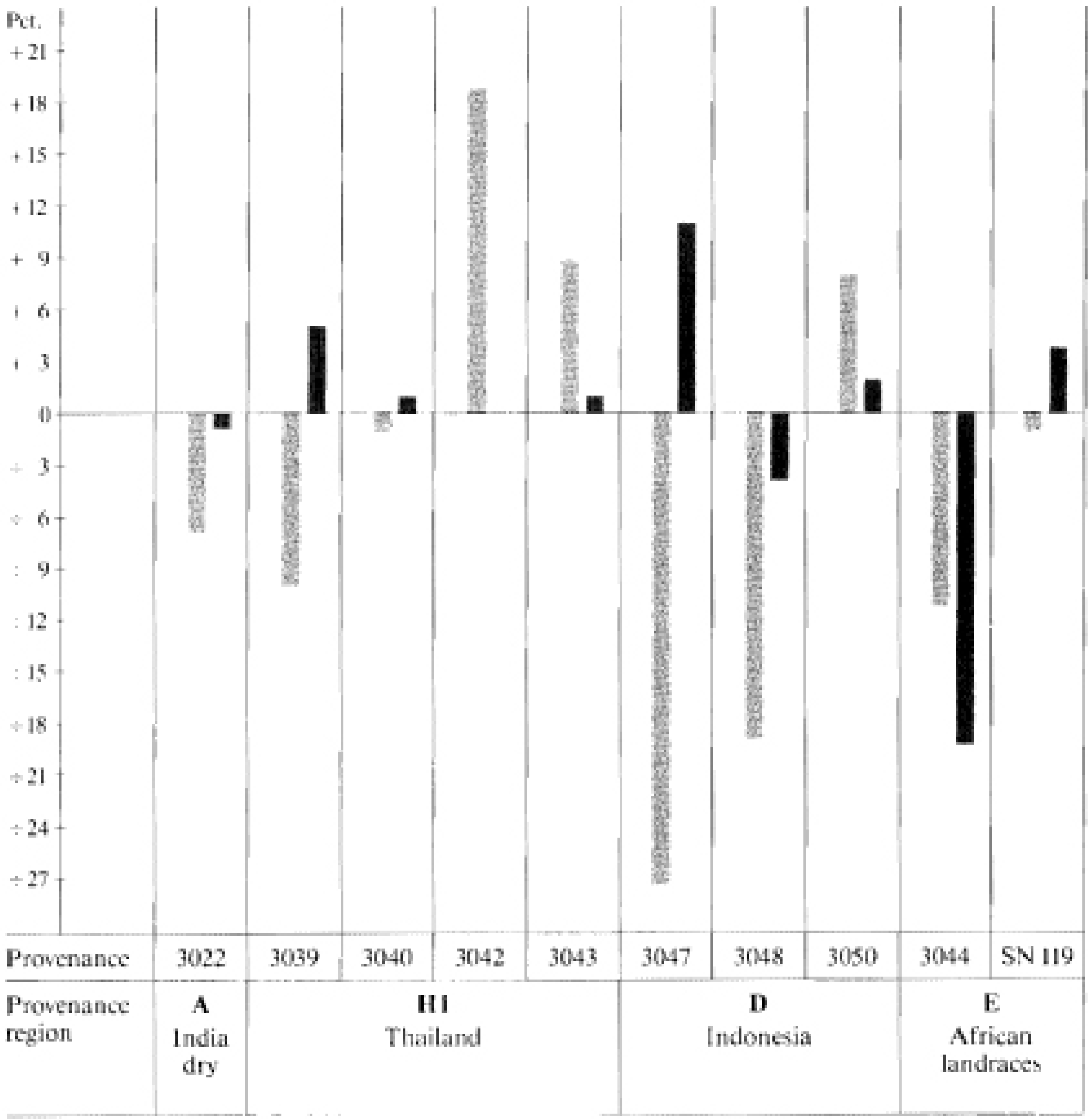
Group	Indiv. Traits		Exp. mean	h²
Health	SURV.	(%)	89	.52
	HEALTH	(%)	59	.37
Growth	BA. AR	m²	13.0	.25
Quality	STR.	(%)	33	.77
	PERS.	(%)	41	.72
	BR. SZ.	(%)	7	.32
	L. FL.	(%)	—	—



