RESULTS OF THE INNOPRISE-FACE FOUNDATION RAINFOREST REHABILITATION PROJECT: RESULTS FROM THE FIRST 3-YEAR PHASE[1]

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1. INTRODUCTION

Increasing world-wide awareness of the effects of climate change is creating pressure to find ways to reduce the levels of greenhouse gases in the atmosphere (Brown et al. 1995). One strategy with great potential is to use trees to sequester CO_2, and it is bringing large investments to the forestry sector, particularly in the tropics (Marsh 1992, 1993). This paper describes one such project.

The Innoprise-Face Foundation Rainforest Rehabilitation Project (INFAPRO) is a cooperative venture between Innoprise Corporation Sdn. Bhd. (Malaysia), and the Face (Forests Absorbing Carbon-dioxide Emissions) Foundation (The Netherlands), an organisation set up by the Dutch Electricity Generating Board to promote the planting of forests to absorb CO_2 from the atmosphere to partially offset the emissions of their power stations. The objective is to carry out the rehabilitation of 25,000 ha of degraded logged forests in Malaysia by enrichment planting and reclamation of degraded areas using indigenous tree species such as dipterocarps, fast growing pioneers and forest fruit trees.

Enrichment planting is a technique for promoting artificial regeneration of forests in which seedlings of preferred timber trees are planted in the under-storey of existing logged-over forests and then given preferential treatment to encourage their growth (Lamprecht 1986). Because of the problems and difficulties involved with large scale planting of logged over forests, the project has been established in the form of large field trials employing different systems with the objective of developing successful strategies for rehabilitation of logged forests (Pinso and Moura-Costa 1993, Moura-Costa 1993).

The concept of sequestering atmospheric carbon by forestry is based on the principle that trees extract CO_2 from the atmosphere in the process of photosynthesis, and use it to produce structural compounds for their growth. The amount of carbon stored in trees in a forest can be calculated by determining the amount of biomass in the forest and applying a conversion factor. As longer-lived, high density trees store more carbon than short-lived, low density, fast-growing trees or other vegetation, enrichment planting logged forests with hardwood trees make it possible to obtain dense stands which accumulate higher amounts of carbon per area than logged forests which are left untreated.

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This report describes the results of the research trials conducted between 1992 to 1995 as part of the INFAPRO project. The research was conducted to address some of the most urgent topics required for better management of the project, by answering the following questions:

1. How to propagate the different species, using different methods ?
2. What size of seedlings would attain optimal survival and maximum initial growth ?
3. What type of planting stock (seedlings, wildings, cuttings) attain best growth and survival ?
4. Which species grow better and where ?
5. What is the influence of rainfall on initial survival ?
6. What light intensities offer best conditions for maximum growth and minimum mortality ?
7. What site preparation should be used to achieve these conditions ?
8. What is the influence of remnant vegetation and site factors on growth and mortality of planted seedlings ?
9. Is soil data useful in determining site suitability ?
10. Can fertilisers speed growth of planted seedlings ?
11. Is mycorrhizae a limiting factor when planting in logged over forest ?
12. What are the main areas where human factor is important ?
13. What is the cost structure of the project ?
14. What is the expected timber yield from the planted stands ?
15. What is the expected carbon sequestration from the planted stands ?

The methods used and results achieved are described in this report. A Geographical Information System was developed to assist in the management and research components of the project and is described.

2. MATERIALS AND METHODS

2.1. Project area and study sites

The INFAPRO project area consists of 25,000 ha of logged-over dipterocarp forests in the Ulu Segama Forest Reserve, eastern Sabah (Malaysia), 5° N, 117° E. Mean annual rainfall is 2,800 mm, and mean annual temperature is 26.7°C (Danum Valley Field Centre records). The geology and soils of the region are complex and variable, and the topography is hilly (Marsh and Greer, 1992). Since 1978 this area has been logged under a modified version of the Malaysian Uniform System (Wyatt-Smith, 1963) on an annual coupe basis; thus, at present, it includes areas of secondary forest at different stages of regeneration. The project area was divided in a series of management units, ranging between 25 to 50 ha, referred to as "planting blocks" throughout this paper. The boundaries of these planting blocks were delimited based on natural features (i.e. rivers and ridges), as well as following roads or the surveyed boundaries of logging coupes.

This paper describes the performance of seedlings in six planting blocks which were established during the first year of the project (1992-1993). These planting blocks were located in logged forests of different "ages" (time after logging), which were logged using either tractor (bulldozers) or high-lead systems for timber extraction. In addition, the volume of timber extracted from the different planting blocks varied (Moura-Costa and Karolus, 1995). Therefore, they now differ in terms of secondary vegetation, canopy density, and soil characteristics (compaction, nutrient levels). A short description is given in Table 1.

A soil survey was conducted to characterise the six planting blocks, by taking ca. 15 auger samples from 0-20 cm from undisturbed micro-sites located on a 200 x 200 m grid across the whole of all blocks. The soil samples were bulked by block before analysing for physical and chemical properties (Majalap-Lee, 1994; Anderson and Ingram, 1989). Results are shown in Table 2 (from Nussbaum, 1994). During the survey, the area covered by skid trails was estimated, and the results are given in Table 1.

2.2. Plant material, propagation methods and nursery environment

The species used for this study were the Dipterocarpaceae *Shorea leprosula* (seraya or meranti tembaga), *Parashorea malaanonan* (urat mata daun licin), *Dryobalanops lanceolata* (kapur paji), *Shorea ovalis* (meranti or seraya kepong), *Shorea johorensis* (seraya majau), *Shorea parvifolia* (meranti or seraya punai), *Dipterocarpus gracilis* (keruing kesat), and the Araucariaceae *Agathis borneensis* (mengilan). The dipterocarp species planted in these trials belong to the timber groups Red Seraya (or Red Meranti - the *Shorea* species planted), White Seraya (or White Meranti - *P. malaanonan*), Kapur (*D. lanceolata*), and Keruing (*Dipterocarpus* spp.), which have different wood properties (Burgess, 1966) and physiological characteristics (Whitmore, 1984).

Plant material was collected from the Ulu Segama Forest Reserve, Sabah, Malaysia, and raised in the operational nursery of the INFAPRO, which is centrally located, close to all the planting blocks (maximum distance ca. 5 km). Planting material was produced either from seeds or from wildings. Seeds were collected in the forest and brought to the nursery for germination. Wildings were collected from the forest, taken to the nursery, potted, watered, and kept in plastic-covered chambers with high humidity for four weeks until a new root system was formed. A detailed description of the propagation techniques used are available elsewhere (Moura-Costa, 1996; Moura Costa et al., 1993; Moura-Costa and Lundoh, 1994 and 1995). All plants were potted in 7 x 21 cm poly-bags containing ca. 80 cm^3 forest top-soil. A survey of the nursery stock was conducted and showed presence of mycorrhizae in all plants examined (S.S Lee, Forest Research Institute Malaysia, unpublished results).

Plants were kept under two layers of neutral density shade netting until one month before field planting, when one layer was removed in order to increase light intensity prior to planting. Light intensity was measured using the light sensor attached to a Parkinson leaf chamber (ADC LCA-3, Hoddeston, UK), giving values around 280 µmol m^{-2} s^{-1} under two layers shade netting (26% of full direct radiation) and 830 µmol m^{-2} s^{-1} (69%) under one layer of netting. Relative humidity in the nursery was measured using a continuous chart recorder (Casella, London) and ranged between 50% at 14:00h and 100% at night. Photoperiod was of 12 h, and mean monthly maximum and minimum air temperature were 32 and 22°C. Plants were watered twice daily throughout the period in the nursery. Because of lack of availability of planting stock, it was not possible to plant the whole range of species chosen in each of the planting blocks. A list of the species planted in each planting block and the initial height of seedlings in the growth trial plots (see next section) is given in Table 3.

An experiment was carried out to compare germination of seeds directly sown into polybags with the traditional method of germination in sand beds. Assessments of germination were carried out two weeks after sowing, sampling 10 % of seeds sown for each treatment. Another experiment tested the effects of two different periods of acclimatization on wilding survival and establishment. Wildings of *Dryobalanops lanceolata* (n = 50,000), *Shorea parvifolia* (n = 2,600) and *Parashorea malaanonan* (n = 5,200) were kept for either two or four weeks in plastic-covered acclimatization chambers (Moura-Costa et al. 1993). Assessments of survival were carried out two weeks after opening the chambers.

2.3. Planting system and site preparation

The planting system used for this study was enrichment line planting, which consists of opening parallel lines every 10 m through the secondary forest matrix and planting seedlings every 3 m along the lines. Opening of lines consist of removing all vegetation growing within the stipulated line width, except for seedlings and trees of commercial timber species and some fruit species. Unless otherwise stated, all planting lines were 2 m wide and opened in the East-West direction. Planting holes were approximately 10 cm diameter and 20 cm deep, and 100 g of Christmas Island Rock Phosphate fertiliser (32% P_2O_5) was applied in each hole. Planting was carried out throughout the year, only interrupted if there were more than three consecutive days without rain. Because planting extended throughout different seasons, rainfall immediately after planting varied from site to site. Rainfall figures for each planting block, collected from the closest of the three existing meteorological stations distributed around the project area, were provided by the Danum Valley Hydrology Project (University of Manchester, ODA). The maximum distance between a meterorological station and any of the planting blocks was 5 km. Four rounds of weeding were carried out during the first year after planting, removing all weeds and climbers around planted seedlings. The area of the planting blocks, as well as the number of seedlings planted in each block is shown in Table 3.

2.3.1. Census of survival and canopy opening, and data analysis

Two months after each block was planted, and again after one year, 100% of the planted area was surveyed to assess survival of seedlings. During this survey, a visual assessment of the degree of canopy cover above each planted seedling was carried out, classifying it as open, half-open or closed canopy. Percentage mortality under each canopy opening class was calculated for each species. Correlations were calculated between initial mortality, canopy openness and rainfall during first month after planting.

2.4. Growth trials

2.4.1. Experimental design

Measurements were made of growth and mortality of seedlings of different species. Within each of the six planting blocks, 4 to 8 contiguous planting lines were selected for measurements of seedling growth, and will be referred to as the "growth plots" throughout this paper. Lines were approximately 450 m long, and contained ca. 150 plants each. Each planting line contained one single species. Although a randomised distribution of species along the lines might have been a more appropriate experimental design, thus avoiding limitations from pseudo-replication (Hurlbert, 1984), the single-species line design was adopted for practical reasons related to the implementation of the project. However, lines were long, covered a wide range of micro-environments, and contained a reasonably large numbers of plants, thus allowing a fair representation of the variability within the planting blocks. The location of the growth plots was chosen so that planting lines used for the trials would not be parallel to the main slopes or streams, avoiding gradients between lines.

