REHABILITATION OF EX-TIN MINING LAND BY AGROFORESTRY PRACTICE

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NIK MUHAMAD MAJID, AZIZAH HASHIM & IDRIS ABDOL. 1994. Rehabilitation of ex-tin mining land by agroforestry practice. In view of the growing public concern for the environment a pilot research project to rehabilitate ex-tin mining land was initiated in Semenyih, Selangor in 1989 with combined funding from Universiti Pertanian Malaysia through the Intensification of Research in Priority Areas (IRPA) programme, and the Board of Science for Technological Development of the U.S. National Academy of Sciences. This research project initially involves the planting of two fast-growing timber species (*Acacia mangium* and *Paraserianthes falcataria*). The experiments conducted were (1) fertilisation, (2) inoculation, and (3) mulching experiments. The basic philosophy underlying this research project is to rehabilitate the sandy areas based on new technology and low capital expenditure. It is hoped that the findings from this project will benefit not only the farmers in Malaysia but also those in other countries such as Indonesia and Thailand where such soils are in abundance and underutilised. The project will also support the governments' desire and aspirations for environmental restoration and sustainability. The project is in its third year and will continue for at least another ten years. This paper describes the present status and future directions of the project.

Key words: Rehabilitation - Malaysia - *Acacia mangium* - *Paraserianthes falcataria*

NIK MUHAMAD MAJID, AZIZAH HASHIM & IDRIS ABDOL. 1994. Pemulihan tanah bekas lombong bijih timah dengan amalan hutan tani. Satu projek penyelidikan perintis untuk memulih tanah bekas lombong bijih timah telah dimulakan di Semenyeh, Selangor pada 1989 dengan dua sumber kewangan, iaitu dari Universiti Pertanian Malaysia (dari program IRPA) dan Lembaga Sains untuk Pembangunan Teknologi, Akademi Nasional Sains, A.S. Pada mulanya, projek ini melibatkan penanaman dua spesies kayu yang cepat-tumbuh (*Acacia mangium* dan *Paraserianthes falcataria*). Eksperimen yang dijalankan ialah (1) pembajaan, (2) inokulasi, dan (3) sungkupan. Falsafah asas projek ini ialah untuk memulih kawasan-kawasan tanah bekas lombong bijih timah berdasarkan teknologi baru dan perbelanjaan yang bermodal rendah. Diharapkan dapatan dari projek ini akan memanfaatkan bukan sahaja para petani di Malaysia malah juga petani-petani di negara-negara lain seperti Indonesia dan Thailand, dimana tanih sedemikian amat banyak didapati dan kurang digunakan. Projek ini juga akan menyokong keinginan dan aspirasi kerajaan untuk pemulihan dan pengekalan alam sekitar. Projek ini kini memasuki tahun ketiga dan akan diteruskan sekurang-kurangnya sehingga sepuluh tahun lagi. Kertas kerja ini menerangkan mengenai status kini dan haluan-haluan masa depan projek ini.

Introduction

The tin mining industry is a very important contributor to Malaysia's economy, producing about one third of total world production. Continuous mining operations which began about 150 years ago have resulted in large areas of barren land, called tin tailings. It is estimated that about 250 000 hectares of land fall under this category (Shamshuddin *et al.* 1986). This represents almost two per cent of the total land area of Peninsular Malaysia. The area is increasing at an average rate of more than 4000 hectares per year (Lim *et al.* 1981).

Tin tailings have been defined as tracts of waste land made up of washed waste products of alluvial mining. The tailings consist of two fractions: sand tailing and slime tailing. The former is very coarse textured and shows an absence of aggregation and profile development. The slime tailing consists mainly of very fine soils and minerals (silt and clay), and has compact structure. In terms of fertility, the tin tailings are extremely deficient in almost all nutrients and have very low water retention capacity.

Various attempts have been made to utilise the tin tailings. Planting of agricultural and horticultural crops has achieved some degree of success. Some areas are being used for housing estates while others are converted into recreational parks. The mining ponds have been used for aquaculture. Agricultural production on the tin tailings is highly intensive and requires high capital input and is therefore beyond the reach of many farmers. The use of these areas for planting forest trees has not received any attention from the authorities. However, in general this waste land has been a source of concern for land administrators, agriculturists, aquaculturists, real-estate developers and environmentalists.