Appendix D, fig. 14

IP 030, AFAKA, Nigeria

Lat. 10° 37' N. Long. 8° 17' E. Elev. 600 m. Annual rainfall: 1300 mm. 10 provenances tested



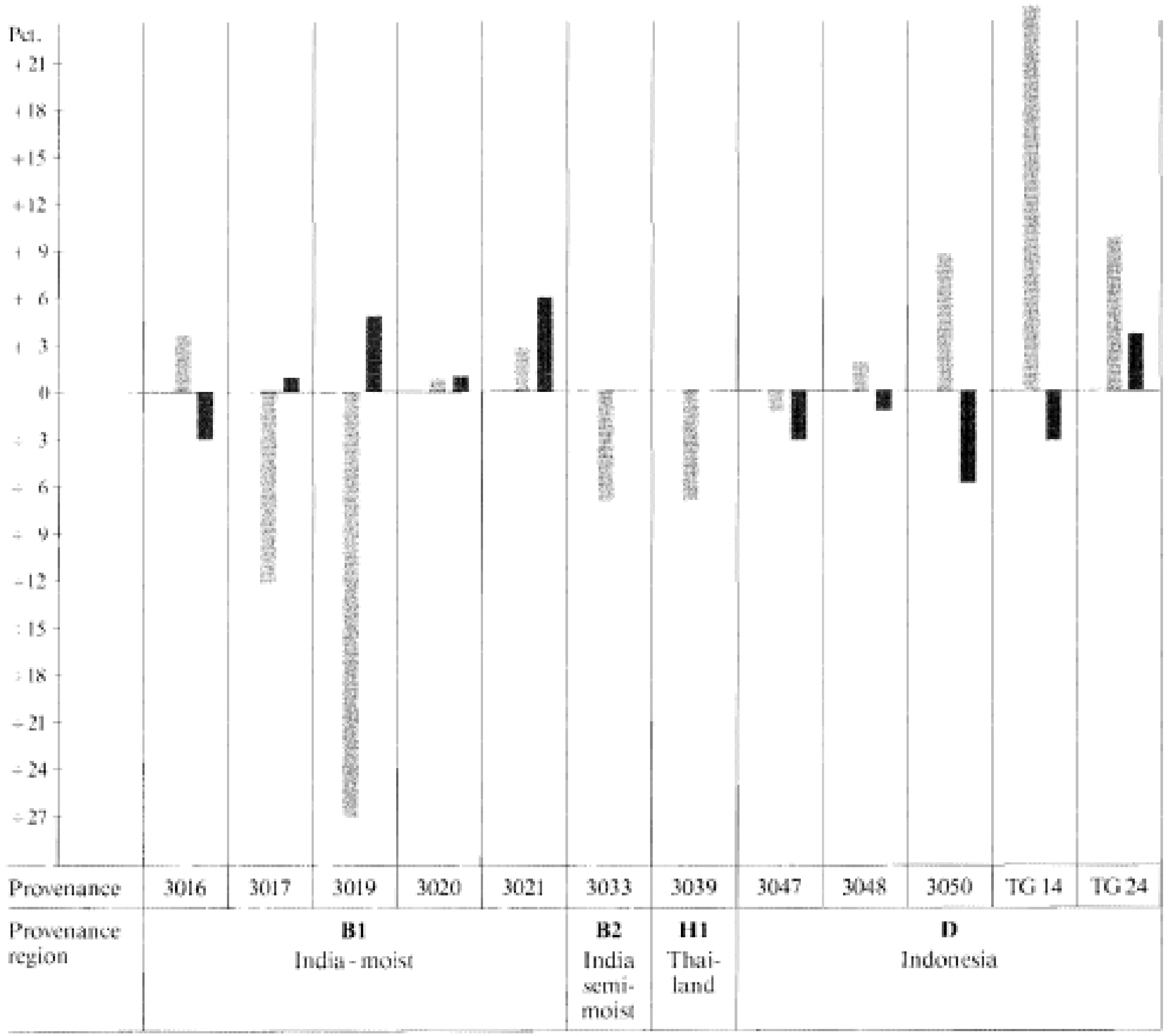
Group	Indiv. Traits		Exp. mean	h^2
Health	SURV.	(%)	92	.35
	HEALTH	(%)	54	.64
Growth (grey)	BA. AR	m^2	10.0	.64
Quality (black)	STR.	(%)	52	.28
	PERS.	(%)	44	.69
	BR. SZ.	(%)	37	.42
	L. FL.	(%)	72	.65

