THE ECOLOGICAL EFFECTS OF SEVERAL REFORESTATION AND REHABILITATION TREATMENTS ON ABANDONED SHIFTING CULTIVATION SITES IN SARAWAK, EAST MALAYSIA.

by

© C. J. Halenda

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ABSTRACT

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The biomass, nutrient contents and soils of a chronosequence, including undisturbed primary forest (UPF), logged over forest (LOF), cleared and burned forest (for cultivation), abandoned cultivation sites, and four rehabilitation treatments were studied. Rehabilitation treatments included 6.5 year old *Acacia mangium*, *Gmelina arborea* and *Leucaena leucocephala* plantations and 7 to 10 year old fallow forest (natural regeneration). Plots were established on Red-Yellow Podzolic soils with an attempt to maintain similar soil conditions. Replicate biomass plots, 10 m x 20 m in size, were established for all treatments with additional one ha plots for each replicate of UPF and LOF plots.

Clearing and burning of LOF for cultivation resulted in decreases in total N and total P, but in temporary increases in organic C, and exchangeable K, Ca and Mg. However, one and a half years after abandonment, C and nutrient levels had decreased to either the lowest levels in the chronosequence or to preburn levels. Carbon and nutrients in the soil increased during the four rehabilitation treatments, approaching UPF or LOF levels, although at somewhat different rates. Potassium levels in *Acacia* and fallow soils remained lower than levels 1.5 years after abandonment.

Results indicate that aboveground biomass of undisturbed forest (476 t/ha) was reduced to 228 t/ha after logging. Clearing and burning of LOF resulted in removal of all living biomass. Rehabilitation treatments resulted in aboveground biomass productions ranging from a low of 20 t/ha (*Leucaena*) to a high of 134 t/ha (*Acacia*). Contributions to aboveground biomass ranged from 1.4 to 17.8 % for litter; 0.7 to 40.3 % for undergrowth; and 41.8 to 96.9 % for overstorey. Within the overstories, stems comprised the largest amount of biomass ranging from 54.8 to 79.0 % followed generally in the order of large branches (3.6 to 9 %) or small branches (4.6 to 16.7 %), twigs (2.3 to 10.7 %), foliage (1.8 to 5.9), and fruit and flowers (0 to 0.5 %).

Aboveground biomass of UPF immobilized the largest amounts of N, P, K, Ca and Mg; followed by LOF. Rehabilitation treatments immobilized different nutrients at varying rates. Overstories immobilized the largest amounts of nutrients except in the *Leucaena* plantation which contained larger amounts of nutrients in undergrowth. Amounts of nutrients immobilized in different vegetative components of the overstories varied with forest type and nutrient. Nutrients taken up by aboveground biomass ranged from 191 to 1271 kg/ha N; 9.1 to 75.4 kg/ha P; 225 to 1161 kg/ha K; 104 to 1624 kg/ha Ca; and 34 to 402 kg/ha Mg.

The return of biomass during rehabilitation treatments was generally accompanied by a restoration of soil nutrients. *Acacia*, *Gmelina* and fallow were found to be satisfactory rehabilitation treatments for abandoned shifting cultivation sites, in terms of biomass production and restoring the protective function of a forest cover. There was some question as to the suitability of *Acacia* as a rehabilitation treatment due to early decline in growth rates and problems with disease and heart rot. *Leucaena* was found to have a negative effect on site recovery resulting in increased undergrowth vegetation which impeded establishment of tree species.

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C.J.H.

1.0 INTRODUCTION

Shifting cultivation is one of the most prevalent agricultural systems in the state of Sarawak, Malaysia. The clearing of forests for shifting cultivation, in previously uncultivated areas, often occurs following logging activity as a result of improved accessibility. Prior to the advent of logging most shifting cultivation was limited to areas that were accessible by river; hence, there was some control over its spread. However, with the expansion of logging and road construction, shifting cultivation has become a serious problem as shifting cultivators now encroach on and threaten State hill forest resources, a chief source of export income for the state of Sarawak.

The problem has been recognized by the State Government as is indicated by recommendations and programmes put forth in the Fourth Malaysia Plan (1981-1985) to be initiated and carried out by the Forest Department. The most important recommendations made concerning this study are:

1) That forest areas affected by shifting cultivation be reforested and rehabilitated;
2) That leguminous tree species be used for land rehabilitation and agroforestry systems; and
3) That information be gathered and pilot studies be conducted in managed and silviculturally treated forest areas.

Lee (1981) suggested several silvicultural techniques that could be used for rehabilitation of abandoned shifting cultivation sites. However, it was pointed out that the ecological effects of these rehabilitation techniques, in Sarawak, are still not clearly understood. If sound management decisions are to be made regarding site rehabilitation, under various local conditions, a better understanding of ecosystem recovery will be required. Lee (1981) presented a broad outline listing the most important research problems involving ecosystem dynamics of recovering shifting cultivation sites. That outline led to the development of the present study.

1.1 Shifting Cultivation

1.1.1 World Situation

Shifting cultivation is one of the main forms of subsistence agriculture practised in many countries throughout the world. It has been estimated that shifting cultivation covers

45 percent of the tropical area (Sanchez, 1976). It is practised in Africa, Oceania, South America, Central America and Southeast Asia and estimates are that about 360 million ha of land, or 30 percent of the world's exploitable soils are under some form of shifting cultivation, supporting over 250 million people worldwide (Hauck, 1974; Hatch, 1983).

Although shifting cultivation is widespread in Southeast Asia, it is predominant mainly in Borneo, Sumatra, Thailand, Burma, Laos, Vietnam, Indonesia, the Philippines, Kampuchea and Southern China (Hatch, 1982). Spencer (1966) estimated that the total area required to support shifting cultivation activity in Southeast Asia was 1,068,799 square km while the annual area cropped was about 168,350 square km. More recent estimates of the annual area cleared range from 850,000 ha (FAO/UNEP, 1981) to 1.56 million ha (Palm *et al.*, 1986). Of the approximately 925 million people living in Southeast Asia it was estimated that 50 million, or six to seven percent of the population live by shifting cultivation (Spencer, 1966). However, more recent reports estimate the total number of people to be much lower at 31 million (Myers, 1980; FAO/UNEP, 1981). Hatch (1983) gives a more recent estimate for Southeast Asia of 100 million people living by shifting cultivation. A further 675 million (72 percent of the population) live by permanent agricultural systems on more fertile lands; the total area of which is in the neighbourhood of 225 to 235 million ha. The total land area of 100 to 110 million ha farmed by shifting cultivators is generally marginal in agricultural productivity potential and is usually located in remote and hilly areas. These sites are often seriously degraded to unproductive grasslands which can be extremely difficult to reforest by either natural or artificial means. It is estimated that some 25 to 30 million ha of *Imperata* wastelands already cover Thailand, the Philippines and Indonesia (FAO/ UNEP, 1981; NRC, 1983).