In view of the depletion of natural forest areas in the country as well as the growing environmental awareness worldwide, it is most opportune that comprehensive research be conducted to determine the feasibility of planting forest and agricultural crops in these areas. Since forest tree species take a longer time to return economic benefits, agroforestry involving the planting of both tree and agricultural crops is a wise land use option for the rehabilitation of mined land. The timber species that have been tested on ex-mining land are *Acacia mangium, Paraserianthes falcataria* and *Ceiba pentandra*. *Setaria anceps*, var. *splendida* and *Arachis hypogea* are planted as living mulch.

This research project is an attempt to answer the question of whether agroforestry practice on ex-mining lands involving the planting of both timber species and agricultural crops or pasture can rehabilitate these low nutrient soils. The study is multidisciplinary. The basic philosophy is to minimise capital input so that these practices are economically feasible for government agencies particularly those involving farmers or farmers' organisations.

It is hoped that results and recommendations from the study will serve as guidelines for proper utilisation of ex-mining land. The study also aims to serve as a model not only for Malaysia but also for other tin-producing countries such as Thailand and Indonesia. This paper describes the experiments in progress and the direction that the research programme aims to follow.

Research objectives

General objective

- to assess the feasibility of rehabilitating abandoned tin mining areas with timber species and agricultural crops

Specific objectives

- to develop a fertiliser regime for optimum growth of the selected species
- to test the feasibility of inoculating the timber species or crops with vesicular-arbuscular mycorrhizal (VAM) fungi for enhancing establishment, growth and sustainability of these species at moderate level of fertiliser input
- to evaluate the growth performance of the timber species when grown in association with leguminous agricultural crops and *Setaria* grass
- to quantify the contribution of tree species and agricultural crops to the improvement and conservation of soil fertility

Hypothesis

The project tests the hypothesis

- that fertiliser application, organic amendments, mycorrhizal inoculation and the practice of agroforestry can help sustain the optimum growth of the species and eventually improve soil fertility

Methodology

Experimental site

The site selected is an old mining area which has been abandoned for over 30 years. The tin-tailing area chosen for the study is located at Semenyih, Selangor which is about 20 km east of Universiti Pertanian Malaysia main campus. An area of 8 ha was selected for the three trials. This area is sandy in texture and it is representative of the entire ex-mining area in the country. The parent material is of riverine alluvium materials, with pH in the range of 3.5 - 5.0.

The experimental site has an undulating topography with loose sandy surface, and lies in a valley with hill slopes of more than 12°. This area also contains swampy patches and small streams which are the result of mining activities. Overall, the area is virtually barren except for patches of some grass species, with isolated hardy shrubs, herbaceous plants and creepers. Some of the species identified include *Clitoria laurifolia, Vitex pubescens, Imperata cylindrica, Eragrostis elongata, Paspalum scorbiculatum* and *Eupatorium odoratum.*

The period between 1990 - 1991 was relatively dry with intermittent unexpected heavy downfalls interspersed with dry spells. Drought and fire therefore became a major hazard. The average rainfall was 209 mm per month, with highest rainfall of 234 mm in March, April and May. The lowest rainfall of 73 mm recorded in 1992 was during the months of December, January and February.

Experimental layout

Three sets of experiments were conducted in line with the objectives of this study. These are (a) inoculation trial, (b) fertilisation trial, and (c) mulching trial. For each trial the area was divided into square plots each measuring 30 x 30 m. In each plot, seedlings from each of the three timber species *Acacia mangium, Paraserianthes falcataria* and *Ceiba pentandra* were planted at a spacing of 3 m x 3 m. Each plot was further subdivided into four equal sections, giving a total of 25 seedlings for each subplot. Two rows of seedlings covering a width of 9 m were planted as buffer zones between each subplot.