Appendix D, fig. 15

IP 032, BLACK RIVER, Papua New Guinea

Lat. 9° 04' S. Long. 147° 06' E. Elev. 50 m. Annual rainfall: 2000 mm. 12 provenances tested

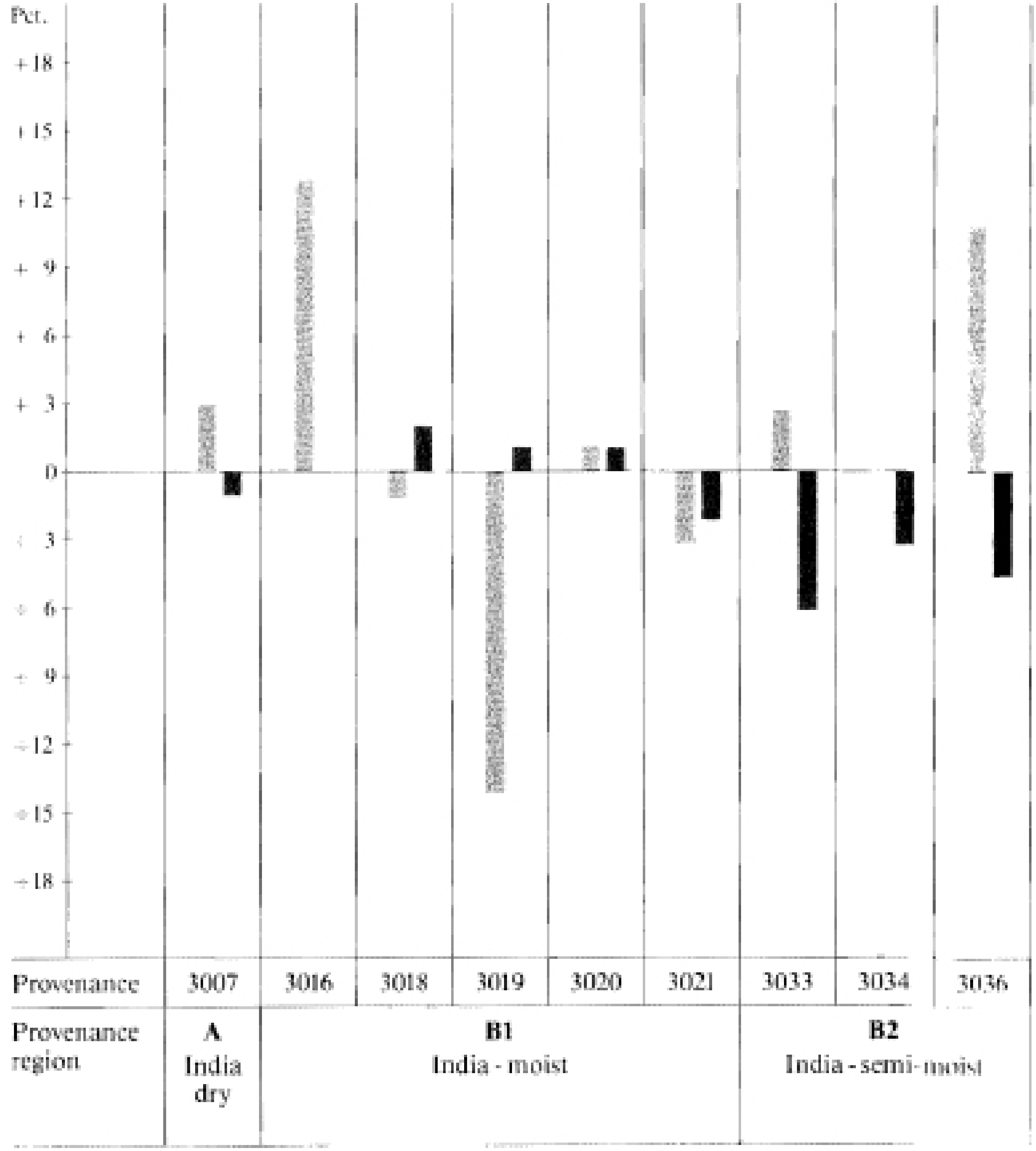
Group	Indiv. Traits		Exp. mean	h²
Health	SURV.	(%)	78	.87
	HEALTH	(%)	21	.86
Growth (grey)	BA. AR	m²	23.0	.91
Quality (black)	STR.	(%)	29	.42
	PERS.	(%)	10	.75
	BR. SZ.	(%)	—	—
	L. FL.	(%)	89	.47