2.4.2. Measurements of growth and mortality

Height measurements were taken for each seedling two months after planting (Table 3). Plants were re-measured one year later. In order to compensate for the different sizes of seedlings at the beginning of the experimental period, growth rates were expressed as relative height increment (RHI), calculated as follows:

$$\text{RHI} = \frac{\text{Final height - Initial height}}{\text{Initial height}} \times 100$$

Mortality rates were expressed as the percentage of seedlings that died between the initial measurements and one year later. Percentage mortality was calculated for either size classes or light classes, as described in the next sections.

2.4.3. Measurements of light (diffuse non-interceptance light - DIFN)

Measurements of light were taken using two Li-Cor LAI-2000 Plant Canopy Analyzers (Li-Cor, USA). This equipment measures diffuse non-interceptance light (DIFN) reaching each sensor, which is an index ranging from 0 (closed canopy) to 1 (totally open canopy; Li-Cor, 1992). In practice, DIFN indicates the probability of diffuse radiation penetrating the canopy and reaching the seedlings (Norman and Welles, 1983). Measurements were carried out for each seedling planted in the growth plots 78A and 88B. One canopy analyser was located in a large clearing and recorded automatically using its internal data-logger, while another was used to manually collect below-canopy readings above each planted seedling. The two LAI-2000 units were then connected, so that each below-canopy reading was matched to the corresponding reading taken in the open. DIFN was automatically calculated by the internal software of the LAI-2000, by comparing the amount of light reaching the below-canopy sensor with the light reaching the sensor located in the open.

A single measurement was taken for each planted seedling without using any of the view-masks provided with the LAI-2000, so that a 360° reading was done. The LAI-2000 measures the attenuation of diffuse sky radiation with a set of five optical sensors, arranged as concentric rings (Welles and Norman, 1991). Our measurements ignored the two outermost rings, since they measure incident light from a low angle, close to the ground, and there was substantial interference from tree stems and rocks. In order to prevent interference from reflection (Welles, 1990), all measurements were taken during totally overcast weather conditions and readings were interrupted in case of rain.

The Li-Cor DIFN readings were compared with measurements of canopy openings taken with a hemispherical canopy densiometer (Forestry Supplies Inc., USA). Readings (*N*=35) were taken simultaneously with both instruments and a linear regression was carried out using DIFN as the dependent variable. In order to determine the accuracy of the Li-Cor DIFN readings, 3 plants were measured five times each, so that the variation in standard error of the readings could be assessed.

2.4.4. Data analysis

Comparisons of relative height increment between growth plots were carried out by one-way ANOVA for each species separately, and the means compared according to Tukey's test. Comparisons of mortality rates between plots were carried out in two ways: once for each species separately, comparing between plots, and once for each plot separately, comparing between species within a plot. Contingency tables of number of plots/species versus status (dead or alive) were tested with a χ^2 test. Correlations were calculated between relative height increment and the soil factors derived from the analysis described in the previous section (Table 2), for each species separately.

2.4.4.1. Growth and mortality of seedlings of different initial height

The influence of initial seedling height on relative height increment during the first year was examined for each species by linear regression. In order to study the influence of initial height of seedlings on mortality rates, seedlings were divided into classes of initial height and the percentage mortality of seedlings in each class was calculated. The upper and lower confidence limits, at *P*>75%, were generated by use of the inverse *F* distribution (Johnson and Kotz, 1970), following the method decribed in Sheil and May (in press). Most species were divided in height classes of 10 cm-intervals, except *S. johorensis, D. gracilis* and *A. borneensis*, which were divided into classes of 5-cm intervals, as the range of initial heights of these species was not wide enough to use broader height classes. I tested whether the pattern of mortality between size classes was best defined by a quadratic or a log power-exponential function (Alder, 1995), by carrying out both a linear regression and a regression using the following equation:

$$\log_e(\text{Mortality}) = \alpha + \beta.\log_e(\text{Initial Height}) + c.(\text{Initial Height})$$

The power-exponential function was chosen to test if data showed a U-shaped curve, i.e. high mortality for both the smallest and largest height classes, and lower mortaltiy for height classes in the middle of the range. Therefore, only the functions which had a negative α coefficient, thus producing a U-shaped curve, were used. The probability of the data fitting the functions was calculated using an *F*-test.

A comparison between growth of *S. leprosula* plants propagated by seeds and wildings was carried out. Approximately 60 plants of each plant type were measured during planting and again 1 year after, and theri relative height increment was calculated.

2.4.4.2. Growth and mortality under different light classes

The influence of light (DIFN) on relative height increment during the first year was examined using a polynomial-quadratic function for each species, and the fit calculated by an *F*-test. In order to study the mortality rate in relation to light, seedlings were divided into classes of DIFN, i.e. 0 to 0.007, 0.008 to 0.014, 0.015 to 0.025, 0.026 to 0.048, 0.049 to 0.089, 0.090 to 0.165, 0.166 to 0.308, and 0.309 to 0.574. The light classes were chosen in order to have at least five means from a minimum of 5 individuals each. The upper and lower confidence limits, at *P*>75%, were generated by use of the inverse *F* distribution (Johnson and Kotz, 1970), following the method decribed in Sheil and May (in press). Mortality was plotted against DIFN, using a logarithmic axis for DIFN (Lang and Xiang, 1986), since data were compressed in the left side of the graph. Theoretically, it was expected that the pattern of mortality in relation to light should be expressed by a U-shaped graph. High mortality should occur in total darkness or very high levels of light, while plants should survive in the middle of the light range. For this reason, it was tested whether the data fitted a power-exponential function (Alder, 1995), as follows:

$$\log_e (\text{Mortality}) = \alpha + \beta.\log_e(\text{Light}) + c.(\text{Light})$$

Only the functions which had a negative α coefficient, thus producing a U-shaped curve, were used. The probability of the data fitting the functions was calculated by an *F*-test.

2.5. Trial on the effects of width of planting lines

A separate trial tested the effect of the width of planting lines on growth of seedlings of *Dryobalanops lanceolata*. Lines of 1.5 -, 2.0 - and 3.0 m - width were opened (3 replicates for each width) in the planting block 88B, and approximately 75 seedlings were planted in each line. The width of planting lines was measured at the ground level, and any vegetation apart from trees or seedlings of commercial species found within the lines was removed. The percentage canopy cover above each planted seedling was estimated using a hemispherical canopy densiometer (Forestry Suppliers Inc., USA). Height of seedlings was measured one year after planting. Percent canopy cover and final seedling height in each width of planting line were compared by one-way ANOVA.

2.6. A GIS study on the effect of remnant vegetation and site factors on growth and survival of planted seedlings

A study of the influence of remnant vegetation and site factors on growth and survival of planted seedlings was carried out using a geographical information system (GIS). This study is described in more detail in van Oorschot et al. (1994) and Moura-Costa et al. (1994). The study sites were the same as those used for the growth trials, as described in Section 2.4. All planted seedlings, as well as existing trees (dbh > 10 cm), patches of grasses, bamboo, vines, streams, and skid trails were mapped and digitized. The GIS package used for this project was PC-ArcInfo running in a 486 IBM-compatible personal computer. Digitization was done using a Summasketch III Professional (Summagraphics, USA) A3 digitiser tablet. The coordinates of the planted seedlings collected from field surveys were used to generate base coverages (digital maps) for each plot. Data bases were created containing the growth rates, survival status (dead or alive) and LAI values for each seedling. The data were attached to the seedlings by using their corresponding coordinates. Rivers, streams, skid trails, rock outcrops, and patches of vines, bamboo and weeds were digitized in ArcInfo as polygons. Trees were digitised as point data and different buffers were created according to their size-classes in order to simulate canopy cover. Coverages were created for each of these factors.

To analyze the data, overlays of the different coverages were produced to study the influence of the various factors on growth and survival of planted seedlings. Another analytical procedure used was to generate buffers surrounding certain physical features in order to study the extent of their zone of influence on seedling growth and survival. After patterns were identified from the maps generated from the overlays, data were extracted and analyzed. The GIS was used to perform the following analyses:

a) Effect of trees and their zone of influence. The differences in growth rates of seedlings planted at different distances from the stem of remnant trees were investigated by using the buffer feature of ArcInfo. Buffer zones of different diameters were created around trees according to their size classes, in order to simulate a zone of dense shade and root competition. A second, larger, buffer was created around the same trees to simulate their canopies (Table 4). Growth data from seedlings in these buffer zones were selected and compared with data from seedlings outside the 'zone of influence' of the trees.

b) Effects of competing vegetation: vines, bamboo and grass **-** By using the overlaying feature of ArcInfo, data were selected from all plants under vines tunnels, bamboo clusters and patches of grass, and compared to data from plants away from them.

c) Effects of streams, riverine areas and skid trails **-** In order to study the effect of riverine conditions on development of seedlings, a 10 m buffer zone was created from the margin of each stream, and data from seedlings located there were selected and compared to seedlings planted elsewhere. Similarly, 3 m buffers were created on each side of skid trails, and the growth and survival of seedlings in these areas were compared with those planted elsewhere.

2.7. Effects of fertilisers on growth of dipterocarp and pioneer tree seedlings

During the last 3 years, two studies were conducted on the effect of fertilisers on indigenous trees. The first was conducted by Yap Sau Wai (INFAPRO), testing the effects of 0, 10, 40 and 80 g of NPK 12:12:17 granular fertiliser on seedlings of *S.leprosula* and *D.lanceolata* planted in 8 sites within the project area. This study is still being carried out and preliminary results are described in Yap and Moura-Costa (1994).

A second study was conducted by Ruth Nussbaum (Un. Exeter and Cambridge, Unesco-MAB), testing the effects of fertiliser and ploughing on growth of seedlings of *S.leprosula, D.lanceolata* as well as the pioneer tree species *Macaranga* and *Octomeles sumatrana* planted in log landings in the 1992 logging coupes. These studies are descibed in more detail in Nussbaum et al. (1994), Nussbaum and Anderson (1995) and Nussbaum (1993, ICSB Internal Reports). The experiment consisted of seven treatments: 1) Compacted soil, 2) compacted soil with fertilizer,3) compacted soil with mulch, 4) dug soil, 5) dug soil with fertilizer, 6) dug soil with mulch, 7) replacement of topsoil. In the compacted soil treatments the only disturbance to the log landing soil was the planting holes. For 'dug' treatments the soil in the whole plot was turned over and broken up with a spade to a depth of 30 cm, two or three weeks before the seedlings were planted. In fertilised treatments each seedling received 100 g of rock phosphate when planted, placed in the planting hole, and 40 g of granular fertilizer (12:12:17 N:P:K + micronutrients) when planted and again after 6 months. The granular fertilizer was placed in a ring about 10 cm from the seedling just below the soil surface to prevent loss through surface erosion. For mulched treatments, pieces of bark, which had been stripped from felled trees a year earlier, were used to cover the surface of the plot. For topsoil treatments, the soil was removed from the plot to a depth of 30 cm and replaced with soil taken from the top 0 - 30 cm in the adjacent undisturbed forest. Measurements of seedling height and basal diameter were taken immediately after planting and repeated after 6 months.