1.1.2 Situation in Sarawak

It is estimated that shifting cultivation supports 250,00 to 300,000 people or at least 40,000 households in Sarawak (Hatch and Lim, 1983). Hatch (1982) compiled estimates, from Sarawak Department of Agriculture statistics, for the total annual area under shifting cultivation in Sarawak since the 1960s. In the 1980 to 1981 season, it was estimated that a total of 75,388 ha or 0.6 percent of land in the State had been cleared, burned and planted with hill padi. Over the previous 20 years the mean annual area cleared and burned for shifting cultivation was 71,432 ha. The estimated maximum and minimum annual area cleared over this 20 year period was 86,394 ha and 62,501 ha respectively. The data did not indicate a trend; however, they did show that from 1966 to 1971, there was a marked increase in area cleared annually. From 1972 to 1977, there was a decrease in area cleared, but from

1977 onwards the area cleared has steadily increased. Hatch (1982) questioned the accuracy of these annual estimates for various reasons and suggested that the annual area cleared could be twice as high as those stated.

Hatch (1982) suggested that estimates by the Sarawak Agriculture Department for annual clearing were probably low since, according to their estimates, the average fallow period would be about 42 years. Due to increased population and land use pressure it is highly unlikely that fallow periods are as long as 42 years. Unpublished survey data by Halenda (1986) indicate the average fallow period to be between 7 and 15 years. Using an average fallow period of 15 years, which Hatch (1982) calculated from previous surveys, it was suggested that a more realistic figure for annual area cleared would be around 150,000 ha.

In terms of total actual land area in use under the shifting cultivation system, there appears to be a broad range of estimates according to different sources. Sarawak Department of Agriculture estimates indicate that the total area is 3,178,085 ha or 25.8 percent of the total land area of Sarawak (Hatch, 1982); data compiled by Hatch suggests that the total area involved was 2,383,563 ha or 19.3 percent. The latter figure includes areas that were actively under shifting cultivation at the time of survey as well as areas that could be recognized as having been cleared for shifting cultivation at some time in the past. Hatch (1983) gives another estimate, determined from aerial photos, of 2,852,792 ha or 23.1 percent of the total area.

It is difficult to determine the actual total area cleared and burned per annum or even the total overall area cleared to date because shifting cultivation areas are often remote and difficult to access. The total areas listed above were determined using a combination of ground observations and aerial photos. Ground observations have often been "eyeball" estimates and there are problems in correctly identifying various land uses from aerial photos. Under these conditions the figures quoted above are at best a broad approximation of the total land area under shifting cultivation.

The Forest Department's main concern with shifting cultivation is its spread into State Forest Reserves and other permanent forest lands and the resultant loss of net revenue and timber. Hatch (1983) estimated that the area of mature forest being cleared annually by shifting cultivators is in the neighbourhood of 30,000 ha, resulting in a revenue loss to the state of M$ 300 million (Cdn $ 148 million). Korsgaard (1986) cites shifting cultivation as one of the main reasons for the rapid disappearance of mixed dipterocarp forests in Southeast Asia.

1.1.3 The Shifting Cultivation System

There are numerous variations of the shifting cultivation system as it is practised throughout the world; hence, a universal definition is not easily found. Watters' (1971) definition is broad enough to describe it on a worldwide scale :

> "... shifting cultivation, can perhaps best be defined as a form of agriculture marked by the rotation of fields rather than crops, by short periods of cropping (one to three years) alternating with generally longer periods of fallow (up to twenty years but often only four to eight) and characterised by clearing by slash-and-burn and the almost exclusive use of human energy..."

This definition generally describes shifting cultivation in Sarawak. Extensive and detailed reports, describing shifting cultivation as practised by the Iban in Sarawak, have been written by Freeman (1955, 1970). Although the original account was written over thirty five years ago, generally, the same methods are still applied today.

The annual cycle begins in the dry season with site selection between March and July, after the previous years harvest has been completed. Sites, either secondary or primary forest, are cleared using a parang (bush knife) or axe. Clearing commences in June or July and continues through to August or September, allowing at least one month for drying prior to burning. The quality of burn is important and should be thorough to release sufficient nutrients for a good crop. Logs and brush on inadequately burned fields may be restacked and burned again (Halenda, 1986). Sowing is carried out immediately after the burn and just prior to onset of the rainy season (Spurway, 1937). The main crop, hill padi (rice), is often interplanted with corn, cucumbers, squash, beans, yams and other local crops. After one or two consecutive years of cropping the most common and final crop planted is tapioca (*Manihot* spp.) although it may not be planted at all. Generally, each padi farmer grows at least three or more varieties of padi (Hatch, 1983).

The intensity of weeding varies with the farmer and number of workers available. Weeding is generally manual work; however, herbicides may be used where people can afford them. Weeding is mainly by cutting weeds at ground level, leaving roots in the ground and causing minimal soil disturbance, thus preventing increased soil erosion.

When crops have been harvested for one to three years, the field is abandoned to regenerate and recover. The fallow period may last from three to thirty years; however, the most common length is between seven and fifteen years. In recent years fallow periods have become increasingly shorter due to increases in population and to land use pressures.

Most species regenerating on fallow sites during this time are fast growing secondary species, predominantly *Macaranga* species and *Ficus* species; however, numerous other species are present and may dominate depending on soil and site characteristics. The cycle is repeated after several years of recovery when the farmer returns to clear and burn the site for sowing. The length of time for a given fallow period is generally determined by the rate of site recovery.

1.1.4 Site Rehabilitation

Due to increased population and land use pressure shifting cultivation sites have often been overused to the point of serious nutrient depletion and site degradation. As a result the natural regeneration and site recovery process becomes very lengthy, and many areas are left dominated by lallang (*Imperata cylindrica* (L.) Beauv.) or various ferns or shrub species. Rehabilitation of such lands is important so that biological productivity can support people once again as well as reduce the pressure for degradation of additional tropical forest lands (Lovejoy, 1985).

As this problem became more serious and spread to State Forest Reserves the Sarawak Forest Department became involved in the rehabilitation of these sites. Attempts at rehabilitation have been carried out mainly through reforestation using several exotic tree species, including *Acacia mangium* Wilde. and *Leucaena leucocephala* (Lam.) de Wit., both of which are nitrogen-fixing, and *Gmelina arborea* Roxb. as well as other exotic and native species. However, the success and effects of these treatments have yet to be determined.

1.2 Objectives

The overall aim of this study is to determine the ecological effects of some of the silvicultural practices presently being used for reforestation and rehabilitation of abandoned shifting cultivation sites in Sarawak. In order to achieve this objective, several plant and soil conditions are examined including:

1) The aboveground organic matter production of all vegetation in the various silvicultural treatments and control plots

2) The proportion of biomass contributed by different components of vegetation in each treatment;

3) The small-litter standing crop (litter crop on the forest floor, at the time of harvest, including branches < 3 cm diameter over bark) produced by each treatment;

4) The total nutrient accumulation of the aboveground biomass by component; and

5) The physical and chemical properties of the soil underlying each treatment.

In this paper *Acacia* refers to *Acacia mangium*, *Gmelina* to *Gmelina arborea* and *Leucaena* to *Leucaena leucocephala*.