IP 038, PAH NOK KAU, Thailand

Lat. 16° 45' N. Long. 102° 00' E. Elev. 300 m. Annual rainfall: 1300 mm. 25 provenances tested

Group	Indiv. Traits		Exp. mean	h^2
Health	SURV.	(%)	72	.42
	HEALTH	(%)	99	.20
Growth	BA. AR	m^2	5.1	.52
Quality	STR.	(%)	15	.42
	PERS.	(%)	30	.52
	BR. SZ.	(%)	8	.66
	L. FL.	(%)	92	.85



Appendix D, fig. 16

IP 038, PAH NOK KAU, Thailand

Lat. 16° 45' N. Long. 102° 00' E. Elev. 300 m. Annual rainfall: 1300 mm. 25 provenances tested

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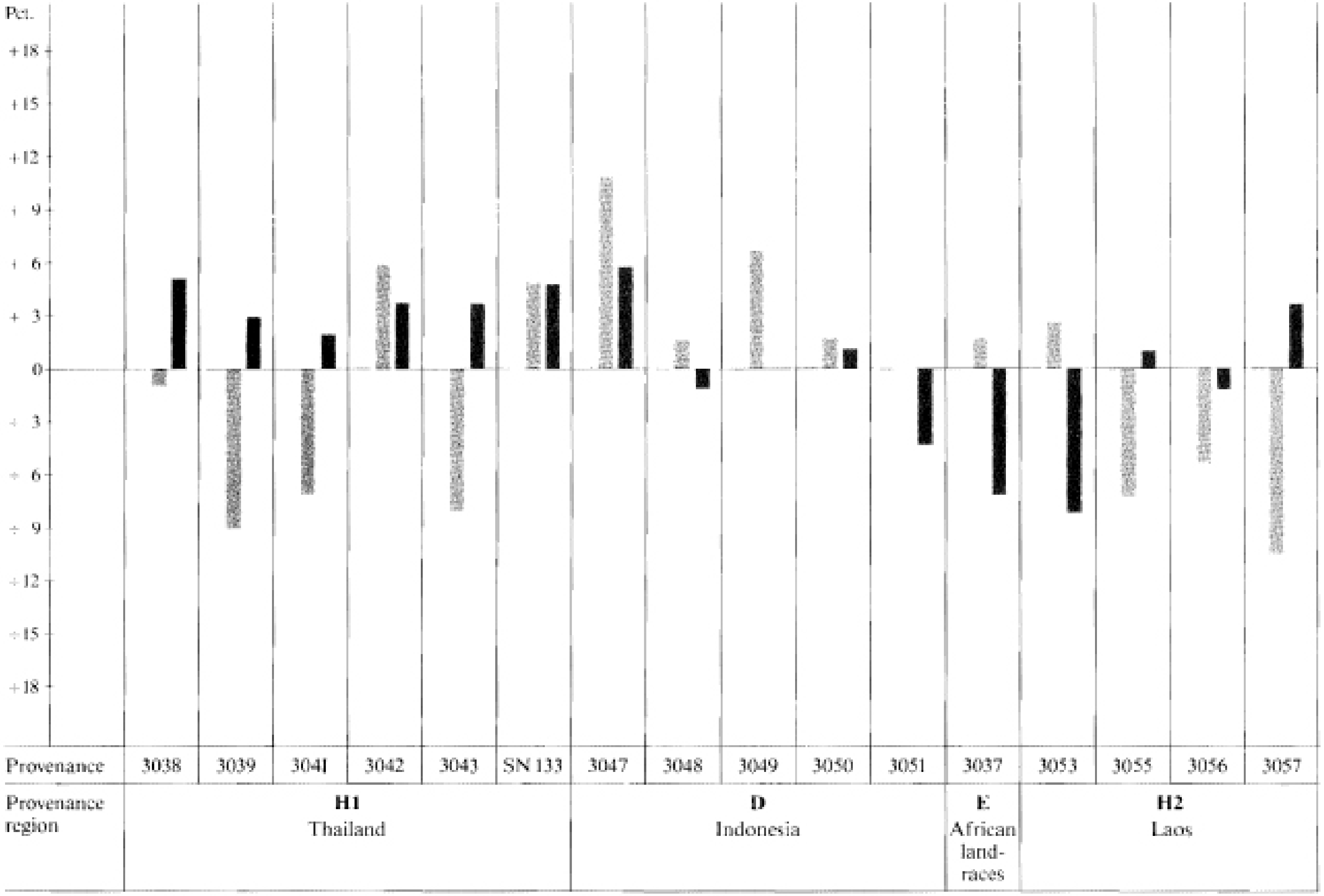
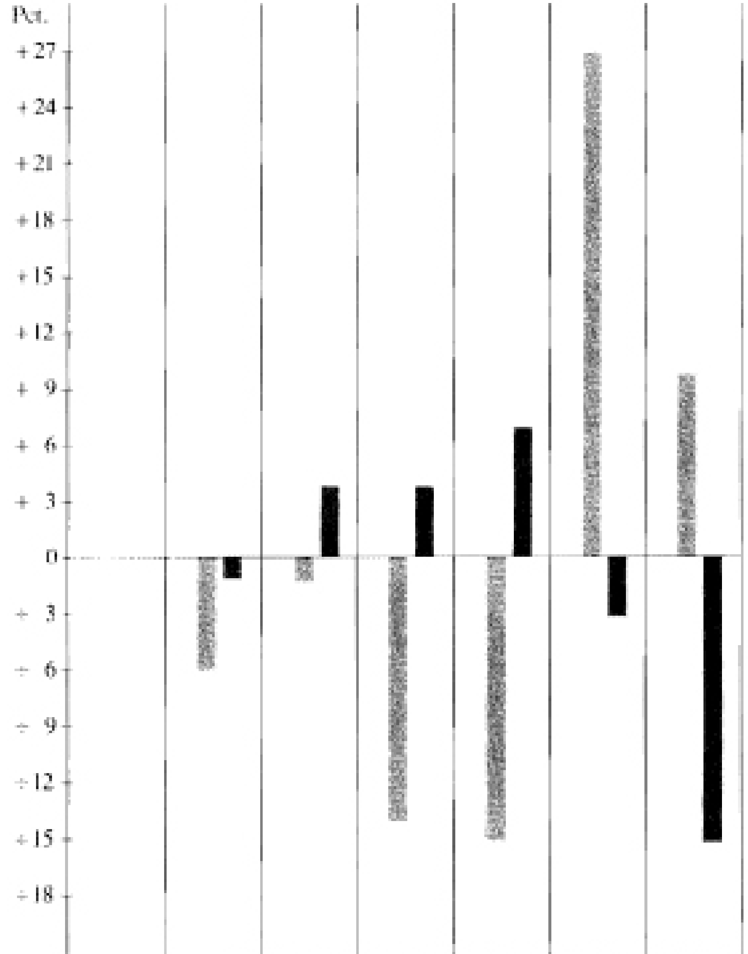


Appendix D, fig. 17

IP 045, RIO ABAJO, Puerto Rico

Lat. 18° 22' N. Long. 66° 44' W. Elev. 335 m. Annual rainfall: 2400 mm. 6 provenances tested