Inoculation experiment

The inoculation experiment was sub-divided into three parts: (i) propagation of the mycorrhizal fungi, (ii) glasshouse experiment to select the most suitable VAMF species, and (iii) field inoculation trials. Three mycorrhizal species were propagated in unsterilised ex-mined sandy soil using the pasture grass *Setaria* as the host plant. Successful establishment of the mycorrhizal fungi was evaluated bi-monthly one year after inoculating the *Setaria* grass. The soil inoculum was then used for the glasshouse trials (50 g soil inoculum per polybag) and field trials.

Suitable mycorrhizal species representing the three common genera are currently being tested under field conditions. This experiment is a 3 x 3 x 2 factorial arrangement of treatments comprising the following treatments:

- two plant species
- three mycorrhizal species namely *Enthrospora*, Gm+Mix and Sc+Mix plus one control
- three replications per treatment

Inoculation technique for the VA mycorrhiza

For many perennial crops where rapid growth responses are not always necessary, methods for VAM inoculation are not critical since even poorly placed inoculum will infect over time. However, it is becoming increasingly evident that growth responses in short season crops are achieved with high inoculum potentials and proper placement of inoculum. In this study, 50 g of the inoculum soil (comprising 50 g soil plus spores, mycelium and colonised root segments of the pasture grass *Setaria*) were spread in a thin layer 8 cm below where the seeds were to be planted.

Fertilisation experiment

Combined NPK fertilisers at 0, 100, 150, 250, 300, 350, 400, 450 and 500 g/ seedling respectively were applied at the onset of the experiment in the middle of October 1989. Each level was replicated three times, giving a total of 657 trees per treatment. The experimental layout is shown in Figure 1.

Fertilisers were applied in circular trenches (10 cm deep × 7.5 cm wide) around the seedlings and 0.3 m away from the base of the seedlings. This was applied in split application, i.e. at 6-month intervals after the first application. Should micronutrient deficiencies develop during the course of the trial, micronutrient fertilisers will be applied either as ground or foliar application. Deficiencies will be diagnosed by visual observation supplemented by foliar analysis. Investigations are currently being conducted in the greenhouse on the same species to determine the optimum rate of both ground and foliar application of macro and micronutrient fertilisers on non-degraded soils.

An alternative step is to initiate a small trial on a number of new plots in the same vicinity to determine tree growth response to application of micronutrient fertilisers with the rate of macronutrient fertilisers similar to that of the main trial as explained above.

Mulching experiment

Peanut and *Setaria* grass are used as living mulch. The experiment is conducted at a site adjacent to the fertiliser plot. This 4 × 4 × 2 factorial experiment comprises the following treatments:

- two timber species
- two types of mulch
- four replications per treatment

Three-month-old seedlings of *Acacia mangium* and *Paraserianthes falcataria* (both exotic species) were transplanted to the field at 3 m distances. Optimum levels of NPK fertiliser (obtained from the fertiliser trial) were applied. The control plots from the fertilisation experiment are considered to be control plots for this mulching trial.

Data collection

This paper presents data collected for a one-year period.

i. Growth parameters

Growth response parameters currently being monitored include height, diameter, leaf area and foliar nutrient content. Height and diameter measurements involve the use of standard measuring tapes. Leaf area is measured using a leaf-area meter. The monitoring of plant height and stem diameter is done on every seedling at monthly intervals.

Figure 1. Plot lay-out for the fertilizer field trial

Block 1					Block 2					Block 3				
							BUFFER ZONE							
A_1NPK_{10}	A_1NPK_2	A_1NPK_8	A_1NPK_5	A_1NPK_1	A_1NPK_6	A_1NPK_4	A_1NPK_3	A_1NPK_8	A_1NPK_9	A_1NPK_5	A_1NPK_1	A_1NPK_2	A_1NPK_7	A_1NPK_4
A_1NPK_9	A_1NPK_4	A_1NPK_7	A_1NPK_6	A_1NPK_3	A_1NPK_7	A_1NPK_5	A_1NPK_2	A_1NPK_1	A_1NPK_{10}	A_1NPK_6	A_1NPK_8	A_1NPK_9	A_1NPK_3	A_1NPK_{10}
							BUFFER ZONE							
A_2NPK_3	A_2NPK_9	A_2NPK_7	A_2NPK_5	A_2NPK_8	A_2NPK_1	A_2NPK_{10}	A_2NPK_4	A_2NPK_2	A_2NPK_3	A_2NPK_7	A_2NPK_5	A_2NPK_8	A_2NPK_3	A_2NPK_1
A_2NPK_{10}	A_2NPK_2	A_2NPK_4	A_2NPK_1	A_2NPK_6	A_2NPK_5	A_2NPK_9	A_2NPK_8	A_2NPK_7	A_2NPK_6	A_2NPK_2	A_2NPK_9	A_2NPK_6	A_2NPK_4	A_2NPK_{10}
							BUFFER ZONE							