2.0 LITERATURE REVIEW

2.1 Mature Primary Forest

Prior to the onset of logging, the shifting cultivation cycle began in undisturbed primary forest (UPF). The most common forest type used by shifting cultivators, in Sarawak, is the Mixed Dipterocarp Forest. Mixed Dipterocarp Forest (MDF) is the dominant forest type in the perhumid Southeast Asian tropics (Whitmore, 1984) and is one of the most valuable rainforest resources in the world (Korsgaard, 1986). It is named after the Dipterocarpaceae family which dominates the forest in basal area, number of trees and canopy volume. The term mixed dipterocarp forest is used in Sarawak to differentiate between dipterocarp forests which are dominated by one species, for example the *Shorea albida* peat swamps. A typical MDF canopy is 30 to 40 meters high; however, trees frequently exceed 60 m or 70 m in height (Yamakura *et al.*, 1986) with the largest trees having diameters of one to two meters or more. The understorey has relatively little ground vegetation due to heavy shading by the canopy. The greatest diversity and continuous extent of MDF is on the island of Borneo (Whitmore, 1984) which includes Sarawak and Sabah in Malaysia, Kalimantan in Indonesia, and Brunei.

Lowland dipterocarp forests have a very mixed forest composition but fairly uniform general characteristics (Brown, 1955). The forest consists of seven to ten very large trees per ha with their crowns clear of the general canopy. Boles are up to 30 m long and contain 500 cu ft/acre (35 m^3/ha) or as much as 2000 cu ft/acre (140 m^3/ha) of merchantable timber on the best sites (Brown, 1955).

The MDF is characterized by a very large number of species with rarely one species being dominant (Scott, 1985). The Dipterocarpaceae family attains its greatest species richness in Sarawak and Brunei (Whitmore, 1984). Kartawinata *et al.* (1981) reported 239 tree species, with a dbh > 10 cm, in 122 genera and 45 families for a 1.6 ha plot in East Kalimantan. The most prominent species was *Shorea laevis* with a density of 21.9 trees per ha. The most common families were Euphorbiaceae, Lauraceae and Rubiaceae. Wyatt-Smith (1966) observed over 200 species in mixed dipterocarp forests in West Malaysia for similar sized plots. Anon (1978) reported that ten ha of perhumid forest, on soils of average fertility in Malaysia, may contain as many as 550 species.

Aboveground dry-weight biomass of mature tropical forests range from 128 to 873 t/ha as reported by several authors (Wycherly and Templeton, 1969; Kato *et al.*, 1978; Proctor *et al.*, 1983; Rai and Proctor, 1986a; Yamakura *et al.*, 1986). Aboveground biomass of MDFs in Malaysia and Borneo tend to be at the upper end of this range at 650 t/ha

(Proctor *et al.*, 1983a) to 873 t/ha (Yamakura *et al.*, 1986). Rai and Proctor (1986a) calculated the mean annual increment to be between 6.4 to 11.1 t/ha/yr of wood in India, while Kato *et al.* (1978) reported increments of 6.5 t/ha/yr for aboveground biomass and 0.5 t/ha/yr for roots. The proportions of biomass, with respect to different vegetative components, is fairly constant. As reported by various authors, approximately 60 to 75 percent of the biomass consists of stem and branches; 8 to 15 percent bark; 15 to 20 percent roots; 4 to 6 percent foliage; and 1 to 2 percent litter (Bartholomew *et al.*, 1953; Golley *et al.*, 1969; Kato *et al.*, 1978).

Litter biomass production in tropical forests from various sources ranges from 3.2 to 10.2 t/ha/yr (Jenny, 1954; Ogawa, 1978; Yoda, 1978). Litter values in mixed hill dipterocarp forests in Sarawak are reported at 6.0 t/ha (Proctor *et al.*, 1983b).

Little information is available on total nutrient content of vegetative components; however, it is known that nutrient content varies with forest biomass and stand age. Ranges reported for rain forests in Venezuela (Uhl and Jordan, 1984) and New Guinea (Grubb and Edwards, 1982) in kg/ha are: 908-2000 N; 45-70 P; 300-907 K; 200-1848 Ca and 260 Mg (only one value reported). Nutrient content in litter is affected by litter composition and total litter biomass. The ranges reported in Malaysian rain forests are narrow: 42-43 kg/ha N; 1.0-1.3 kg/ha P; 7.1-9.6 kg/ha K; 7.2-22.1 kg/ha Ca and 3.8-4.1 kg/ha Mg (Yoda, 1978; Proctor *et al.*, 1983b).

The MDF grows on well drained clay loam and clay soils (Hatch, 1982), the most common being Red-Yellow Podzolic (RYP). These soils are discussed in section 2.6.

2.2 Logged Over Forest

The expansion of logging has led to the widespread practice of shifting cultivators moving onto recently logged sites as logging operations make forest land more accessible (Palm *et al.*, 1986). It is estimated that 70 to 80 percent of clearing and burning occurs on recently logged areas and that shifting cultivation is the primary cause of deforestation in Southeast Asia (FAO/UNEP, 1981). Reports indicate that these areas are preferred because less work is involved in clearing the land and it is more accessible to landless farmers.

Studies on logged over forest in Malaysia deal mainly with the damage resulting from logging. In Sarawak, conventional logging approximates the Malaysian Uniform System which involves selective felling where only marketable tree species > 46 cm dbh are removed (Lee, 1982). However, Abdulhadi *et al.*, (1981) found that the average extraction of 11 trees per ha resulted in about 40 percent of the residual trees sustaining branch and crown damage, with the greatest amount of damage occurring in the 10 to 20 cm dbh class. Fifty-five percent damage was reported in a similar study by Nicholson (1958). Tree density was reduced by 186 trees per ha and basal area by 19.2 m^2 per ha. It was inferred that the extraction of one tree resulted in the disappearance of 17 others.

Logging activity also resulted in 25 to 30 percent of the ground area becoming bare and damaged with a decreased rate of water infiltration (Abdulhadi *et al.*, 1981). It was also found that on bare ground the dominant regrowth was composed of secondary species. Six months after logging bare ground areas were heavily invaded by 30 pioneer species, the most prominent of which were *Macaranga* species, *Endospermum diadenum* and *Anthocephalis chinensis*. No primary forest tree species were found on the sites; however, on older logged over forests dipterocarps, including *Shorea parvifolia*, *S. leprosula*, *S. palembanica* and *Dipterocarpus caudiferus* had returned to the site and had good growth rates. Abdulhadi *et al.* (1981) concluded that primary forest tree species only reestablish after conditions have become favourable for germination and seedling establishment. Primary and secondary tree species are defined in the glossary.

Six years after logging Malmer and Grip (1990) found that logged sites in Malaysia still had very poor infiltration rates due to compaction. They also noted that since six years was more than half the calculated plantation rotation age for these areas; minimizing damage to logged over forest areas becomes a serious issue. They suggested that cable yard or manual logging be used for such sensitive areas.

Miller (1981) studied growth and yield of a logged over forest in East Kalimantan, Indonesia. He found that the average net growth rate after logging was two to three m^3/ha/year, which is significantly higher than that of undisturbed primary forest, but comparatively less than plantation growth rates (12 to 20 m^3/ha/year). Miller (1981) indicated that replacement of volume after logging could take from less than five years to more than 40 years and was dependent on logging intensity, slope position and soil type.