2.8. A survey of the mycorrhizae populations in logged and primary forest around the INFAPRO area

A survey of the populations and types of mycorrhizae found in primary and logged over forest of different ages was conducted within the INFAPRO area. The study was conducted as a bioassay, planting mycorrhizae-free seedlings of *S. leprosula* and *Hopea nervosa* in 6 different sites, 3 in recently logged forest (1 to 2 years after logging, ie., 1991 and 1992 logging coupes), and the other 3 in the closest primary forest to these sites. Seedlings were dug 6 months after planting and their root systems were examined for mycorrhizae associations. This study is described in more detail in Lee et al. 1994.

2.9. Cost structure and work efficiency

An analysis of the cost structure of the project was conducted using the cost records collected for the two initial years of the project. The amount of time spent for different project activities was also calculated based on the cost data available for this period.

2.10. Estimation of timber and carbon yield from the project

The amount of carbon sequestration expected from this project was estimated using figures from the literature and data from the project. The formulas used for calculation of biomass and carbon were those of Kira (1978) and Chan (1982). The following assumptions were used for the calculations in this paper:

- a pre-planting biomass of logged forest (5 years after logging) of 125 t ha^{-1} (based on Putz and Pinard 1993), growing at a rate of 1.0 t ha^{-1} $year^{-1}$ until planted trees reach 20 cm dbh. After that, it is assumed that the only increases in biomass in the site will be due to the growth of planted trees, while the biomass of the secondary forest matrix decreases at a rate of 1 % per year;

- an initial reduction in the site's biomass of 18 % as the result of the initial opening of lines, although trees with dbh larger than 10 cm and existing seedlings of commercial timber species and fruit trees were not removed during site preparation;
- after discounting unplantable points (*i.e.,* rivers, rocks, points already occupied by natural regeneration or trees) and the initial mortality (*ca.* 15% during first two months), an average of 280 seedlings establish per ha (considering that 3 rounds of replanting will be conducted);
- under optimal conditions, dipterocarp trees grow at an initial rate of 1.6 cm dbh year^{-1} during the initial 20 years; 1.2 cm year^{-1} between year 20 and 40; and 0.8 cm year^{-1} after 40 years (Vincent 1961 a, b; Tang and Chew 1980, Hassan *et al.* 1990, Moura-Costa *et al.* 1994 a, b). The initial rate of 1.6 cm year^{-1} was chosen because this was the growth rate of the 50 fastest growing seedlings per ha (Moura-Costa *et al.* 1994a, b), which would be most likely the ones that survive until the end of the rotation;
- tree mortality of 2 % per year during the initial 30 years, and then 1.5 % per year (Hassan *et al.* 1990, Korsgaard 1992). These rates are substantially lower than the initial mortality observed during establishment phase;
- a commercial thinning operation is carried out 30 years after planting, removing 50 % of the existing trees;
- a recovery rate of 30 % of timber into wood products, which decompose at a rate of 7 % per year;
- a total of 80 t C ha^{-1} is stored in soil and necromass.

3. RESULTS AND DISCUSSION

3.1. Plant production

From our experience with plant production, it was found that seeds must be taken immediately to the nursery for germination. When fresh seeds were used, germination rates of up to 97 % (n = 5,000, SE = 1.2) were obtained after 2 weeks for *Dryobalanops lanceolata, Shorea leprosula* and *Parashorea malaanonan*. Sharp decreases in germination rates were observed when seeds were kept for more than two weeks, with less than 50 % (n = 5,000, SE = 4.2) germination. It was found that germination rates and seedling establishment after direct sowing into poly-bags were not significantly different from the levels achieved using sand beds (Table 5). For this reason, germination of seeds directly in poly-bags was adopted as a standard practice in the project nursery, since this practice greatly reduces costs and the mortality derived from transplanting of young seedlings.

If seeds were not collected from the forest, they quickly germinated, and the resulting wildings were be cultivated. Wildings were pulled from the forest floor in the most efficient way (one person can collect up to 180 wildings per hour) but this method often damaged their root system. Thus, special care had to be given during an acclimatization period after transfer to the nursery. Wildings were watered and kept in plastic covered chambers with high humidity, until a new root system was formed. Survival was significantly higher after four weeks acclimatization in a high humidity environment provided by the plastic-covered beds (Table 6). Species differences were observed, with *S. parvifolia* showing higher levels of survival (94.4 %) followed by *D.lanceolata* (88.2 %) and *P.malaanonan* (40.9 %). Longer periods in the acclimatization chambers might be required for increasing survival rates of wildings of the latter two species.

Vegetative propagation by cuttings have also been carried out in order to provide another alternative for plant production, following the methods described in Moura-Costa and Lundoh (1994, 1995) and Moura-Costa (1996). The average percentage rooting of large batches of cuttings (n = 600) ranged between 60 and 90 %, depending on the species.

Experiments were also carried out to find out a suitable potting mixture for growing dipterocarp seedlings (Yap and Moura-Costa 1994). The best potting mixture tested consited of a 1:1 mixture of soil and composted saw dust, with 14 g Rock Phosphate per plant.

3.2. Initial survival and causes of mortality

The mean survival rate of all seedlings planted in the six planting blocks was 88.6% two months after planting (Table 7). Although higher rates of initial mortality were expected in planting blocks with less canopy cover, this did not appear to be true. The highest mortality rates were observed in planting blocks 88A and 91A (18.7% and 25.7%, respectively), although block 88A had a low percentage of plants under open canopy. It appeared that the most important factor determining initial survival of seedlings was rainfall following planting. The amount of rainfall (total rainfal during the initial 30 days after planting and number of rain days during the initial 15 days after planting) was lowest for blocks 91A and 88A, possibly explaining the high mortality in these blocks. Survival was positively correlated with number of rain days during the initial 15 days after planting (Pearson product-moment coefficient of correlation r=0.813; P=0.038, N=6), and with rainfall during the first month after planting (r=0.788, P=0.050, N=6). It is important, therefore, to take rainfall into consideration when plannng planting operations. Historical series are important in helping decision-making at the management level. Although the lowest rainfall during the study year was May, analysis of the rainfall patterns around the project area, from 1986 to 1992, showed that the probability of a month having lower rainfall than the others is only significant for the month of April (Nussbaum, 1995).

The percentage survival in different blocks one year after planting are shown in Table 7. A similar rank between sites is still observed after one year. The rate of mortality decreased between the initial census and the 1st year census (Table 8). The high initial mortality was probably due to a combination of factors, ie. light, rainfall after planting, transplant shock, poor handling of seedlings. It decreased after the initial establishment phase, since a substantial proportion of plants initially died due to poor handling or transplant shock. It is expected that this rate will decrease even further after seedlings reach aproximately 3 m height, since they will be less susceptible to mammal browsers, damage by falling debris (branches, rotten vines), and less likely to desiccate.

3.3. Growth trials

3.3.1. General performance of the different species in different sites

The relative height increment of the different species planted in the six growth plots are given in Table 9. The overall average growth rate of all seedlings in the six plots combined was about 68%. The highest overall average growth rates were achieved in plots 78B (96%) and 81A (94%). The lowest overall average growth rates (39%) were recorded in plot 88A.

At the species level, seedlings of *S. leprosula* had the fastest growth rates, averaging 133% over all six plots, and over 200% in the plot 91A. High growth rates were also observed for the other Red Serayas, i.e. 92% for *S. parvifolia*, 90% for *S. ovalis*, and 64% for *S. johorensis.* The lowest growth rates were recorded for *P. malaanonan* (38%), and *A. borneensis* (16%), possibly because of heavy herbivory which was observed for the seedlings of these species (data not shown). Some seedlings of *A. borneensis* were found totally defoliated, while seedlings of *P. malaanonan* suffered damage to the main stem. *Dryobalanops lanceolata* and *Dipterocarpus gracilis* had average growth rates (66% and 64%, respectively).

There was much variation in growth rates of species in different plots. The differences between growth rates in the best plots compared to the worst plots reached up to 245 fold, for *A. borneensis*, and 10 fold, for *P. malaanonan*. Reductions in size caused by herbivory possibly contributed to the large differences in growth observed for these species. The smallest variation in growth between plots was observed for *D. lanceolata*, i.e. growth in best plot was 2 fold growth in the worst plot, possibly reflecting less site specificity of this species. All species showed significantly ($P<0.001$) higher growth rates in plot 78B than in 78A, except *D. lanceolata* (no significant difference).

Examination of maximum relative height increments achieved by individual seedlings may provide an insight into the potential growth rates of different species. This analysis showed that *S. leprosula* had the highest maximum RHI (965%), followed by *D. lanceolata* (556%), *S. ovalis* (540%), *S. johorensis* (466), *S. parvifolia* (433%), *P. malaanonan* (373%), *A. borneensis* (257%), and *Dipterocarpus gracilis* (217%).

The combined average mortality rate of all species during the first year was 40.6% (Table 10). Plots 88A, 78A and 81A had mortality rates significantly higher than the combined average of all plots, while in plots 88B and 78B mortality was significantly lower (χ^2=126.2, $p \leq 0.005$). The highest mortality rates were recorder for *A. borneensis* (55.8%) and *P. malaanonan* (49.9%), significantly higher than the average mortality for all species (χ^2=130.81, $p \leq 0.005$). However, while *A. borneensis* showed significant differences in mortality between plots (χ^2=53.22, $p \leq 0.005$), there were no significant differences in mortality of *P. malaanonan* between plots. The lowest mortality rates were observed in *D. lanceolata* (29.5%) and *S. leprosula* (33.5%), significantly lower than the average for all species (χ^2=130.81, $p \leq 0.005$). The mortality rates of both these species were significantly ($P<0.005$) lower at plot 88B and higher at plot 91A (χ^2=27.36, $p \leq 0.005$ for *D. lanceolata,* and χ^2=27.58, $p \leq 0.005$ for *S. leprosula*). *Dipterocarpus gracilis* had the highest mortality (47.3%) in plot 88B, the only plot where it was planted, significantly higher ($p \leq 0.005$) than the average for this plot (χ^2=34.72, $p \leq 0.005$). In this same plot, mortality of *S. parvifolia* (34.1%) was not significantly different from the plot average (25.7%).

There were no significant correlation ($P \leq 0.05$) between RHI and any of the soil factors listed in Table 2. In a general way, the chemical composition of soils from the six study plots was very similar, without marked contrasts between plots, and are around the average for Sabah soils (Goh et al., 1989).

3.3.2. Growth and mortality of seedlings of different initial height

Figure 2 shows the yearly relative height increment of seedlings plotted against classes of initial height. A significant ($P<0.005$) negative linear relationship between initial height and yearly relative height increment was found for all species, except *Dipterocarpus gracilis* (not significant).