Note: 1. A_1: *Acacia mangium;*
A_2: *Paraserianthes falcataria;*
2. The layout for *Ceiba pentandra* plot is as above.

ii. Soil and foliar sampling

Soil samples are randomly collected from each section prior to planting and at three months intervals after planting to determine the chemical, physical and biological soil properties.

Foliar samples from twelve trees from each section are collected for nutrient analysis once in three months. Samples are collected from the mid-crown and the upper-crown on each randomly selected tree. (There is no established guideline on foliar sampling of tropical fast-growing timber species.)

Other information recorded regularly are climatic data, visual symptoms of deficiency or toxicity, pests and diseases.

Laboratory analysis

Soil analysis

Soil samples are analysed for their chemical, physical and biological characteristics. Rhizosphere soils are being assessed for presence of VAM spores, while root fragments sieved out are evaluated for mycorrhizal colonisation once every three months. The root staining method is used for this purpose.

Soil pH is determined in 1:2.5 soil to solution ratio (0.01N KCl) using a pH meter; total N and P determined calorimetrically with an autoanalyser; available P determined by Bray II; CEC and exchangeable cations (K, Ca and Mg) by the leaching method (1N NH_4OAc at pH 7.0); the micronutrients by the wet digestion method and by atomic absorption spectrophotometry; and soil organic carbon by the Walkley and Black (1934) procedure.

The physical soil properties determined are texture, temperature, hydraulic conductivity and moisture content. Texture is determined by the pipette method, soil temperature by soil thermometer, hydraulic conductivity by the Constant Head method (combination permeameter), and moisture content by the gravimetric method.

In the case of microorganisms, *Rhizobium japonicum, R. tritolii* and *R. melofi* have been identified as being the most effective strains for some agricultural crops, particularly soybean. No trials have been reported for fast-growing tropical timber species. It is therefore necessary to isolate the strains from existing nodules in the laboratory and subsequently test these strains in the field to select the most effective strain.

Foliar analysis

The foliar samples are being analysed for total N, P, K, Ca, Mg, Al, B, Cu, Fe, Mn and Zn. The modified wet digestion method of Parkinson and Allen (1975) has been used to prepare the foliage samples. Total N and P are analysed simultaneously on the original digest by an autoanalyzer. K, Ca, Mg, Al, Cu, Fe, Mn and Zn concentrations in the digest are determined by atomic absorption spectrophotometry. The Azomethine-H colorimetric procedure is employed to analyse for boron.

Statistical analysis

The data are subjected to analysis of variance and Duncans New Multiple Range test. Other statistical tools may be employed if deemed necessary.

Preliminary results

Inoculation experiments

Field propagation of the VAM fungi

Spore number and formation of mycorrhizae were seen to fluctuate with weather conditions. Presence of indigenous species was also detected during the spore count, making up a small portion (1%) of the total count.

Data were collected at bimonthly interval commencing May 1989, for a period of one year. The data collected include soil pH, total soil C, N, P, K, Ca and Mg, spore production per g soil (Sp) and per cent root infection (In).

All the data collected over a one-year period were subjected to Analysis of Variance (ANOVA) using SAS. Comparison of means was by DMRT. Correlation analysis was also done to identify the soil factors which are of importance to spore production and infection of the fungi in *Setaria* roots. Polynomial analysis was also done to find the best fit curve especially for percentage infection in the grass root.