2.3 The Shifting Cultivation Phase

The shifting cultivation system has generally been described in section 1.1.3. In Sarawak, padi is sown just prior to the rainy season by using a dibble stick and sowing three to ten seeds per dibble hole. The dibbling method causes a minimum of disturbance to the soil as opposed to hoeing. Padi matures in about 160 days and harvesting takes place at the end of the rainy season in March or April (Hatch, 1983). The land is then either left fallow, planted with padi a for a second year, or often the final crop will be tapioca. The decision of whether or not to crop again is dependent on the success of the previous crop and the amount of pest and weed problems encountered. Norman (1979) reported a decline in padi yield by 34 percent in the second year and by 55 percent in the third year of harvest for shifting cultivators in Malaysia.

The expected biomass of padi harvest varies considerably and is dependent on numerous site factors. On sites where primary jungle was cleared and burned yields of 1000 kg/ha can be expected or in exceptional cases where disease and pest attack is low 2000 kg/ha may be obtained (Hatch, 1983). However, such high yields are now rare due to the lack of available primary forest and the expected yields are now commonly 700 kg/ha. In areas where sites have been cleared and burned for several generations the yields commonly drop to 300-400 kg/ha (Hatch, 1983).

Nutrient removals from a site, through padi harvest, have been reported by DeGues (1973), Morrison (1984) and Sanchez (1976). DeGues (1973) specifies that the amount of nutrients removed refer to the panicle only which is the only part of the plant removed in padi harvests in Sarawak. The other authors do not specify the type of harvest. Removals indicate the amount of nutrients removed per 1000 kg/ha of padi. The amounts removed were 10-23 kg N; 2.7- 4.7 kg P; 2.3-6.7 kg K; 0.8-2.6 kg Ca and 0.2-1.9 kg Mg. All of the minimum values reported were from DeGues (1973) except for Mg which is the maximum given. The effect of shifting cultivation on soil and soil nutrients is discussed in section 2.6.

2.4 The Fallow Forest Phase

Several studies on the fallow forest phase have been carried out in Malaysia. One type of study monitors plant succession in which only the changes in plant species are recorded. Kochummen (1966) began such a study in the 1940s, on a site that was previously a lowland dipterocarp forest planted to padi. One year after abandonment the site was dominated by the secondary tree species *Macaranga gigantea* and *Mallotus macrostachs*. A creeper, *Mikania cordata* was common as well as *Imperata cylindrica* and the fern *Nephrolepis biserrata*. After 17 years the area was dominated by *Macaranga gigantea* at heights of 17 to 20 meters, *Pellacalyx axillaris*, *Girononniera nervosa* and *Shorea parvifolia* (seedlings from remnants left standing). There was a total of 100 species on the site and it was estimated that primary forest species would be dominant within fifty years. Another study (Kochummen and Ng, 1977) reported that 30 years after abandonment the dominant species were *Antidesma cuspidatum*, *Eugenia fastigiata*, *Macaranga triloba*, *Lindera* spp. and *Timonius wallichianus*. The succession towards primary forest was expected to be slow due to its isolation from a seed source for primary tree species.

A more recent study in Sarawak (Ewel *et al.*, 1983) recorded the floristics and biomass of fallow forests on poor, intermediate and better quality sites. Better quality sites were found to be more species rich as well as having greater biomass. All sites were dominated by *Macaranga* spp., *Ficus* spp., *Dillenia* spp. and *Callicarpa* spp.

Studies reporting height and diameter measurements of fallow forests are scarce. Chai (1981) reported a mean height of 8.0 m and a mean dbh of 6.2 cm for a 10 to 14 year old fallow forest in Sarawak. Ranges were 3.5 to 12.8 m for height and 2.2 to 16.8 cm for dbh. The biomass of this fallow forest was 35.4 t/ha.

Biomass studies throughout the tropics appear to be the dominant type of study on fallow or successional forests. Depending on fallow forest age and site quality biomass has been reported to range from 10.9 to 140 t/ha (Bartholomew *et al.*, 1953; Ewel, 1971; Snedaker, 1980; Aweto, 1981; Koopmans and Andriesse, 1982; Ewel *et al.*, 1983; Saldarriaga *et al.*, 1988). Litter biomass was reported to range from 3.4 to 7.4 t/ha (Nye and Greenland, 1960; Koopmans and Andriesse, 1982).

Information on nutrient uptake of fallow forests in Southeast Asia is rather scarce. However, studies have been carried out in other parts of the tropics and some patterns in nutrient uptake are noticeable by comparing the data (Bartholomew *et al.*, 1953; Nye and Greenland, 1960; Koopmans and Andriesse, 1982; Andriesse and Schelhass, 1987). Generally, it appears that nutrient uptake is more rapid in younger forests and that the rate of uptake decreases as a forest grows older. Generally, nitrogen and potassium are taken up in the largest amounts followed by lower amounts of calcium and magnesium, and then by much smaller amounts of phosphorus. In younger fallow forests it appears that potassium is taken up in the largest amounts while in older fallow it appears to be nitrogen. However, there is not sufficient data to establish any definite trends in nutrient uptake for a specific fallow forest on a given soil type. Andriesse and Schelhass (1987) report the nutrient content of a 12 to 14 year old fallow forest in Sarawak to be 132 kg/ha N; 6.2 kg/ha P; 208 kg/ha K; 117 kg/ha Ca and 23 kg/ha Mg.

There is some understanding of biomass and soil nutrient relationships in fallow forests. Generally, site recovery through the growth of fallow forest occurs by nutrient and humus build up in the topsoil. Nutrients are taken up from the soil and stored in the biomass. Some of these nutrients are returned to the topsoil through litterfall and root sloughing (Jordan, 1985). Studies have shown that eventually, as the forest matures, the percentage of nutrients in the aboveground biomass becomes greater than that in the soil, with the exception of nitrogen (Nye and Greenland, 1960; Sabhasri, 1978; Zinke *et al.*, 1978). This build up of nutrients in the biomass is the foundation on which the shifting cultivation system works. When forest nutrient levels are great enough, shifting cultivators return to clear and burn the fallow forest. Nutrients in the biomass are returned to the topsoil in ash and act as a fertilizer for the next rice crop.

The preceding paragraphs deal mainly with areas that recover to tree species relatively quickly after abandonment; however, some areas become densely colonized by grass species such as lallang (*Imperata cylindrica*). Establishment of grasses usually occurs when fallow periods are too short to restore soil fertility, or when sites are frequently burned. This results in a decline in the productive capacity of the soil (Jordan, 1985) as well as reduced soil organic matter (Nye and Greenland, 1960). Total ecosystem nutrient stocks are also greatly reduced when forest areas are converted to grasslands (Scott, 1978). In order for tree species to re-establish, total nutrient stocks must be rebuilt (Jordan, 1985). However, Lambert *et al.* (1990) noted that the dominance of grass species, with their extensive root systems, inhibits the establishment of other plant species. *Imperata cylindrica* also has rhizomes that are not easily destroyed by short term fires making it a difficult species to eradicate (Toky and Ramakrishnan,1983a). This problem is illustrated by Drew *et al.* (1978) who observed that *I. cylindrica* in Thailand maintained an almost constant biomass for nine years; biomass of woody vegetation became significant only after twenty years of recovery. In such cases of grass species dominance it may be beneficial to site productivity to assist the recovery process through establishment of plantations.