The pattern of mortality of seedlings of different initial heights differed between species (Fig. 3). A significant negative linear relationship was found between initial height and final mortality for *D. lanceolata* (R^2=0.667, P=0.047, N=6), *S. leprosula* (R^2=0.743, P=0.002, N=7), *Dipterocarpus gracilis* (R^2=0.722, P=0.004, N=8) and *A. borneensis* (R^2=0.771, P<0.001, N=11); in other words, higher mortality occurred between smaller seedlings. A power-exponential function provided a better fit for the pattern of mortality of *S. ovalis* (R^2=0.596, P=0.1, N=8), and *S. johorensis* (R^2=0.843, P=0.009, N=8). No relationship was observed for *P. malaanonan* and *S. parvifolia*. It appeared that the optimum size of seedlings for planting is about 40 to 50 cm, for most species.

A possible explantion for differences in mortality of seedlings of different heights is the differences in shoot:root ratios. Tall seedlings have more leaves, and therefore evapotranspirate more than shorter seedlings. Since their root systems are limited to the size of the planting bags, taller seedlings are more likely to suffer from root constraints and desiccation. This is particularly true for seedlings grown from seeds, which can form extensive root systems in a short time. Wildings, on the other hand, take a longer time to form a good root system and have the opposite problem as seedlings. In many cases tall wildings which are not kept in the nursery for long enough are transferred to the field before a large enough root system is formed, suffering from desicattion at the time of planting. It is important, therefore, that the nursery manager inspects the root systems of each batch of seedlings before dispatching them to the field.

3.3.3. Growth of different types of planting material

A comparison of types of planting material has shown that seedlings of *Shorea leprosula* had an average relative height increment of 200 % over one year, much higher than wildlings of the same species, which showed a relative height increment of 70%. These differences are probably due to the better root systems of seedlings as compared to wildlings. It is expected that these differences will be reduced after the first year.

3.3.4. Growth and mortality under different light classes

Results of linear regression between percentage canopy openness measured with a canopy densiometer and diffuse non-interceptance light (DIFN) measured with a Li-Cor 2000 Plant Canopy Analyser showed a significant positive relationship (R^2=0.890, P<0.001, N=35) between these measurements. The average standard error of the DIFN measurements was c.a. 5% of the mean. Thus, the Li-Cor DIFN readinds were considered adequate for use in further analysis, since they are faster to take and less subjective compared to the readings taken with the hemispherical densiometer.

Figure 4 shows the relative growth rates of the different species in response to light (DIFN). All species showed a positive height growth response to increasing light levels, with the exception of *P. malaanonan*. The optimal amount of light has to take into consideration the patterns of mortality, as described below.

Mortality rates of the different species plotted against light (DIFN) classes are shown in Figure 5. The power-exponential function fitted the data pattern of most species at $p \leq 0.100$, except *P. malaanonan*. For most species, mortality increased as light approached the highest values. Theoretically, it was also expected that mortality should approach 100% at near-zero levels of light, since plants cannot survive in complete darkness. However, this rise in the left side of the curve was only obvious for *S. leprosula, S. johorensis* and *Dipterocarpus gracilis*. The upper limit of light intensity for survival also varied between species. If a 50% mortaltiy threshold is adopted, the model suggests that it is reached at the lowest light levels by *D. gracilis* (DIF*N*=0.037), followed by *S. ovalis* (0.057), *S. johorensis* (0.125), *A. borneensis* (0.225), *S. parvifolia* (0.315), *S. leprosula* (0.51) and *D. lanceolata* (0.56).

3.4. Trial on width of planting lines, canopy cover and seedling growth

There were no significant differences in the average canopy density above seedlings planted in lines of different widths (1.5, 2.0 and 3.0 m), nor in the average height of seedlings planted in these lines. Since line width was measured on the ground, opening wider lines did not necessarily affect the canopy openness. In many cases seedlings were shaded by branches of trees located outside the planting lines which were not removed during site preparation. Vine tunnels, hanging from trees located outside planting lines, also caused substantial shading.

A more elaborate system for canopy manipulation have to be adopted. This should take into account other silvicultural objectives aiming at improving growth rates of the stand as a whole. Furthermore, liberation thinnings must be carefully conducted in order to prevent excessive opening of the canopy. Too much light may promote the growth of vines, bamboo and weeds, as has been observed in some sites (81A, 88C, 78C). It is preferable to have slow growth under a weed-free environment than to have to eradicate bamboos and vines after canopy opening. This is particularly relevant considering that stand maintenance and weeding is one of the most expensive project activities (see Section 3.7).

One of the approaches for canopy opening used by the project is to carry out vine cutting. This activity, however, has to be done at least 6 months prior to planting. After the vines decompose and drop, a second round of site preparation, preparing the lines at the ground level, should take place. This activity would result in a more open canopy and also reduce the amount of litter felling on seedlings, which is one of the main causes of mortality in DVFC forests (Still 1993). Another study in the same forest found that high mortality was observed when vine cutting was done after seedlings were planted, presumably because of litter felling (van Oorshot et al. 1994, Moura-Costa et al. 1994).

3.5. Effects of remnant vegetation and site factors on growth and mortality of seedlings

Influence of trees - It was found that seedlings planted in the close vicinity of trees (i.e. the inner buffer zone ring created with the GIS) suffered a strong reduction in growth rates (Table 11). Seedlings in the outer ring had faster growth than those close to the tree stems, but still lower than those planted outside this "zone of influence" of trees. It is interesting to notice that among the range of dipterocarp species studied, *Dipterocarpus* spp. did not exhibit any site preference in relation to proximity to trees. Conversely, the *Shorea* spp. suffered strong reduction in growth rates when under competition for light and nutrients. Generally, the greatest effects of competition with trees were observed in the Plot 78B. No reduction in growth rates was observed from tree competition in Plot 81A.

As it would be expected, it was found that seedlings grown under the canopy of remnant trees grew slower than those outside their shade zone. It was also found that the closer to the tree stem the seedlings were planted, the slower their growth rates, possibly because of more intense root competition (Putz 1992) and deeper shade (Sasaki and Mori 1981). On the other hand, seedlings planted in the open had fast growth but suffered high mortality. The silvicultural implications of this is that in some cases liberation thinning is required, but taking the precaution not to remove too many trees. Obviously, the decision of whether or not to carry out liberation thinning depends on the value of the tree species shading the seedlings. The planning of thinning operations could be optimised by simulations carried out in the GIS, testing the effects of different treatments prior to their actual implementation in the field.

Effects of competing vegetation - Vine tunnels caused a reduction in growth rates of seedlings of some species (Table 12). No consistent pattern of mortality was observed, although in some cases these tunnels caused death of seedlings when they collapsed. In a natural situation, vines can also strangle seedlings, but in this enrichment planting project vines are removed from seedlings every three months during the weeding operations. Although it was expected that bamboo clusters would cause mortality of planted seedlings due to climbing (Yap et al. 1996), this was not observed. High seedling mortality was observed within patches of grasses (Table 12).

Growth suppression was caused by competing vegetation, particularly dense patches of climbing vines, in accordance with Hutchinson (1981). Given that vine tunnels may have the same effect as shading trees (Fox 1968), and that vines do not have any commercial value, it is highly recommended that they are removed during the early stages of site preparation prior to enrichment planting. No growth suppression or mortality was observed in the vicinity of bamboo clusters, but this may change when seedlings become taller providing a support for the climbing bamboo (Yap *et al*. 1996). High mortality was observed in areas infested with grass, possibly because of inadvertent cutting of seedlings during weeding operations. This could be avoided if wooden sticks were used to mark the location of young seedlings during their early development. Since grass occurs in open areas (Ipor and Tawan 1992), it is also possible that dipterocarp seedlings in their vicinity actually suffered from the excessive radiation and drought in these sites.

Influence of riverine areas and skid trails - Although it was expected that seedlings grown in riverine areas would grow faster than those elsewhere, because of the presence of alluvial soil and high water availability in these sites, this was only true in plot 88B. The absence of large differences in growth rates in plot 78B may be because this is a fairly flat site between two rivers, so even the seedlings away from the rivers may still benefit from high water availability and alluvial soils. All the plots studied had many zero order streams (ie. streams that only appear after rainfall) and seedlings planted in these sites suffered high mortality (Table 12). This is possibly because the underlying soil is frequently saturated and anaerobic, killing roots through lack of oxygen. Seedlings of all species showed higher mortality rates when planted in skid trails. A reduction in growth rates was observed in seedlings planted in skid trails in plot 88B, but not in 81A.

3.6. Effects of fertilisers on growth of dipterocarp and pioneer seedlings

The results derived from the study conducted by Yap Sau Wai are still unconclusive. Until this stage it is not clear whether or not fertilisers can be used to enhance growth of dipterocarp seedlings planted in the forest under storey. There are a series of possible reasons for these observations: 1) It is possible that variation in light levels are masking the full expression of results; 2) there may be enough nutrients in the forest under storey for seedlings to develop normally, specially since these species are ecto-mycorrhizal; 3) fertilisers may be leaching at a fast rate; 4) the application of fertilisers may lead to increased root competition, reducing its effectiveness; 5) fertilisers may be suppressing mycorrhizae, causing a disadvantage for fertilised seedlings; 6) dipterocarp seedlings are not able to efficiently metabolize the nutrients in the forms provided. These factors are under investigation as part of a separate research programme (Yap S.W., University of London).

Results from experiments in log landings indicate very strongly that one of the most important factors limiting the growth of dipterocarps in these areas is nutrient deficiency. Figure 6 shows the relative height increments of the *D. lanceolata* 3 months after planting. *Shorea leprosula* had a greater height increment than *Dryobalanops lanceolata*, but the increase in basal diameter was similar for both species. For both species the fertilised seedlings had significantly better growth for both height and basal diameter, than unfertilised seedlings ($p < 0.05$, $F > 6.55$). Digging did not produce a significant difference in height or basal diameter. Replacement of topsoil resulted in growth as good as that of fertilised seedlings. Similar response was observed for seedlings of *Macaranga* and *Octomeles*.

3.7. A survey of mycorrhizae in logged and primary forest

Results from the survey of mycorrhizae populations has shown that seedlings in logged forests have substantially more mycorrhizae associations than seedlings planted in the primary forest. Seedlings also showed higher growth rates in logged forests. Approximately 50 mycorrhizae types were identified in the seedlings studied, half of them common to both logged and primary forests. There was higher diversity of mycorrhizae types in seedlings planted in the primary forest. These results are described in further detail in Lee et al. (1994). A survey of seedlings in the operational nursery of the INFAPRO showed that most seedlings had at least 2 types of mycorrizae.

3.8. Cost structure and work efficiency

The percentage contribution of different project components on the total cost of the project, and the labour efficiency for performing different project activities are shown in Table 13. It can be seen that the most expensive activities are planting (ca. 35% for site preparation and planting) and weeding (24 %). Seedling production accounted for 11% of the cost of the project. The approximate cost of one seedling is RM 0.50 (US$ 0.20), but this figure varies depending on the method of plant propagation used (seeds, wildings, cuttings). Analysis of the cost structure of the project shows that 90% of the costs are spent on labour, and 10% on capital goods.