The analysis of variance showed significant differences between fungal species and time of sampling for all data collected except for infection level in the grass roots (data not shown). Significant interactions between treatment and month were obtained for total C, spore number, soil N, P and K content. Since the introduced species is now mixed with indigenous species, the following introduced species were accordingly designated: AL+Mix, SC+Mix and GM+Mix.

Of the seven soil properties investigated, only total C, N, K and Mg were correlated significantly with spore production and percentage root colonisation by the mycorrhizal fungae (Table 1).

The polynomial equations for infection in the grass roots for the three mixed species are as follows:

. In (Al+Mix) $= 153.6 - 112.4M + 37.5\ M^2 - 3.5\ M^3$
$r^2 = 0.52$

. In (Gm+Mix) $= 132.8 - 72.5\ M + 21.6\ M^2 - 1.8\ M^3$
$r^2 = 0.24$

. In (Sc+Mix) $= 170.5 - 120.6\ M + 36.5\ M^2 - 3.17\ M^3$
$r^2 = 0.59$

Table 1. Correlation matrix of the soil properties analysed in relation to spore number (Sp) and five root infections (In)

Var. pH	C	Sp	In	N	P	K	Ca	Mg
Al+Mix								
pH								
C	0.158							
Sp	-0.092	0.513*						
In	-0.166	-0.012	0.551**					
N	-0.087	-0.226	-0.446	-0.585**				
P	0.354	-0.000	-0.317	-0.390				
K	0.119	-0.185	-0.463	-0.552**	0.754**	0.523		
Ca	-0.153	0.301	0.029	-0.106	-0.009	-0.284	-0.220	
Mg	0.093	-0.098	-0.298	-0.498*	0.595*	0.525	0.876	-0.138
SC+Mix								
pH								
C	0.503*							
Sp	0.112	0.087						
In	-0.502*	-0.010	-0.153					
N	-0.738**	-0.543	-0.022	0.182				
P	0.521**	0.329	-0.135	-0.247	0.810*			
K	0.309	0.058	-0.081	-0.705**	-0.421*	0.592**		
Ca	0.167	0.001	-0.266	0.009	-0.063	-0.160	-0.110	
Mg	0.260	0.229	0.072	-0.273	-0.420*	0.430*	0.427*	0.283
GM+Mix								
pH								
C	0.299							
Sp	-0.294	0.178						
In	-0.152	0.176	0.490*					
N	-0.287	-0.509*	-0.179	-0.471*				
P	0.446*	0.361	0.060	-0.208	-0.073			
K	0.235	-0.160	-0.082	-0.466	0.723**	0.416*		
Ca	0.160	-0.032	-0.267	-0.130	-0.108	-0.294	-0.165	
Mg	-0.086	0.009	0.069	0.334	0.635**	0.499*	0.805**	-0.384

Notation : n = 24, *($p < 0.05$), **($p < 0.01$).

Infection in roots was seen to decrease with time until the third sampling (data not shown). Infection level, however, was seen to increase after the addition of 15 kg ha^{-1} of NPK fertiliser, and then decrease again. Total N also decreased with time. This probably indicates that the fertiliser level must be maintained in order to sustain an optimum level of infection in the plant roots.

The total soil N can also be fitted into a polynomial curve with the following equations:

$$\text{N (Al+Mix)} = 0.10 + 0.67\,M - 0.22\,M^2 + 0.02\,M^3$$
$$r^2 = 0.56$$
$$\text{N (Gm+Mix)} = 0.17 + 0.59\,M - 0.19\,M^2 + 0.016\,M^3$$
$$r^2 = 0.60$$

$$N\ (Sc+Mix) = 1.26 - 0.77\ M + 0.19\ M^2 - 0.01\ M^3$$
$$r^2 = 0.84$$

Inoculation trial in the greenhouse

This greenhouse experiment aimed to test the effectiveness of field propagated mixed species versus pot propagated VAM culture. The experiment was started on 2 October 1991, using *Paraserianthes falcataria* as the test plant.

The analysis of variance (ANOVA) showed significant ($p < 0.05$) increments in top dry weight as a result of mycorrhizal inoculations, P levels and interactions between species and P levels. Dry weight of roots was not significant. Table 2a gives the mean dry weight of tops of seedlings as a result of mycorrhizal inoculation and Table 2b gives the mean dry weight of shoot as a result of P fertilisation.