2.5 The Plantation Phase

Tropical plantations have been widely studied for biomass and nutrient uptake, though generally not from the perspective of site recovery. There is an extensive number of tree species planted in the tropics; however, only the species included in this study will be reviewed here. These include *Acacia mangium* and *Leucaena leucocephala*, both of which are leguminous and nitrogen-fixing, and *Gmelina arborea* which does not fix nitrogen. An average rate of dry weight stemwood biomass production in tropical forest plantations is 7.5 t/ha/yr (Ewel *et al.*, 1983). Ten t/ha/yr is considered high (Lugo *et al.*, 1988). Total aboveground biomass production on less fertile sites has reached 9 t/ha/yr but usually ranges from 3-6 t/ha/yr (Dawkins, 1963). However, extremely high plantation biomass production has been reported ranging from 20.4 to 28 t/ha/yr in Malaysia and Indonesia (Anon, 1978).

2.5.1 *Acacia mangium*

Acacia mangium has been widely planted in Southeast Asia because of its ability to fix nitrogen and grow under extremely poor site conditions. *Acacia* is a pioneer species belonging to the subfamily Mimosoideae. It is indigenous to Northeastern Australia, New Guinea, and the Moluccas and Irian Jaya in Indonesia. It establishes itself on disturbed sites where it grows mainly on acidic Ultisols and rarely on soils derived from basic parent material (NRC, 1983). The tree has relatively good form, nodulates profusely and tolerates a soil pH as low as 4.2. Limitations of *Acacia* are that it requires a high annual rainfall (1000 mm to 4500 mm) where soil moisture remains relatively high year round (NRC, 1983). It has been reported to grow well on eroded, rocky, thin mineral soils and deeply weathered soils. *Acacia* also appears to prefer low elevations but has been found to occur naturally above 700 m asl (NRC, 1983).

Studies on *Acacia* plantations in Sarawak, Malaysia have dealt mainly with height and diameter measurements. Mean annual height increments (MAHI) ranged from 1.4 m to 4.6 m, while mean annual diameter increment (MADI) ranged from 1.6 cm to 3.6 cm for trees between 1.5 and six years of age (Butt and Ting, 1983; Lim, 1985; Lim and Basri, 1985; Chai, 1986; Lim, 1986; Halenda, 1990).

Mean annual height increment of two to fourteen year old *Acacia* trees in Sabah ranged from 1.6 m to 4.6 m, and MADI ranged from 2.0 cm to 4.9 cm (Amir, 1982; Jones, 1983; NRC, 1983). Tan (1983) reported MAHI, for three to five year old dominant *Acacia* in Sabah, ranging from 4.3 m to 4.9 m and MADI ranging from 3.2 cm to 3.8 cm. The general growth trend appears to indicate that height and diameter growth begins to decrease after 3 to 3.5 years of age.

Growth rates in West Malaysia appear to be slightly better overall than Sarawak and Sabah with MAHI ranging from 3.9 m to 4.3 m and MADI ranging from 3.2 cm to 5.0 cm (Kamis and Amran, 1984; Lim, 1988). A similar range of growth rates has been reported for Indonesia (Djazuli *et al.*, 1985; Sudjadi *et al.*, 1985; Priasukmana and Leppe, 1986; Voss *et al.*, 1987); Bangladesh, Costa Rica and Hawaii (NRC, 1983). Growth rates in the Philippines were among the poorest reported on some sites but comparable on others, with MAHI ranging from 0.6 m to 3.4 m, and MADI ranging from 0.5 cm to 3.8 cm (NRC, 1983; Dalmacio, 1987).

Biomass studies on *Acacia* in Sarawak are limited to trees under five years of age. Lim and Basri (1985) reported the aboveground biomass of a 3.5 year old plantation, at a spacing of 3 m x 3 m, to be 54.4 t/ha. Lim (1985) extrapolated the biomass of 3.5 year old open grown *Acacia* to represent plantation conditions estimating biomass to be 64.1 t/ha or a mean annual biomass increment (MABI) of 18.3 t/ha/year. The soils for both sites were Red-Yellow Podzolic. Growth in a 4.5 year old *Acacia* plantation was estimated at 82.1 t/ha with a MABI of 18.2 t/ha/year (Lim, 1986), indicating an insignificant change in MABI between 3.5 and 4.5 years of age. A four year old *Acacia* plantation in West Malaysia was estimated to have a biomass of 80.4 t/ha or a MABI of 20.1 t/ha/year (Lim, 1988). This was the only study reporting litter biomass under *Acacia* plantations. Litter production was estimated at 10.2 t/ha/year or an accumulation rate of 7.1 t/ha, 85 percent of which was made up of leaf litter.

Nutrient content studies were carried out in Sarawak by Butt and Ting (1983); however, they only included a foliage analysis. Nutrient content of foliage was: 2.9% N, 5803 ppm K, 3256 ppm Ca, 1370 ppm Mg, 795 ppm P. Similar results were found in other *Acacia* species in Japan (Anon., 1979). Kurosaki (1988) studied nutrient content of eight month old *Acacia* in Sabah that had been fertilized at various rates. Another study (Sim and Nykvist, 1991) examined the nutrient content of 1.5 year old *Acacia*, also in Sabah. The range of these nutrient concentrations are summarized in Table 1.

Table 1. Percent nutrient concentrations of *Acacia mangium* in Sabah.

	Nitrogen	Phosphorus	Potassium (Percent)	Calcium	Magnesium
8 months *					
Foliage	1.10 - 1.20	-	0.15 - 0.29	0.23 - 0.43	0.03 - 0.05
Stem	0.67 - 1.57	-	0.16 - 0.21	0.18 - 0.26	0.04 - 0.06
1.5 years **					
Foliage	2.4 - 3.1	0.07 - 0.18	1.2 - 1.8	0.25 - 0.55	0.05 - 0.15
Twigs	0.4 - 1.3	0.02 - 0.10	0.7 - 1.8	0.20 - 0.30	0.02 - 0.25
Branches & Stem	0.4 - 0.6	0.01 - 0.04	0.3 - 0.9	0.10 - 0.25	0.02 - 0.04

* Kurosaki (1988)
** Sim & Nykvist (1991)

Generally, N was found in the highest concentrations followed by Ca, K and Mg in that order, for eight month old trees. For 1.5 year old trees the sequence of nutrient concentrations was N>K>Ca>Mg>P with the exception of the branches and stem component where K was sometimes found in higher concentrations than N. Foliage had the highest nutrient concentrations followed by twigs and then branches and stems. Nutrient concentrations in the eight month old trees were found to be low compared to other *Acacia* species growing elsewhere; however, Kurosaki (1988) concluded that this was due to the young age of the study trees.