Site preparation and planting are the least efficient operations in the project. This is because the current operational guidelines require repeated entries of the workers in the forest to perform different activities at separate times. It is expected that savings could be achieved if site preparation activities were optimised and improved. This would not only reduce the direct cost of this activity but also greatly improve the overall quality of the project implementation, resulting in improvements of seedling initial survival and mortality during the first 2 years. A large proportion of mortality is due to debris felling, accidental cutting of seedlings during weeding operations, and damage due to poor handling of seedlings. This could be avoided or minimised if a well supervised and systematic site preparation was carried out.

3.9. Estimate of carbon sequestration and timber yields from the project

The results of a projection of stand development and biomass production are given in Table 14. It is expected that after approximately 10 years, planted trees will be large enough to compensate for the reductions in biomass assumed to result from site preparation. After 30 years, trees are expected to reach *ca.* 42 cm dbh, justifying a commercial thinning of 50 % of the stand. At this time, the total amount of carbon offset would have reached 170 t C ha^{-1} (before thinning). The remaining trees will be left to continue growing until the end of the 60-year rotation. The total amount of carbon offset stored in standing trees at the end of the rotation amounts to 183 t ha^{-1}, plus the carbon stored in the wood products harvested at year 30. The average yearly carbon offset will be 100 t C $ha^{-1}yr^{-1}$ during a 60-year rotation. Apart from the carbon benefits, a total of 346 m^3 ha^{-1} of high quality timber will be produced during this time. These trees will eventually be harvested, but during the whole rotation the forest will be managed for promoting natural regeneration in order to maintain a healthy stand with a large carbon storage.

3.10. The Geographical Information System of the INFAPRO

A Geographical Information System was developed to assist the management and research components of the INFAPRO (Soo S.M., Mapping Unit, ICSB). The system runs in the software PC Arc-Info and can be used or searched through Arc-View I or II. Currently the system includes the following information:

- Maps of the region, and of all the planting compartments and research plots;
- Contour lines drawn from 1:50,000 maps;
- Soil data;
- Rivers and roads;
- Location of buildings, nurseries and field centre;
- Location of logging coupes, divided into logging compartments, and a data base of all timber extracted from each compartment divided into the main timber groups (Moura-Costa and Karolus 1995);

- For 3 research plots (5 ha each), a much more detailed mapping was carried out. This included all trees above 10cm dbh, patches of weeds, vines, bamboo, skid trails and streams (described in detail in van Oorschot et al. 1994, and Moura-Costa et al. 1994)..

The system is connected to the Plantation Record Software (Esther Li, ICSB, KK), which captures all the data related to field operations such as planting dates, species planted, number of seedlings, mortality and growth rates, replanting and maintenance activities, as well as cost data. This GIS is also linked to a remote sensing monitoring system (MONIS) developed by the Face Foundation, so that satellite imagery could be more easily linked to the project data. The combination of all these factors in a single system provides an useful tool for planning, monitoring and supervision of both the operational and financial aspects of the project, as well as valuable research tool.

4. GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

4.1. Plant production, nursery techniques and quality of planting stock

Large scale plant production has been carried out using different propagation systems. The performance has been satisfactory, i.e. 95 % germination rates of dipterocarp seeds, 90 % establishment of wildings, 85% rooting of cuttings. This last system, vegetative propagation by cuttings, is now been adapted for scaling up to a mass-propagation scale. It is recomended that vegetative propagation is used within a selection and cloning program, in order to allow genetic improvement of the planting stock. Since the genetic base of dipterocarps is very wild, there is great scope for selection, and great improvements in growth rates can be expected using this approach.

Selection is also recomended at the nursery stage. It is expected that growth and survival rates of planted seedlings would greatly improve if there was better selection of planting stock prior to planting. This could be based on systematic culling procedures to be introduced in the nursery operations, discarding the worst 30 % of the planting stock. This system, however, can only be introduced if plants in the nursery are periodically sorted by height classes, in order to minimise suppression of growth of some plants due to lack of light. It is often the case that the planting contractor chooses the tallest seedlings for field planting. However, it is often better to select plants with larger basal diameter, since this factor is strongly correlated to rooting ability (Moura-Costa, unpublished results). A low diameter:height ratio, therefore, may be the most adequate criterion.

Analysis of seedling growth and survival by height classes has shown that there is an optimal height for maximum growth and minimum mortality. For most species, this ranges around 40 to 50 cm height.

Shorter or taller seedlings tend to show higher mortality. Seedlings taller than 60 cm should not be planted in the field.

As root development is perhaps the most important seedling characteristic related to the probability of survival after field planting, it is strongly recommended that the nursery manager inspects the root system of each batch of plants prior to dispatching to the field. This is particularly relevant in the case of wildings and cuttings. The use of a lighter potting mix, thus enabling better root development, would greatly improve initial seedling survival.

4.2. Seedling survival and causes of mortality

The main causes of seedling mortality were low rainfall, debris felling, poor handling of seedlings, and accidental damage during weeding operations. Therefore, mortality can be easily reduced if planting operations are more carefully planned and supervised. It is essential that planting is not carried out during the driest season (mid-March to mid-May). Vine felling was one of the main causes of mortality, and could be easily avoided if vine tunnels were cut at least 6 months prior to site preparation. Accidental cutting of seedlings tended to happen in areas colonised by grass and bushy vegetation. This source of mortality could be minimised if longer-lasting planting sticks (pancang) were used to mark the location of planted seedlings. If missing, these sticks should always be replaced during maintenance operations. Higher survival would also be expected if there was close supervision of planting, in order to avoid exposure of seedlings to direct sun, careless handling, and other bad planting practices. Similarly, seedling selection and hardening at the nursery would also increase the survival rates in the field.

A certain proportion of mortality is due to site-specific factors. For large scale planning, it appeared that, within the range of average canopy openness of the sites planted, canopy openness did not affect the initial survival of most species, except for *Parashorea malaanonan* (results not shown). This species should not be planted in the more open areas. In an individual seedling scale, however, it was found that mortality is linked to light intensity, and the optimal light varies from species to species. It is recommended that these preliminary findings are further investigated by specific experiments to define simple and objective recommendations for field planting.

4.3. Site selection and species performance and silviculture

A series of factors influence growth and survival of dipterocarps, and have to be considered when planning a planting operation. Some of them are listed, as follows:

Light, remnant vegetation and silviculture

Apart from its effect on survival, as discussed above, light is also important for growth of dipterocarp seedlings. The optimal level of light, however, differs between species. Furthermore, the best light intensity for growth often does not correspond with the best for survival. It was found that the Red Merantis and *D. lanceolata* can tolerate higher light intensities, while *P. malaanonan* and *Dipterocarpus* perform better in darker environments. These results are in ccordance with Sasaki and Mori (1981).
The type of remnant vegetation is directly related to light at ground level, and is an important factor in what regards growth and survival of planted seedlings. Seedlings planted in areas infested with climbing vines tend to have slow growth, due to excessive shading. In a further stage, vine tunnels create a "ceiling" blocking the way of emerging seedlings. It is necessary that vines are cut prior to the planting. However, if this vine cutting is not done well in advance (at least 6 months before), the cut vines will decompose and fall in planted seedlings, causing excessive mortality. Bamboo is another source of seedling mortality. Although at this stage it has not caused much seedling mortality, it is expected that it will be a problem when seedlings reach higher diameters (Yap et al. 1995). Grasses pose great problems for planted seedlings. Firstly, root competition may reduce availability of water and nutrients. Secondly, they tend to cover small seedlings, prevent their identification during weeding operations, and leading to accidental damage by cutting. Planting in these areas usually lead to fast growth, because of high light availability, but seedlings have to be properly marked with permanent planting sticks (pancang).

Stand manipulation can be used in order to control the amount of light given to seedlings as well as the deleterious effects that some plants have on planted seedlings. Liberation thinning is one possibility that could be explored by the project. It is necessary that this activity is carried out based on well defined guidelines, so that the right trees are taken out, improving the stand as a whole. Vine cutting is another possibility, taking the precautions discussed above.

Canopy manipulation must be carefully conducted in order to prevent the excessive opening of the canopy. Too much light would result in fast growth of vines, bamboos and weeds, as has been observed in some sites in the project area. It is preferable to have slow growth under a weed-free below-canopy environment than have to eradicate bamboo and vines after canopy opening.

Considering the importance of light, and therefore canopy cover, it is recommended that more attention is given to the type of vegetation existing in a site prior to planting. Vegetation maps would greatly improve the possibilities for planning of the planting operations. These can be produced from aerial photographs, identifying areas of dense remnant forest, areas colonised by pioneer trees, open areas of belukar. Ground surveys would then identify which of these areas contain enough natural regeneration.

Based on these information, a plan for rehabilitation of these areas should be drawn, targeting areas for enrichment planting, pioneer tree planting, or silvicultural treatments for fostering natural regeneration.

Soils and mycorrhizae

No evident effects of soil nutrients on seedlings performance were observed, possibly because there were not large differences in the average nutrient content of soils from different planting blocks. It is unlikely that the type of soil survey conducted for this study could provide useful information concerning site suitability for planting dipterocarps. The surveys were conducted to characterise the soils within planting blocks, which boundaries were arbitrarily defined prior to the survey and did not reflect any possible differences in soils. Most of the soils in the project area belong to either the Bang or Gumpal soil associations, which have the same parent material and geological origin (Acres *et al.*, 1975). However, there is much micro-site variation which could be identified if the survey was conducted in a different way. This may have been the case if comparisons were made between ridge tops and bottom of valleys. It is recomended that soil survey are conducted prior to deciding on the location of planting sites, so that sites can be chosen taking into account differences in soils.

A separate study was conducted to assess the mycorrhizae populations in the different secondary forest types within the project area (Lee *et al.*, in press). It was found that there is a large diversity of mycorrhizae associations in seedlings planted in logged over forests, and in seedlings planted in a wide range of soil types in the nursery. This information is important in the sense that it discards this factor as a matter of concern for the planning of planting operations. At this stage there is no information about the plant-fungus associations, i.e. which fungus better associate with which plant species. This is further complicated if site specificity is taken into account. However, the fungi surviving in the logged forest are probably the most adapted to these sites, and therefore most likely to perform well.

A series of field trials were also conducted to test the effect of fertiliser application on dipterocarp seedling growth (Yap *et al*., in press). Until this point in time, however, it is not possible to provide any recommendation on fertiliser applications for improving growth of planted dipterocarp seedlings in the under storey of logged forests. However, if planting is carried out in severely degraded ares, the application of 40 g of 12:12:17 NPK fertilisers was shown to improve growth rates by up to 10-fold (Nussbaum 1995, Nussbaum and Anderson 1995).

Water

Water availability is an important factor controlling the growth and survival of seedlings. Rainfall during time of planting has a strong effect on seedling survival, and planting should not be carried out in dry periods. This is particularly important if the planting site is too open, or if the species planted are susceptible to drought.

Seedling growth and survival, for most species, was better in areas with higher water availability, i.e. riverine or flat areas. This is well illustrated from the differences in growth and mortality of seedlings planted in blocks 78B (a riverine area) and 78B (same vegetation but in a slope). High mortality is also observed in block 81A, a drier site with high incidence of canopy openness.