Group	Indiv. Traits		Exp. mean	h^2
Health	SURV.	(%)	99	.00
	HEALTH	(%)	100	.00
Growth ▒	DBH	cm	5.4	.86
Quality ■	STR.	(%)	1	.27
	PERS.	(%)	89	.00
	BR. SZ.	(%)	47	.88
	L. FL.	(%)	93	.95

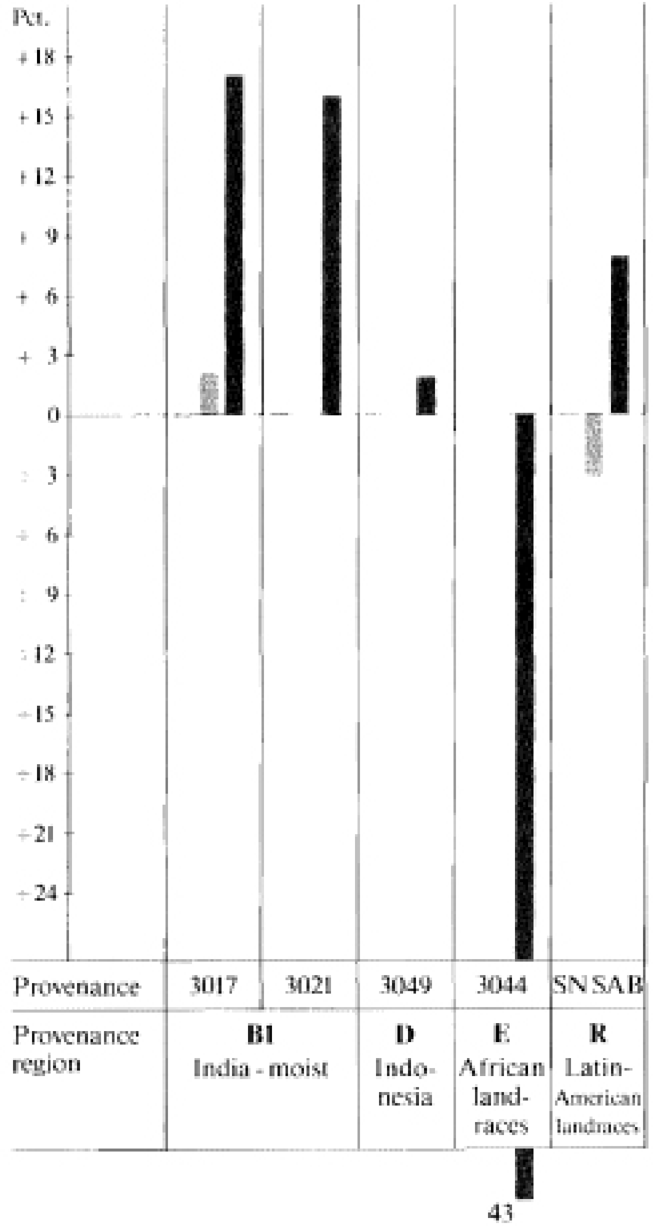


Provenance	SN SAB	3017	3021	3040	3049	3044
Provenance region	**R** Latin-American landraces	**B1** India - moist		**H1** Thai-land	**D** Indo-nesia	**E** African land-races

Appendix D, fig. 18

IP 047, ST. CROIX, Puerto Rico

Lat. 17° 45' N. Long. 65° 50' W. Elev. 250 m. Annual rainfall: 1500 mm. 5 provenances tested