2.5.2 *Gmelina arborea*

Gmelina arborea is a medium to large sized tree of the Verbenaceae family, native to India, Burma, Indo-China, Pakistan, Nepal and Southern China. It grows best in wetter monsoonal areas below an altitude of 1000 m, but tolerates an annual range of rainfall between 750-4500 mm (Butt and Sia, 1982). It is a long lived pioneer species which in its natural range often takes advantage of gaps created in a forest canopy (Endacott and Esteban, 1977).

Growth rates of *Gmelina* vary considerably with soil type and site quality. There are no published growth rates for *Gmelina* in Sarawak; however, in Sabah reported MAHI ranges from 3.7 m to 4.8 m and MADI ranges from 3.5 cm to 5.0 cm for four to five year old trees (Tan and Jones, 1982; Tan and Sim, 1986). Tan (1986) reported growth rates of *Gmelina* planted on sites of differing disturbances including: disturbed, undisturbed, burned and unburned. Two year old trees attained total heights ranging from 4.5 m to 6.9 m and diameters from 4.9 cm to 9.6 cm. Three to seven year old trees had MADIs ranging from 1.6 to 3.7 cm. The best growth rates for trees aged from six months to seven years were on sites that were burned prior to planting, followed by trees planted on undisturbed sites. The poorest growth rates were attained on either unburned or disturbed sites.

Mean annual height increments in West Malaysia are reported to range from 1.1 m to 1.9 m and MADI to range from 1.8 cm to 3.1 cm for one to three year old trees (Kamis and Amran, 1984); MAHI ranged from 2.3 m to 3.4 m and MADI ranged from 2.4 cm to 2.6 cm for seven to eleven year old trees (Freezaillah and Sandrasegaran, 1966).

Biomass studies on *Gmelina* have been carried out in various countries including Costa Rica, Nigeria and Brazil. Biomass studies in Nigeria reported total biomass ranging from 63.4 to 161.0 t/ha, or a MABI of 7.3 to 24.8 t/ha/year for 5.5 to 14.5 year old *Gmelina* (Chijioke, 1980; Akachuku, 1981). Five year old *Gmelina* in Costa Rica attained a total biomass of 70 t/ha, or a MABI of 14 t/ha/year (Rose and Salazar, 1983). Total biomass reported for studies in Brazil ranged from 55.9 to 122 t/ha, or a MABI of 9.3 to 20.0 t/ha/year for 6 to 8.5 year old trees (Chijioke, 1980; Russell, 1987). The differences in biomass were not necessarily a result of age. For example, in Brazil, two plantations of the same age on different soil types, resulted in more than twice as much biomass on a more fertile soil. Other *Gmelina* plantations in Brazil indicate considerably lower average growth rates for many areas at 3 to 6 t/ha/year (Schmidt, 1981).

Nutrient accumulation of *Gmelina* varies considerably. In Brazil the order of nutrient uptake was N>K>Ca>Mg>P, while in Nigeria it was K>Ca>N>Mg >P, with the amounts of nutrients taken up also varying considerably (Chijioke, 1980). The highest percent nutrient concentration was found in foliage followed by bark, branchwood and stemwood (in that order) with the exception of Ca in bark which was higher or as high as that in foliage. The nutrient content (as a percent of dry weight) was lower in older stands than younger stands and N, P, K and Ca content of biomass was higher on fertile soils while Mg content was lower. The range of mean annual nutrient uptake for aboveground biomass of 5.5 to 14.5 year old trees (in kg/ha) was 14.1-74.2 N, 1.4-10.5 P, 14.3-188.9 K, 7.0-100.5 Ca and 3.4-16.7 Mg (Chijioke, 1980). This broad range of nutrient uptake results from a combination of plantation age, total biomass and site fertility.

2.5.3 *Leucaena leucocephala*

Leucaena has been widely studied throughout the tropics, mainly because of its value as a nitrogen fixing species and its numerous uses in agroforestry. A very broad range of growth rates has been reported for *Leucaena* because of its many genetic varieties that greatly differ in size and form. There are over 800 known varieties (NRC, 1984); however, these can be classified broadly into three main types (Brewbaker *et al.*, 1972). The Hawaiian genetic type includes bushy varieties reaching heights of 5 m. The Salvador type is tall, tree-like and attains heights of 20 m. It is also known as the "Hawaiian Giant" or by the designators K8, K28 or K67. The third group is the Peru type which attains heights of 15 m, but has more extensive branching than the Salvador type (NRC, 1984).

Leucaena has several limitations in that it prefers lowland tropics (below 500 to 1000 m asl), depending on latitude; it requires a reasonable mineral balance in the soil, and is intolerant of acidic soils (Oakes, 1968) or soils with a high Al content. On acidic or high Al soils, characteristic of Ultisols and Oxisols in Malaysia and other tropical regions, *Leucaena* does not perform well. Ahmad and Ng (1981) found that height growth rates declined by as much as five to nine meters with increasing soil acidity after two years growth. They suggested the critical level, below which growth was not satisfactory, appeared to be between pH 4.4 and 4.7. Durst (1987) reports that *Leucaena* grows poorly when soil pH is below 5.5 and at altitudes above 500 m. *Leucaena* is also a slow starter, generally requiring weed free conditions for establishment (NRC, 1984). On favourable sites it has attained mean annual height increments of three to six meters (Ahmad and Ng, 1981; Van Den Beldt, 1983) and mean annual diameter increments of 2.6 cm to 4.6 cm after three to eight years (Van Den Beldt, 1983; NRC, 1984).

Numerous biomass studies on *Leucaena* have been carried out; however, many only report foliage biomass (for fodder or mulch production) or branchwood biomass (for fuelwood production). As a fodder producer *Leucaena* (K8) has been found to produce between 30.3 and 198.1 t/ha/year of leafy vegetation at various densities between ages of one to three years, in India (Desai *et al.*, 1988; Ponammal and Gnanam, 1988).

The use of *Leucaena* in Malaysia has been somewhat limited; therefore, few studies, to date, have been carried out. *Leucaena* planted as a shade tree with *Tectona grandis* in West Malaysia attained a mean height of 9.4 m on better sites and 3.8 m on poorer sites 29 months after establishment and at a spacing of 3 m x 3 m (Ng *et al.*, 1983).

Nutrient content in *Leucaena* foliage and fine stems are reported to have the following percentages of nutrients in dry weights: 2.2-4.3 N, 0.2-0.4 P, 1.3-4.0 K, 0.8-2.0 Ca and 0.4-1.0 Mg (NRC, 1984). These values would be slightly higher for samples of foliage only.

2.6 Soils

Soils under tropical rain forests are generally poor in nutrients; thus, a lush forest growth does not reflect an inexhaustible supply of soil nutrients (Bullock, 1969). Generally, tropical soils have a relatively low nutrient storage status, low pH and tend to be relatively high in aluminum content (Andriesse, 1972). Reported ranges of chemical concentrations in soils under Malaysian MDFs are as follows: 0.3-11 % C; 0.04-0.51 % N; 100-240 ppm total P; 0.047-0.54 me/100 g soil K; 0.018-0.55 me/100 g soil Ca; 0.039-0.35 me/100 g soil Mg 2.5-37 me/100 g soil C.E.C. and 4.1-4.7 pH (Ashton, 1964; Allbrook, 1973; Proctor *et al.*, 1983a). Some of the variation in these nutrient concentrations results from samples being taken from different soil depths; however, all concentrations were within the top 30 cm of soil.