Table 2a. Growth of *Paraserianthes falcataria* inoculated with various mycorrhiza

Mycorrhiza :	Shoot dry weight (g) (mean of 12 reps.)
Enthrospora	4.93b
Sc+Mix	3.25a
Control	3.45a

Note: Data identified with the same letter are not significantly different, while those having different letters are significantly different ($p < 0.05$).

Table 2b. Growth of *Paraserianthes falcataria* at various levels of P fertilisation

P levels :	Shoot dry weight (g)
P0	3.13b
P1	3.46b
P2	4.46a
P3	4.46a

Note: $^*p < 0.05$.

Results obtained clearly indicate superiority of the *Enthrospora* spp. over the mixed species. Dry weights of tops inoculated with *Enthrospora* was highest (4.93 g) at maximum fertilisation of 450 kg P/ha compared to maximum weight of only 3.25 g from seedlings inoculated with Sc+Mix. This further proved the ability of the *Enthrospora* species to multiply and establish rapidly in the seedling roots, thus enhancing seedling growth. It has become evident that the *Enthrospora* species was not inhibited by high P application. This is probably due to the fact that this particular species has acclimatised to soils with high P levels since the species were first isolated from highly fertilised rubber soils.

Mycorrhizal field trial

In the field trial two timber species (*Acacia mangium* and *Paraserianthes falcataria*) were used as test plants. One hundred uniform seedlings from each timber species were preinoculated with the respective mycorrhizal fungi: *Enthrospora* spp., AL+Mix, SC+Mix and GM+Mix. A total of 100 uniform seedlings were inoculated with autoclaved soil inoculum to represent the controls. At age 6 months, 75 uniform seedlings from each treatment were subsequently transplanted to the field in Semenyih. No basal fertiliser was applied at the time of planting. However, based on observations made on trees from the fertiliser trial, it was thought necessary to add some organic soil conditioner to each planting hole to reduce or even prevent leaching. Twenty grams of organic soil conditioner were therefore placed at the base of each seedling at the time of planting (30 January 1991).

A total of 25 *Acacia* seedlings were planted in each subplot, with a spacing of 1 m between trees, and 1.5 m between plots. There were 3 blocks per plant species. Each block consist of 4 subplots, which represent each treatment. A total of 12 subplots were planted with *Acacia*. The same experimental layout was prepared for *Paraserianthes* species. (None of the seedlings were inoculated with *Rhizobium*.)

The seedlings were only fertilised when the plants showed symptoms of nutrient deficiency. Two months after transplanting, several *Acacia* seedlings showed symptoms of K deficiency. As a result fertilisation was done on both timber species, although K deficiency symptom was less obvious on *Paraserianthes* seedlings. Subsequent fertiliser application was made only when nutrient deficiency symptoms became obvious.

One month after transplanting, and four months thereafter, seedling girth diameter and plant heights were measured from nine seedlings representative of each treatment. Soil samples were also collected from each treatment plot and analysed for pH, total C, N, P, K and Mg content. Data collection was done prior to application of fertiliser.

Data were collected at six-month intervals commencing in December 1991. During this period, the third and fourth leaves from five plants per plot were sampled and analysed for N, P, K, Ca and Mg contents. Plant heights and stem diameter were also recorded. Root samples were collected and assessed for mycorrhizal colonisation. Soil samples were also collected once in every six months and analysed for nutrient content.

To date, only data collected in December 1991 are available. These are presented in Table 3. The research area was completely burnt in early May 1992 during an unexpected dry spell.

The results indicate that *Paraserianthes* seedlings responded better to mycorrhizal inoculations. This is obvious from the significantly greater height for these seedlings compared with that of control plants. The greatest height of 87.58 cm was obtained from plants inoculated with *Enthrospora*, compared to only 67.56 cm for control plants (5 months after transplanting date).