A GIS analysis has shown that seedlings planted in the proximity of streams often grow faster. It is necessary to find out how wide is this "zone of influence" of streams. This could be done by using the buffering features of the GIS developed for the project, which contains data on rivers and seedling growth rates.

The Red Serayas (particularly *S. leprosula*) were the species which most benefited from planting in riverine areas. On the other hand, *D. lanceolata* did not seem to have any preference for these areas. This information can be used for site allocation for planting of different species. Further studies have to be conduced about water requirements of a larger range of dipterocarp species.

4.4. Species selection

Species of the Red Seraya timber group were the fastest growing among those planted, specially *S. leprosula* and *S.parvifolia*, in accordance with results from other reports (e.g. Appanah and Weinland 1993). Growth rates of these species ranged between 90 and 200 % relative height increment in one year, or up to 4 m height increment in one year. These species appeared to be very site demanding, greatly benefiting from light and water availability.

D. lanceolata was the species which showed less variability in relation to site specificity. Although this species did not show very fast growth in the best sites, its growth rate was not much reduced when planted in the worse sites. Furthermore, *D. lanceolata* showed the lowest mortality rates among the species planted, standing drier conditions and high light intensity. It did not show severe problems of herbivory.

P. malaanonan was the only dipterocarp species which suffered from insect herbivory, which significantly reduced its growth rates and caused mortality. This species did not seem to respond to light in terms of growth rates, and showed high mortality in open sites. Therefore, it is recommended that this species is planted in areas with closer canopy cover.

Dipterocarpus was only planted in one site, so it is not possible to draw conclusions about its site preferences. It showed relatively low growth rates (50 % relative height increment in one year) and average mortality. This was the species with the lowest light threshold for 50 % mortality, i.e. above relatively low levels of light mortality rates starts to increase.

Agathis borneensis did not perform well in any of the sites planted, except block 78B where relative height increment was 68%, possibly because of the high water availability in this site. This species suffered from intensive insect herbivory, totally defoliating some of the seedlings, and mortality rates were very high (up to 75% over one year).

4.5. Costs and efficiency

It has been found that one of the most expensive operations is maintenance. These costs may be reduced by introducing more objective operational guidelines, more intensive supervision and by conducting a more careful site preparation. Training of field staff would greatly improve the efficiency of project operations.

4.6. GIS

The development of a GIS for the project has created a useful tool for assisting the management and research activities. It allows a better, permanent record keeping of maps and data, which is easily accessible. It is important that this system is updated frequently, including all new research and operational data.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Acres et al 1975. Soils of Sabah. ODA, London.

Alder, D. 1995. Growth modelling for mixed tropical forests. Tropical Forestry Papers No. 30. Oxford Forestry Institute, Oxford, 231 pp.

Ali, I.B.H., 1964. Enrichment planting in Selangor, with particular reference to *Dryobalanops aromatica* (kapur). The Malayan Forester, **27**: 3-17.

Appanah, S. and Weinland, G., 1993. *Planting quality timber trees in Peninsular Malaysia - a review.* Malaysian Forest Record No. 38. Forest Research Institute Malaysia, Kepong. 21 pp.

Anderson, J.M. and Ingram, J.S.I., 1989. Tropical soil biology and fertility. A handbook of methods. The Cambrian News, Aberystwyth, 171 pp.

Burgess, P.F., 1966. Timbers of Sabah. Forest Department, Sabah, 501 pp.

Chan, Y.H. (1982): Storage and release of organic carbon in Peninsular Malaysia. International Journal of Environmental Studies 18: 211-222.

Fox, J.E.D., 1968. Logging damage and the influence of climber cutting prior to logging in the lowland dipterocarp forest of Sabah. *The Malayan Forester* **31**: 326-347.

Goh et al 1989. Report on soil surveys from the state of Sabah.

Hassan, A., W.M. Wan Razali, S. Idris and A.R. Kassim (1990): Growth performance of indigenous species under enrichment planting in logged over forests. In: Malaysian forestry and forest products research. Appanah, S., Ng, F.S.P. and Ismail, R. (eds). Pp. 30-40.

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 54:187-211.

Hutchinson, I.D., 1981. Approach adopted to define interim guidelines for silviculture and management of mixed dipterocarp forest in Sarawak. In: Tropical Forests: source of energy through optimization and diversification. Universiti Pertanian Malaysia. Pp. 127-146.

Ipor, I.B. and Tawan, C.S., 1992. Weed management in the rehabilitation of areas of degraded tropical rainforest. In; Proceedings of the International Symposium on Rehabilitation of Tropical Rainforest Ecosystems. September 1992, Kuching, Sarawak.

Johnson, N.L. and Kotz, S. 1970. Distributions in statistics: continuous univariate distributions, Vol. 1 and 2. Houghton-Mifflin, Boston.

Kira, T. 1978. Community architecture and organic matter dynamics in tropical lowland rain forests of Southeast Asia with special reference to Pasoh Forest, West Malaysia. In: Tropical trees as living systems. Tomlinson, P.B. and Zimmermann, M.H. (Eds.). Cambridge University Press, New York. Pp. 561-590.

Korsgaard, S. 1992. An analysis of growth parameters and timber yield prediction, based on research plots in the permanent forest estate of Sarawak, Malaysia. The Council for Development Research, Copenhagen. 124 pp.

Lang, A.R.G., and Xiang, Y. 1986. Estimation of leaf area index from transmission of direct sunlight in discontinuous canopies. Agricultural and Forestry Meteorology 37:229-243.

Lee, S.S., Alexander, I., Moura-Costa, P.H. and Yap, S.W., 1994. Mycorrhizal infection of dipterocarp seedlings in logged and undisturbed forest. In: Proceedings of the 5th Round Table Conference on Dipterocarps. Chiang Mai, Thailand, November 1994.

Li-Cor 1992. LAI-2000 Plant Canopy Analyzer. Instruction Manual. Li-Cor Inc., Nebraska, USA. 102 pp.

Majalap-Lee 1994. Manual for soil analysis procedures of the Laboratory of soils of the Forest Research Centre Sabah. FRC, Sandakan.

Marsh, C. and Greer, A.G., 1992: Forest land-use in Sabah, Malaysia: an introduction to the Danum Valley. Philosophical Transactions of the Royal Society of London B, vol. 335, pp. 331-340.

Moura-Costa, P.H., 1993. Nursery and vegetative propagation techniques for genetic improvement and large scale enrichment planting of dipterocarps. In: T.E. Lovejoy and R.B. Primack (Editors), Proceedings of the workshop on ecology, conservation and management of southeast Asian rainforests, 12-14 October 1992, Kuching, Malaysia. Yale University Press, (in press), 15 pp.

Moura-Costa, P.H. 1995. Tropical forestry practices for carbon sequestration. In: Dipterocarp Forest Ecosystems: Ecology, Sustainable Management and Products, Schulte, A. (Ed). Indonesian-German Project, GTZ, Samarinda (in press).

Moura-Costa, P.H., Ganing, A., Lundoh L. and Ong, C.L., 1993. Experiments on nursery techniques for raising seedlings and wildings of dipterocarps on a large scale. Technical Publication, ASEAN-Canada Forest Tree Seed Centre, Bangkok, Thailand, (in press), 6 pp.

Moura-Costa, P.H., 1993. Large scale enrichment planting with dipterocarps, methods and preliminary results. In: Proceedings of the Yogyakarta Workshop, BIO-REFOR/IUFRO/SPDC: Bio-reforestation in Asia-Pacific Region. Suzuki, K., Sakurai, S. and Ishii, K. (Eds.). Pp. 72-77.

Moura-Costa, P.H., 1994. Nursery and vegetative propagation techniques for genetic improvement and large scale enrichment planting of dipterocarps. In: Ecology, conservation and management of Southeast Asian rainforests. Primack, R.B. and Lovejoy, T. (Eds.). Yale University Press, (in press).

Moura-Costa, P.H., Ganing, A., Lundoh, L. and Ong, C.L., 1993. Experiments on nursery techniques for raising seedlings and wildings of dipterocarps on a large scale. Technical report. ASEAN-Canada Forest Tree Seed Centre, Thailand.

Moura-Costa, P.H. and Karolus, A. 1995. Tiber extraction volumes of the Ulu Segama Forest Reserve, Sabah, Malaysia. ICSB Internal Reports, 120 pp.

Moura-Costa, P.H. and Lundoh, L., 1994. A method for vegetative propagation of *Dryobalanops lanceolata* (Dipterocarpaceae) by cuttings. *Journal of Tropical Forest Science* **6**(4): 533-541.

Moura-Costa, P.H. and Lundoh, L., 1995. The effects of auxins (IBA, NAA and 2,4-D) on rooting of *Dryobalanops lanceolata* (kapur, Dipterocarpaceae) cuttings. *Journal of Tropical Forest Science* **7**(2).

Moura-Costa, P.H., Yap, S.W. and Ganing, A., 1994. Large scale enrichment planting with dipterocarps as an alternative for carbon offset. In: Proceedings of the IUFRO International Workshop on Sustainable Forest Management. October 1994, Hokkaido, Japan.

Moura-Costa, P.H., Yap, S.W., Ong, C.L., Ganing, A., Nussbaum, R. and Mojiun, T., 1994. Large scale enrichment planting with dipterocarps as an alternative for carbon offset - methods and preliminary results. In: Proceedings of the 5th Round Table Conference on Dipterocarps. Chiang Mai, Thailand, November 1994.

Moura-Costa, P.H., van Winkel, I., van Oorschot, G. 1994. The use of GIS to study the influence of site factors in enrichment planting with dipterocarps. In: Proceedings of the seminar on development of research in Danum Valley. December 1994.

Norman, J.M. and Welles, J.M. 1983. Radiative transfer in an array of canopies. Agronomical Journal 75:481-488.

Nussbaum, R. 1993. Report on the trials on rehabilitation of log landings and skid trails for the INFAPRO. ICSB Internal Reports.

Nussbaum, R. 1994. Report on the soil survey carried out for the INFAPRO. ICSB Internal Reports.

Nussbaum 1995. The effects of selective logging of tropical rainforest on soil characteristics and growth of planted dipterocarp seedlings in Sabah, Malaysia. PhD thesis. Exeter University, UK.

Nussbaum, R., Anderson, J. and Spencer, T., 1994. The effects of selective logging of tropical rainforest on soil characteristics and growth of planted dipterocarp seedlings in Sabah, Malaysia. In Primack, R.B. & Lovejoy, T. (eds). *Ecology, Conservation and Management of Southeast Asian Rainforests*. Yale University Press, Connecticut. (in press).

Nussbaum, R., Anderson, J. and Spencer, T., 1993. Investigation of treatments to promote regeneration of log landings and skid trails after selective logging of rainforest in sabah, malaysia. In: Proceedings of the Yogyakarta Workshop, BIO-REFOR/IUFRO/SPDC: Bio-reforestation in Asia-Pacific Region. Suzuki, K., Sakurai, S. and Ishii, K. (Eds.). Pp. 81-84.