Proctor *et al.* (1983a) calculated the weight of nutrients within the top 30 cm of RYP soils (Merit family) under a MDF in Sarawak as 99 t/ha C; 6000 kg/ha N; 360 kg/ha P; 96 kg/ha K; 4.6 kg/ha Ca and 22 kg/ha Mg. Prior to disturbance by man the rain forest and its underlying soils exist in a nearly closed nutrient cycle where most nutrients are stored in the biomass and topsoil (Jordan, 1985). Greenland and Kowal (1960) found that two-thirds of the root systems in Nigerian soils were found in the top 20 to 30 cm of soil, suggesting that the subsoil plays a secondary role in the nutrient cycle.

Research has been carried out on the effects of shifting cultivation and the subsequent fallow phase on soil in Thailand (Nakano, 1978; Sabhasri, 1978; Zinke *et al.*, 1978; Kyuma *et al.*, 1985; Tulaphitak *et al.*, 1985a, 1985b), Indonesia (Arimitsu, 1983); Malaysia (Andriesse, 1977; Hatch, 1983), and Nigeria (Lal *et al.*, 1975; Adedeji, 1984). The reported effects of clearing, burning and cultivation include increased soil temperature; increased rate of organic matter decomposition; increases in the amount of rain reaching the soil; increased evapotranspiration; variable effects on soil physical properties and infiltration rates; increased bulk density; and increased to severe erosion. Red-Yellow Podzolic soils have an infiltration rate of 7.4 to 23.6 cm per hour and suffer readily from compaction; soils having coarser textured topsoils can present serious erosion problems (Sanchez, 1976). Organic matter in the top 20 cm of soil was also found to decrease by 25 percent during the first two years after clearing and burning (Cerri *et al*, 1991). This decrease was due to humus of forest origin decomposing faster than additions of humus from agricultural origin. This is a critical loss since soil organic matter is the main exchange surface in humid tropical soils (Cerri *et al.*, 1991).

After a forest is cleared and burned mineral elements are released into the soil by rapid oxidation and by deposition of ash (Ovington, 1968; Adedeji, 1984; Buschbacher, 1987). Increases were reported to be slight for N, P and K and large for Ca and Mg (Jordan, 1987; Scott, 1987). However, Andriesse (1977) and Kyuma *et al.* (1985) reported large increases in K and available P. Stock and Lewis (1986) found a significant increase in total N content down a 200 cm profile after fire. The increase in N from ash deposit was 66 kg/ha; however, this began to decrease in the months following the fire. They also noted a flush of ammonium immediately after burning at the soil surface but this was of short duration. Guha (1969) found that after fire organic N was rapidly converted to soluble nitrate form. Soluble nitrate in the top 30 cm of soil in an undisturbed forest increased by 22 to 135 kg/ha after clearing and burning. However, it was also estimated that 148 kg/ha of N may be lost from the top 30 cm of soil through leaching within three weeks. Jordan (1989) also reported a flush of ammonium and nitrate immediately after clearing and burning.

Forest burning also resulted in increased pH which begins to drop within four months (Tulaphitak *et al.*, 1985) but still remains higher than normal levels after five years of cultivation (Martins *et al.*, 1991). Available nutrients, however, rapidly decline from the enhanced levels after initial burning (Eden *et al.*, 1991). Exchangeable bases released from ash material are translocated through the profile for at least the first year of cultivation (Brinkmann and Nascimento, 1973). Higher pH levels associated with more bases contribute to increased C.E.C. and clay mineral dispersion (Gombeer and d'Hoore, 1971); however, this effect is limited to the upper 35 cm of soil and effects diminish with increasing length of cultivation. Stocks of Ca and Mg begin to decline during cultivation while N, P and K begin to decline after abandonment (Scott, 1987). Jordan (1987) reported that P began to decline during cultivation; however, leaching losses were not appreciable because soluble P is rapidly fixed by iron and aluminum to form insoluble compounds. These compounds are not readily available to many agricultural plants; thus, P deficiency is often a problem in tropical agriculture (Olson and Engelstad, 1972).

Reports on nutrients in soil after abandonment and during the fallow phase vary somewhat due to differences in site conditions, climate, soil types and experimental techniques. In general P was found to show little change throughout the recovery period but tended to decrease slightly as biomass increased (Zinke *et al.*, 1978; Saldarriaga, 1986; Scott, 1987). Nitrogen was found to decrease for up to ten years during fallow probably because losses due to volatilization and leaching were greater than atmospheric inputs (Zinke *et al.*, 1978; Saldarriaga, 1987). However, Scott (1987) reported continued decline in N for up to 30 years of fallow.

Calcium stocks were reported to drop for the first three to seven years (Andriesse, 1977; Zinke *et al.*, 1978) but then to increase with forest maturity (Scott, 1987). However, Saldarriaga (1987) reported decreases in Ca for the first 35 years of recovery. Potassium and Mg were reported to decrease slightly in the first two to three years and then to slowly increase during 30 years of recovery (Scott, 1987). Saldarriaga (1987) reported continued slight losses and a levelling off towards 80 years of recovery, followed by increases as forest maturity was approached.

During early succession (two to eight years) Buschbacher *et al.* (1988) found that the largest organic matter and nutrient stocks were contained in the soil for all nutrients except K. They found that 48 to 97 percent of nutrients were in the soil except for K, 75 percent of which was contained in the living biomass. In general the effects of the fallow phase are that nutrients in the soil are taken up and immobilized in the biomass. If the fallow forest is left to mature, eventually nutrient stocks, with the exception of N, will increase in the biomass to a proportion that is greater than that in the soil (Zinke *et al.*, 1978; Saldarriaga, 1986). It is likely that many of the above effects are similar under Malaysian conditions; however, due to differences in soil types and climate the extent to which they occur is not known.

3.0 THE STUDY AREA

3.1 Location

The study was carried out in Niah Forest Reserve (F.R.) and Sawai Protected Forest (P.F.), Sarawak, Malaysia; Figure 1 shows the general location of the study area. The control plots (undisturbed primary forest and logged over forest), the cleared and burned plots (two days, two weeks and one month after clearing and burning) and the abandoned plots (1.5 years after abandonment) were located in Sawai P.F. The plantation and fallow plots were located in Niah F.R.

The plots in Niah F.R. were located at 3° 40' North and 113° 44' East, 106 km Northeast of Bintulu on the Bintulu-Miri Road. Appendix I (Figure A.3) shows the location of the plantation and fallow plots. In Sawai P.F., the logged over forest plots were located at 3° 26' North and 113° 51' East, and the undisturbed primary forest plots were located at 3° 34' North and 113° 44' East. The location of the UPF and LOF plots are shown in Appendix I (Figures A.1 and A.2, respectively); the burned and abandoned plots were located at 3° North and 113° East.