Table 3. Effect of mycorrhizal inoculation on plant height and stem diameter of *Paraserianthes* seedlings at five sampling times

	Sampling time (month) 1991				
	Feb	Mar	April	May	Jun
VAM spp.					
***Ent**					
Plt ht (cm)	49.11b	51.37b	68.55b	79.05b	87.58b
Stem dia (cm)	5.15a	7.91a	9.56a	10.78a	12.95a
GM+Mix					
Plt ht (cm)	44.84b	48.19c	59.04c	67.89c	74.26c
Stem dia (cm)	4.59a	7.08a	8.17b	8.97b	11.30a
SC+Mix					
Plt ht (cm)	44.04b	48.59c	62.15d	67.52d	71.50d
Stem dia (cm)	4.88a	7.00a	7.87b	8.56b	10.91a
Control					
Plt ht (cm)	37.70a	41.33a	55.08a	62.59a	67.56a
Stem dia (cm)	4.59a	7.17a	8.67ab	9.72ab	11.28a

Note: (i) Values with the same letter within a column do not differ significantly at $p < 0.05$;
(ii) Statistical analysis using the SAS package was done separately for plant height and stem diameter. However for the purpose of this report, plant height and stem diameter measurements are tabulated together under the respective mycorrhizal species.

The *Acacia* seedlings appeared to be adversely affected by the presence of the mycorrhizal fungi. The general trend was that the control plants had a more vigorous growth compared to plants inoculated with the introduced species (data not shown). Observations made on the roots of some weeds growing in the control plots indicated a fair colonisation of these roots by the indigenous mycorrhizal species.

Fertilisation experiment

Optimum height and diameter growth for *Acacia mangium* was obtained with the application of NPK fertiliser at the rate of 400-500 g/seedling (Tables 4 & 5 respectively). Foliar analysis (Table 6), revealed that height increment was positively but not significantly correlated with foliar N, P, K and Mg, whereas the diameter increment was positively and significantly correlated to foliar K. Based on these results, it can be concluded that the NPK fertiliser applied at the rate of 400 g/seedling is adequate for optimum early growth of *Acacia mangium* on tin tailings. A significant implication from this experiment is the fact that timber species, and in this case, *Acacia mangium*, could be successfully used to rehabilitate such infertile soil environments.

Table 4. Monthly mean height increment (cm) of *Acacia mangium* after fertilisation

Treatment level	Months 1	2	3	4	Total
T1	23.89	2.45	4.75	3.56	34.65
T2	23.86	1.29	6.24	6.12	37.51
T3	21.07	4.10	5.21	4.79	35.17
T4	23.29	4.80	5.33	3.80	37.22
T5	23.59	4.06	5.99	5.05	38.69
T6	24.12	5.41	5.83	3.89	39.52
T7	22.64	5.48	5.64	7.98	41.74
T8	22.63	4.29	6.09	5.24	38.25
T9	22.19	5.32	8.07	8.44	44.02
T10	23.27	5.51	6.94	4.85	40.57

Note: Duncan's New Multiple Range Test showed no significant difference in height increment among the following treatments : T1 (control), T2 (100 g NPK/seedlings), T4 (200 g NPK/seedling), T5 (250 g NPK/seedling), T7 (350 g NPK/seedling) and T8 (400 g NPK/seedlings).

Table 5. Monthly mean diameter increment (cm) of *Acacia mangium* after fertilisation

Treatment level	Months 1	2	3	4	Total
T1	0.29	0.12	0.08	0.07	0.56
T2	0.29	0.16	0.18	0.16	0.79
T3	0.28	0.16	0.19	0.13	0.76
T4	0.29	0.18	0.16	0.09	0.72
T5	0.29	0.18	0.21	0.10	0.78
T6	0.30	0.22	0.18	0.06	0.76
T7	0.30	0.19	0.23	0.20	0.92
T8	0.29	0.16	0.21	0.09	0.75
T9	0.35	0.11	0.12	0.18	0.76
T10	0.28	0.20	0.21	0.19	0.88

Note: Duncan's New Multiple Range Test showed all NPK-fertiliser levels contributed significantly ($p < 0.05$) to increasing the radial growth compared to the control seedlings.