Nussbaum, R., Anderson, J. and Spencer, T., 1994. Factors limiting the growth of dipterocarp and pioneer tree seedlings planted on disturbed soils following rainforest logging in Sabah, Malaysia. *Forest Ecology and Management* (in press).

Putz, F.E. and Pinard, M.A., 1983. Reduced impact logging as carbon-offset method. *Conservation Biology* **7**(4): 755-757.

Putz, F.E., 1992. Reduction of root competition increases growth of slash pine seedlings on a cutover site in Florida. *Southern Journal of Applied Forestry* **16**: 193-197.

Sasaki, S. and Mori, T., 1981. Growth responses of dipterocarp seedlings to light. The Malaysian Forester, **44**: 319-345.

Sheil, D. and May, R.M. (in press). Estimating turnover in tropical forests: the implications of heterogeneous populations.

Still, M.J. 1993. Population dynamics and spatial patterns of dipterocarp seedlings in a tropical rain forest. PhD Thesis. University of Sirling, UK. 180 pp.

van Oorschot, G., van Winkel, I. and Moura-Costa, P.H., 1994. The use of GIS to study the influence of site factors in enrichment planting with dipterocarps. In: Proceedings of the 5th Round Table Conference on Dipteocarps, Chiang Mai, Thailand, November 1994.

Vincent, A.J. (19):61 a. A note on the growth of Dryobalanops oblongifolia Dyer (Keladan). Malayan Forester 24:210-224.

Vincent, A.J. (19):61 b. A note on the growth of Shorea macroptera Dyer (Meranti melantai). Malayan Forester 24:190-209.

Welles, J.M., 1990. Some indirect methods for estimating canopy structure. *Remote Sensing Reviews* **5**: 31-43.

Welles, J.M. and Norman, J.M., 1991. Instrument for indirect measurement of canopy architecture. *Agronomy Journal* **83**: 818-825.Whitmore, T.C., 1984. Tropical rain forests of the far east. Clarendon Press, Oxford, 352 pp.

Wyatt-Smith, J., 1963. Enrichment planting. In: Manual of Malayan silviculture for inland forest, Part III, Chapter 6. Malayan Forest Records No 23, Forest Department, Kuala Lumpur, pp. 6: 1-15.

Yap, S.W., Chak, C.V., Majuakim, L., Anuar, M. and Putz, F.E., 1994. Climbing bamboo (*Dinochloa* spp.) in Sabah: biomechanical characteristics, mode of ascent, and abundance in a logged-over forest. Journal of Tropical Forest Science (in press)

Yap, S.W. and Moura-Costa, P.H. 1994. Potting media for *Hopea nervosa*. Technical Report No. 1. Innoprise-Face Foundation Rainforest Rehabilitation Project. 11 pp.

Table 1. Description of the vegetation, slope, area, and logging details of the planting blocks used for this study.

Year planting block was logged and block code	General description	Type of log extraction[1]	Skid trail extent (% of total area)[2]	Volume logged (m3/ha)[1]	Area (ha)	Average Slope (%)
1978.A	Close canopy consisting predominantly of pioneer tree species (mainly Macaranga spp.), little undergrowth , very few remnant timber trees.	high lead/ tractor	25	94	55.06	22
1978.B	Close canopy consisting predominantly of pioneer tree species (mainly Macaranga spp.), little undergrowth, lowland area in the margin of two rivers	tractor	38	152	52.92	2
1981.A	Site extremely disturbed by high lead yarding, few remaining trees except for large Koompassia excelsa,, presence of bamboo and bushy vegetation and grasses,	high lead/ tractor	27	92	55.64	20
1988.A	Bushy vegetation, presence of grasses and lianas, open canopy and patches of dense vegetation	high lead/ tractor	47	94	55.84	22
1988.B	A combination of patches of undisturbed forest with dense canopy cover, and areas with scant vegetation, pioneer trees and lianas	tractor	29	73	51.78	8
1991.A	Recently logged area, few tall pioneer trees, some large remnant dipterocarp trees, presence of vines (mostly Merremia), need for intensive weeding	tractor	40	106	29.26	16

1. From Moura-Costa and Karolus (1995); 2. From Nussbaum (1994).

Table 2. Results of soil survey for the six planting blocks. Figures were derived from a bulked sample (15 sub-samples), taken from 0-20 cm in undisturbed microsites within the planting blocks. Data from Nussbaum (1994).

Planting block	**78A**	**78B**	**81A**	**88A**	**88B**	**91A**
Soil association[1]	Mentapok	Mentapok	Gumpal	Bang	Gumpal	Bang
pH (in H_20)	4.94	5.32	5.55	5.05	5.18	4.74
Organic Carbon (%)	1.645	0.895	1.000	1.295	1.495	1.665
Total N (%)	0.115	0.105	0.115	0.155	0.145	0.150
Total P (%)	148.510	151.930	208.945	179.210	237.030	156.020
Available P (ppm)	2.985	1.260	na	1.365	na	3.105
K (meq %)	0.135	0.075	0.180	0.190	0.310	0.205
Mg (meq %)	1.905	2.935	3.375	5.235	3.540	1.090
Ca (meq %)	1.555	2.265	3.265	2.480	3.740	0.905
Na (meq %)	0.035	0.070	0.045	0.050	0.075	0.035
Al (meq %)	4.110	1.330	3.400	6.115	7.800	6.670
H (meq %)	5.395	1.995	4.940	7.150	9.005	7.850
CEC[2] (meq %)	13.135	8.670	15.205	21.220	24.470	16.755
Base saturation (%)	28.350	61.666	46.601	36.526	31.432	13.859
Sand (%)	50.991	59.974	48.700	29.477	27.700	61.147
Silt (%)	26.103	18.293	20.700	41.300	22.500	16.687
Clay (%)	20.553	17.085	29.700	28.579	50.000	19.952

1. From 'The Soils of Sabah', (Acres et al., 1975); 2. Cation Exchange Capacity.

Table 3. Total number of seedlings in the six planting blocks, as well as number and initial height of seedlings of different species used for the growth trial plots. Seedlings were measured two months after planting.

Planting block code	Total number of seedlings in planting blocks	Species	Mean initial height (cm) (mean +/- SE)	Initial number of seedlings in growth trial plots
78A	16,057	*S. leprosula*	40.95 (0.66)	104
		D. lanceolata	52.87 (1.01)	109
		P. malaanonan	63.05 (1.95)	89
		A. borneensis	28.27 (0.75)	100
78B	13,372	*S. leprosula*	44.28 (0.74)	104
		D. lanceolata	41.61 (0.91)	74
		P. malaanonan	33.19 (0.96)	88
		S. johorensis	32.46 (0.44)	96
		A. borneensis	25.89 (1.06)	63
81A	15,770	*S. leprosula*	45.01 (0.63)	187
		D. lanceolata	47.54 (0.65)	190
		P. malaanonan	61.39 (0.56)	174
		S. johorensis	31.43 (0.59)	130
		S. ovalis	36.35 (1.37)	160
88A	17.546	*S. leprosula*	43.61 (0.78)	207
		D. lanceolata	45.10 (0.82)	255
		P. malaanonan	51.21 (0.87)	246
		A. borneensis	28.23 (1.02)	288
88B	16,046	*S. leprosula*	44.07 (0.97)	260
		D. lanceolata	45.71 (0.41)	484
		S. parvifolia	47.41 (1.02)	123
		S. ovalis	44.74 (1.05)	119
		D. gracilis	18.38 (0.37)	108
		A. borneensis	33.27 (1.17)	134
91A	7,175	*S. leprosula*	43.61 (0.78)	187
		D. lanceolata	45.10 (0.82)	194
		P. malaanonan	51.21 (0.87)	174
		S. johorensis	32.52 (0.63)	98
		A. borneensis	28.23 (1.02)	197

Table 4. Buffer zones created to study the zones of influence of tree crowns and root competition.

Tree size-classes	Buffer size (radius, in m)	
	Outer ring (crown cover)	Inner ring (competition zone)
Small	2.5	1.5
Medium	5.0	2.5
Large	11.5	4.0

Table 5: Seed germination: difference between sand beds and direct sowing on poly-bags. Assessments carried out 2 weeks after sowing.

	S.parvifolia	*D.lanceolata*	*P.malaanonan*
Poly-bags	87.6 ± 1.3	na	na
Poly-bags covered by a plastic roof	97.1 ± 2.1	na	66.0 ± 4.2
Sand beds	91.62 ± 1.2	97.4 ± 1.2	72.4 ± 3.8

Table 6: Percentage survival of wildings after acclimatization period of 2 or 4 weeks. Assessments were carried out two weeks after opening the acclimatization chambers. Number of seedlings in braquets.

	Length of acclimatization period	
	2 weeks	4 weeks
S.parvifolia	25 (1,000)	94.4 (1,600)
D.lanceolata	69.11(5,000)	88.2 (45,000)
P.malaanonan	na (0)	40.9 (2,600)

Table 7. Rainfall patterns, canopy openness and initial survival of seedlings planted in the six planting blocks. Assessments were carried out 2 months after planting, except for survival after one year.

Block code	N[1]	% plants under open canopy	Planting month[2]	Rainfall after planting (mm)[3]	No of rain days after planting[4]	Initial Survival (%)[5]	Survival 1 yr (%)[6]
78A	16,057	3.7	April	169	10	95.4 (1)	84.8 (1)
78B	13,372	7.4	April	169	10	92.4 (4)	80.5 (3)
81A	15,770	15.9	February	270	12	93.5 (3)	77.8 (4)
88A	17,546	7.5	May	89	7	81.3 (5)	73.0 (5)
88B	16,046	13,9	January	288	9	94.5 (2)	84.0 (2)
91A	7,175	12.6	May	89	7	74.3 (6)	63.7 (6)
TOTAL/	89,966	-	-	-	-	-	-
MEANS	-	10.2	-	-	9.1	88.6	77.3

1: Number of seedlings planted in each planting block; 2: All planting blocks were planted in 1993; 3: Total rainfall during first 30 days after planting; 4: Number of rain days during initial 15 days after planting; 5: Assessment carried out two months after planting; 6: Assessment carried out 1 year after first assessment; Rank of survival shown in brackets.

Table 8. Mortality rates (% per month) during initial post-planting period and during the first 10 months after this establishment phase.

Block code	Establishment phase (0-2 mo)	1st year (2-12 mo)
78A	2.3	1.2
78B	3.9	1.4
81A	3.3	1.8
88A	9.8	1.1
88B	2.8	1.2
91A	13.8	1.5
Mean	6.0	1.4

Table 9. Relative height increment (%) of different species in different plots, one year after planting. Means (SE), following ANOVA between plots for each species.