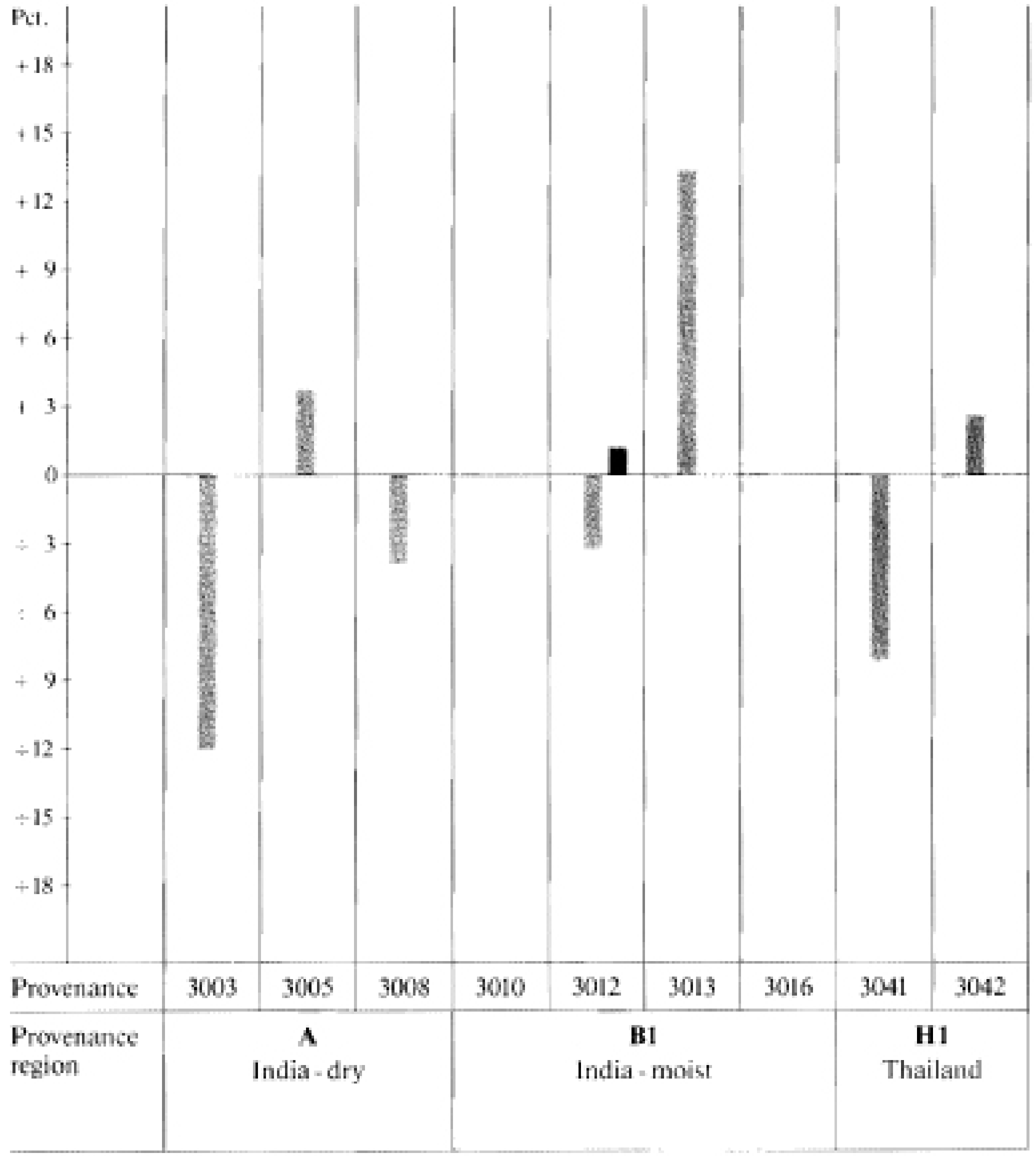
Group	Indiv. Traits		Exp. mean	h²
Health	SURV.	(%)	97	.82
	HEALTH	(%)	100	.00
Growth	DBH	cm	9.5	.36
Quality	STR.	(%)	99	.00
	PERS.	(%)	72	.89
	BR. SZ.	(%)	32	.94
	L. FL.	(%)	82	.98

Appendix D, fig. 19

IP 046, TRACT 105, Puerto Rico

Lat. 18° 15' N. Long. 65° 55' W. Elev. 325 m. Annual rainfall: 2100 mm. 9 provenances tested

Group	Indiv. Traits		Exp. mean	h²
Health	SURV.	(%)	88	.55
	HEALTH	(%)	99	.50
Growth	DBH	cm	7.8	.36
Quality	STR.	(%)	1	.00
	PERS.	(%)	60	.02
	BR. SZ.	(%)	40	.00
	L. FL.	(%)	100	.23