Growth of *Paraserianthes falcataria* has been extremely slow on the sandy tailings. It appears that this species is not suitable for rehabilitation of sandy areas. In the case of *Ceiba pentandra* the seedlings were only recently transplanted to the field. Survival is excellent (100%) and monitoring of growth rate is in progress. It is still too early to make an assessment of the growth performance of this species on tin tailings.

Social aspects : land ownership

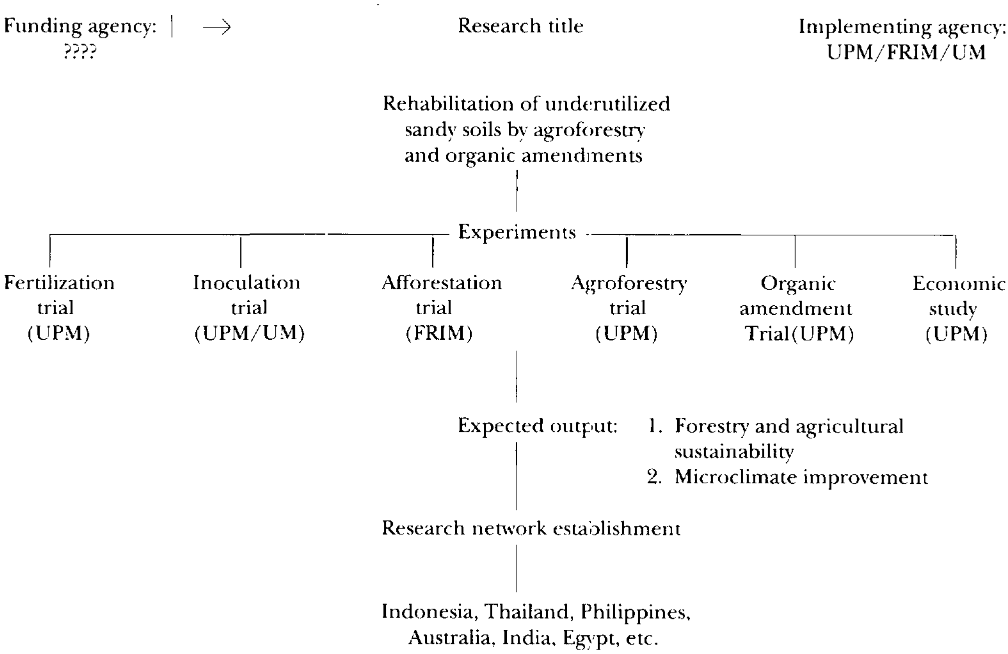
Mining land in Malaysia belongs to the respective state governments. The current practice is for the mining company to carry out mining operations on a lease-term basis, normally for a period of 10-20 years after which the area is handed back to the state government.

There is no provision in the mining enactment that the mining company has to restore the mined area to its original natural state or to rehabilitate the area. The company is, however, required not to cause siltation and pollution to the water system. How this is to be carried out is not spelt out in the enactment.

Future directions

The monitoring and collection of data for the three major experiments (fertilisation, inoculation and mulching trials) that started in 1989 will continue for at least another 12 years, the rotation cycle of *Acacia mangium* on ordinary mineral soil. Pending funding we plan to expand the research programme to include similar experiments on BRIS Soils, and to include an additional experiment on silvicultural manipulation on tin tailings. In addition, an economic assessment of the various projects will also be done. The general schematic diagram for the proposed expansion and continuation of the research programme which will also involve the Forest Research Institute Malaysia and the University of Malaya is given in Figure 2. It is also hoped that a regional research network will be established on this important subject.

Figure 2. General scheme of the proposed research programme



Conclusion

The first three years of the research project has been plagued with delays particularly with regards to land and seed acquisition. In spite of these difficulties and the harsh environmental conditions, *Acacia mangium* has been successfully established, but *Paraserianthes falcataria* does not seem to adapt well to the environment. It is still too early to make any conclusive statement for *Ceiba pentandra.* We hope to plant timber species such as *Casuarina equisetifolia, Terminalia catappa* and *Acacia auriculiformis.* The performance of peanut and *Setaria* grass can be described as satisfactory. Detailed results will only be available once analysis of the samples collected over the past three years is completed.

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