	78A	**78B**	**81A**	**88A**	**88B**	**91A**	**Means**
D. lanceolata	70.09 ab (10.90)	75.44 ab (10.93)	82.10 a (8.57)	74.27 ab (6.96)	54.31 b (3.98)	41.19 b (7.21)	66.23
S. leprosula	78.90 d (7.33)	141.60 b (9.85)	161.00 b (12.76)	88.80 cd (9.66)	127.20 bc (8.69)	204.90 a (13.13)	133.73
P. malaanonan	23.60 bc (8.96)	96.25 a (9.28)	44.10 b (4.97)	9.32 c (4.93)	na	23.07 bc (4.70)	38.47
S .parvifolia	na	na	na	na	92.90 (10.50)	na	92.90
S. ovalis	na	na	123.70 a (14.20)	na	57.60 b (6.78)	na	90.65
S. johorensis	na	97.20 a (9.14)	61.77 b (9.36)	na	na	34.89 b (7.96)	64.62
D. gracilis	na	na	na	na	58.28 (6.45)	na	58.28
A. borneensis	0.28 bc (3.383)	68.65 a (11.20)	na	-14.84 c (2.82)	12.11 b (3.00)	17.95 b (3.68)	16.83
Means	43.22	96.42	94.53	39.39	67.06	64.40	68.85

Figures followed by the same letter are not significantly different according to Tukey's test, $p \leq 0.001$.
na = not available

Table 10. Percent mortality of different species at different growth plots, one year after planting. Comparisons of mortality between plots and between species were conducted using chi-square contingency tables. Plus (+) and minus (-) signs denote whether means were significantly different from the total mean of a given plot or species, and the level of significance (1 sign, $p \leq 0.05$; 2 signs, $p \leq 0.01$; 3 signs, $p \leq 0.005$). The absence of a sign indicates that no significant difference was found. Signs at the right of the figures correspond to comparisons between plots, signs below figures correspond to comparisons between species. P values are also given for the overall chi-squares.

	78A	78B	81A	88A	88B	91A	Means	c^2	p
D. lanceolata	38.2 +	26.6	33.9	29.0	21.5 ---	42.3 +++	29.5	27.36	***
			-	---			---		
S. leprosula	37.4	32.4	32.1	39.1	19.6 ---	45.0 +++	33.5	27.58	***
			---	-	-		---		
P. malaanonan	58.0	35.0	54.0	55.3		41.1	49.9	10.68	ns
		-					+++		
S. parvifolia					34.1		34.1		
S. ovalis			51.4 +		25.8 --		40.3	11.62	***
S. johorensis		29.7 --	60.7 +			48.6	49.0	12.51	***
			+++				++		
D. gracilis					47.3		47.3		
					+++				
A. borneensis	65.8	44.8		76.7 +++	25.9 ---	44.2 -	55.8	53.22	***
	++			+++			+++		
Means	49.0 +++	33.2 -	45.9 +	51.4 +++	25.7 ---	44.3	40.6	126.2	***
c^2	15.43	4.24	26.22	67.59	34.72	1.35	130.81		
p	***	*	***	***	***	ns	***		

Table 11. Relative height increment (%) of seedlings in relation to proximity to trees. (diameters of the inner and outer rings are related to the size class of trees (see Table 4).

	Plot 78B			Plot 81A			Plot 88B			Mean		
	inner ring	outer ring	open	inner ring	outer ring	open	inner ring	outer ring	open	inner ring	outer ring	open
D.	-	-	-	-	-	-	65.1	54.2	65.3	65.1	54.2	65.3
Dl	13.7	96.4	73.4	61.7	80.4	95.5	63.2	68.1	90.0	57.8	77.5	90.0
Pm	73.2	102.2	120.2	25.2	52.0	43.8	-	-	-	58.2	71.9	67.9
Sj	68.0	163.5	71.2	79.2	90.0	89.2	-	-	-	72.3	81.0	125.9
Sl	122.6	141.7	154.5	208.7	151.3	155.6	159.7	203.2	254.3	168.5	170.1	169.8
So	-	-	-	120.1	121.7	142.1	32.6	71.9	57.4	60.8	92.9	108.8
Sp	-	-	-	-	-	-	104.5	87.4	125.8	104.5	87.4	125.8
Ab	78.3	69.6	60.9	-	-	-	15.2	17.2	20.9	26.4	32.2	32.4
Mn	77.2	100.6	119.5	108.2	104.8	108.2	73.9	88.4	86.7	83.9	95.8	105.4

D = Dipterocarpus; Dl = Dryobalanops lanceolata; Pm = Parashorea malaanonan; Sj = Shorea johorensis; Sl = S. leprosula; So = S.ovalis; Sp = S.parvifolia; Ab = Agathis borneensis; Mn = mean.

Table 12. Relative height increment (RHI, %) and mortality (%) of seedlings grown under the influence of different site features or competing vegetation.

	Plot 78B		Plot 81A		Plot 88B		Mean	
	mort	RHI	mort	RHI	mort	RHI	mort	RHI
Vines	12.5	69.1	44.3	81.1	37.2	50.4	39.7	69.3
Bamboo	-	-	34.7	114.8	27.3	88.8	33.3	109.6
Grass	75.0	251.8	70.7	99.9	-	-	70.9	107.3
Open	33.8	101.6	37.1	123.7	29.5	87.5	32.2	98.7
Streams	36.0	104.6	49.4	95.2	27.9	125.8	40.7	107.8
No Streams	32.7	100.8	44.3	110.8	30.1	70.6	36.2	91.2
Skids	-	-	53.5	104.4	30.4	74.5	36.8	80.6
No Skids	-	-	45.8	107.0	30.1	85.9	38.8	96.3
Mean	33.8	101.1	46.2	106.9	29.7	84.4	37.6	96.2

Table 13. Percentage contribution of different project activities on total cost of the project, and labour efficiency under different activities. Means (N=11) (sd).

Project activities (specific)	% contribution to total project cost	Labour efficiency (work days/ha)
Boundary survey	0.7	0.25 (0.05)
Site preparation:		6.40 (1.35)
Line opening	18.3	
Marking planting points	4.4	
Transport seedl.	0.2	
Planting	12.0	2.00 (1.32)
Maintenance:		0.37 (0.14)
Replanting	0.1	
Road maintenance	0.3	
Weeding	24.0	
Supervision	13.5	1.50 (0.30)
Seedlings	11.0	-
Overheads+research	12.4	1.35
Capital costs (per year)	2.8	-
TOTAL	**100**	**-**

Table 14. Figures of growth, survival, biomass and carbon accumulation of enrichment planted and non-planted logged forests.

Year	B_{LF} (t/ha)	B_{ep} (t/ha)	N planted trees/ha	dbh (cm)	V_{trees} (m^3/ha)	B_{trees} (t/ha)	TC_{ep} (t/ha)	TC_{LF} (t/ha)	$C_{Wood\ products}$ (t/ha)	Cumulative C offset (t/ha)	Average C offset (t/ha/yr)
0	125	103	280	0	0	0	137	150	0	-13	0.00
5	130	107	253	8	5	9	145	153	0	-8	-13.87
10	135	111	229	16	29	51	170	156	0	15	-6.02
15	140	109	207	24	75	128	213	158	0	54	7.25
20	145	104	187	30	118	201	250	161	0	89	23.26
25	150	99	169	36	167	282	293	164	0	129	40.38
30	155	94	76	42	110	184	236	167	27	96	57.40
40	165	85	69	54	177	295	293	172	13	133	71.62
50	175	77	62	62	221	367	329	178	6	157	86.20
60	185	69	56	70	265	438	364	184	3	183	100.02

B_{LF} = Biomass of logged forest; B_{ep} = biomass of logged forest excluding enrichment planting; V_{trees} = volume of planted trees;
B_{trees} = biomass of enrichment planted trees; TC_{ep} = total carbon in enrichment planted forest; TC_{LF} = total carbon in non planted logged forest; $C_{wood\ products}$ = carbon accumulated in wood products after harvesting at year 30; Cumulative C offset = TC_{ep} - TC_{LF} + $C_{wood\ products}$; Average C offset = Total cumulative carbon offset until a point in time averaged by the number of years.

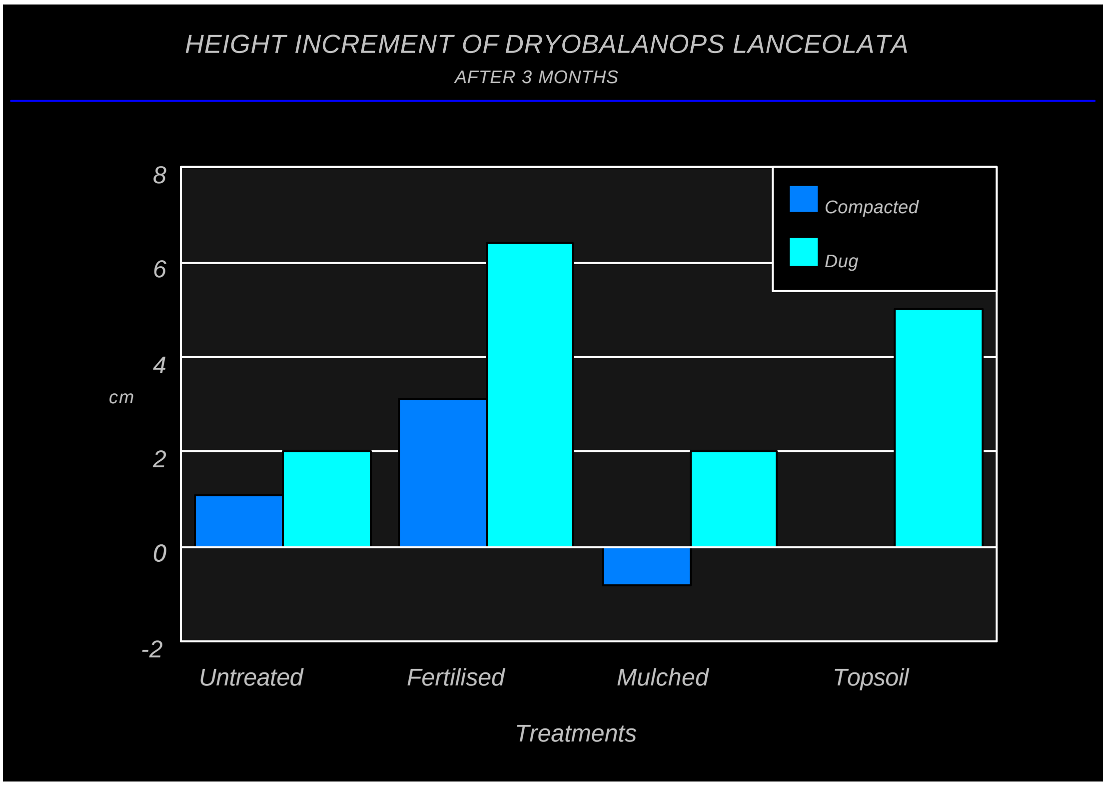

Figure 1. Growth increment of *D. lanceolata* seedlings after different soil treatments.(From Nussbaum et al., 1994).