Appendix E: Table E-1

Appendix E: Provenance x site interaction tests

Table E-1: Provenance x site interaction tests

Analysis No.1

Source of Variation	SS (partial)	d.f.	MS	F-test	E(MS)
Pr-reg	5.7414	4	1.4354		σ^2 + q(pr-reg * tr-reg) + 0.434 σ^2 pr(pr-reg) + 3.65 σ^2 pr-reg
Pr(pr.reg)	44.435	41	1.0838	2.00**	σ^2 + 1. 20 σ^2 pr(pr-reg)
Trial-reg	411. 23	6	68.538	50.70***	σ^2 + q(pr-reg * tr-reg) + 1.70σ^2 tr(tr-reg)
Trial (tr-reg)	70.910	10	7.0910	13.11***	σ^2 + 2.35 .σ^2 tr-reg
Pr-reg * tr-reg	24.332	18	1.3518	2.50**	$\sigma^{2\,+}$ + q(pr-reg * tr-reg)
Error	35.152	65	0.5408		σ^2

Pr = provenance
reg =region
tr =trial

Appendix E: Table E-2

Analysis No.2
2-way ANOVA within each of the 6 trial regions

Trial region 1: PNG; Thailand; India, A.P.

Source	SS (partial)	d.f.	MS	F	E(MS)
Pr-reg	23.702	4	5.9255	5.70***	$\sigma^2 + 5.46\ \sigma^2$ pr-reg
Trial	196.381	3	65.460	62.96***	$\sigma^2 + 6.81\ \sigma^2$ tr
Error	45.750	44	1.0398		σ^2

Trial region 2: Central America

Source	SS (partial)	d.f.	MS	F	E(MS)
Pr-reg	7.7611	3	2.587	2.96*	$\sigma^2 + 2.35\ \sigma^2$ pr-reg
Trial	23.137	3	7.712	8.82***	$\sigma^2 + 2.44\ \sigma^2$ tr
Error	17.485	20	0.8742		σ^2

Trial region 3: Brazil

Source	SS (partial)	d.f.	MS	F	E(MS)
Pr-reg	13.463	3	4.488	7.73***	$\sigma^2 + 2.66\ \sigma^2$ pr-reg
Trial	0.2624	1	0.2624	0.45^{ns}	$\sigma^2 + 3.77\ \sigma^2$ tr
Error	6.9672	12	0.5806		σ^2

Trial region 4: West Africa moist

Source	SS (partial)	d.f.	MS	F	E(MS)
Pr-reg	4.2313	3	1.410	7.42ns	$\sigma^2 + 0.859\ \sigma^2$ pr-reg
Trial	5.3413	1	5.341	28.09*	$\sigma^2 + 0.518\ \sigma^2$ tr
Error	0.3804	2	0.1902		σ^2

Trial region 5: West Africa semi-moist

Source	SS (partial)	d.f.	MS	F	E(MS)
Pr-reg	0.9154	4	0.2289	1.01ns	$\sigma^2 + 1.81\ \sigma^2$ pr-reg
Trial	5.1220	12	2.561	11.29*	$\sigma^2 + 2.97\ \sigma^2$ tr
Error	4.3099	19	0.2268		σ^2

Trial region 6: West Africa dry

Source	SS (partial)	d.f.	MS	F	E(MS)
Pr-reg	1.4057	3	0.4686	0.50ns	$\sigma^2 + 1.18\ \sigma^2$ pr-reg
Trial	16.659	1	16.659	17.83**	$\sigma^2 + 2.18\ \sigma^2$ tr
Error	11.215	12	0.9346		σ^2

Appendix E: Table E-3

Table E-3: Analysis No.2 continued

2-way ANOVA of all trials (ignoring trial-regions)

Reference one zone =all trials

Source	SS (partial)	d.f.	MS	F	E(MS)
Pr-region	17.316	4	4.3290	4.50**	$\sigma^2 + 12.5\ \sigma^2$ pr-reg
Trial	1231. 955	16	76.9972	80.03***	$\sigma^2 + 4.17\ \sigma^2$ tr
Error	120.269	125	0.9622		σ^2