3.2 Climate

Sarawak lies within the tropical monsoon belt where climate is largely influenced by the Indo-Australian Monsoon (Whitmore, 1984). In global classification, Sarawak's climate is of the equatorial perhumid type (Bailie, 1978). It is characterised by heavy rainfall ranging from 3048 mm to 5588 mm per annum, a mean annual temperature of 26° C and a high relative humidity (Anon, 1980). Rainfall intensity can be very high often exceeding 100 mm per hour (Hatch, 1982) indicating potential erosion problems. The rainy and dry seasons are not very well defined but generally the Northeast Monsoon brings heavier rains from November to February. June through August are relatively dry months due to the rain shadow effect of the Sumatran mountain range and the East-west mountain range in Borneo (Whitmore, 1984).

Mean annual rainfall for the Niah F.R. and Sawai P.F. area, calculated from 1980 to 1985 data (the major growth period for the Niah plots), was 3209 mm. The heaviest mean monthly rainfall during this period was from November to January with a range of 304 mm to 353 mm, while the lowest rainfall occurred from June to August with a range of 138 mm to 212 mm. February also tended to be drier with a five year average of 190 mm. The long term mean annual rainfall, based on 13 years of data prior to 1980 and on

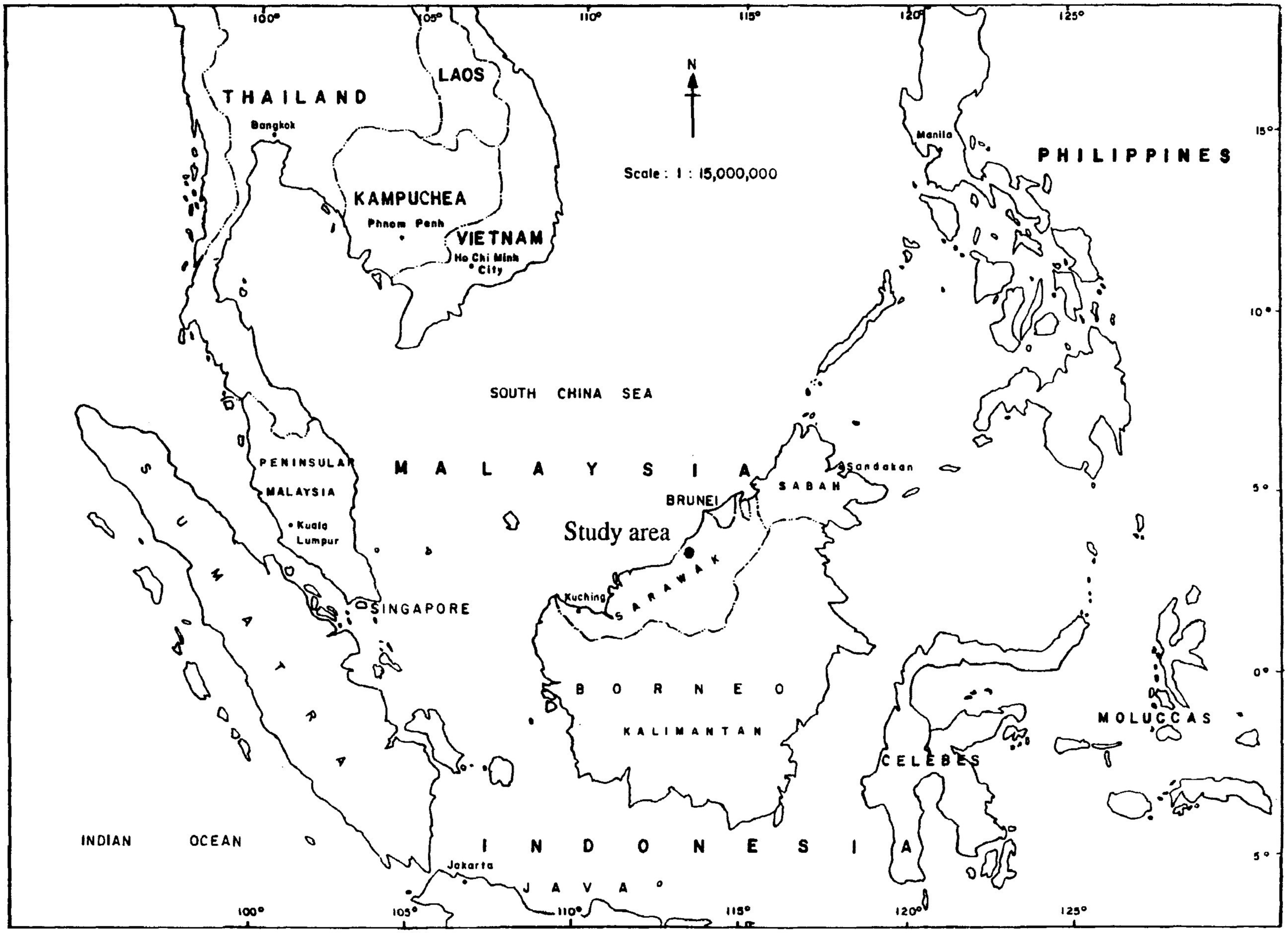


Figure 1. Location of the study area.

isohyetals maps, is estimated to be between 3500 to 4000 mm (Anon., 1980). Figure 2 shows the maximum, minimum and mean monthly rainfall for the area from 1980 to 1985.

Mean annual temperature for the area is 26° C with the monthly means fluctuating less than 2° C. The mean minimum and maximum daily temperature range is 22° to 32° C. Daily relative humidity ranges from 90 to 100 percent in the morning to 67 to 100 percent in the afternoon.

3.3 History of the Study Area

The study site in Niah F.R. was originally logged in 1970 and 1971. Logging activity opened up the area making it more easily accessible; thus, shifting cultivators were soon attracted and settled within the Forest Reserve to farm on logged sites. It is not known how many cycles of shifting cultivation any particular piece of land underwent up until 1980 when the shifting cultivators were finally evicted from the Forest Reserve.

In 1979, the Sarawak Forest Department started reforesting the abandoned shifting cultivation sites within the Reserve. The species used in the reforestation project included *Acacia, Gmelina* and *Leucaena* in plantations and *Araucaria cunninghammi* in line plantations. The remaining abandoned areas were left to regenerate naturally (fallow forest). The control plots, representing areas which had not been affected by shifting cultivation, were located in Sawai P.F. These plots included disturbed primary forest which had been logged once, in 1978, and undisturbed primary forest which had never been logged or disturbed by man.

3.4 Treatments

Two types of control plots were included in the study to represent areas that were not affected by shifting cultivation. The first type was in undisturbed primary hill dipterocarp forest (UPF) representing areas that had not been affected by man. The second type was in logged over hill dipterocarp forest (LOF) which had been harvested using the Malaysian Uniform System seven years prior to this study. Plots representing areas affected by shifting cultivation were established on cleared and burned sites two days, two weeks and one month after clearing and burning and on cultivated sites 1.5 years after abandonment. These four sites were used to examine soil changes due to cultivation practices, but prior to establishment of rehabilitation treatments.

The silvicultural treatments used for rehabilitation of abandoned shifting cultivation sites included *Acacia* and *Gmelina* plantations with tree spacings of 3.7 m x 3.7 m and

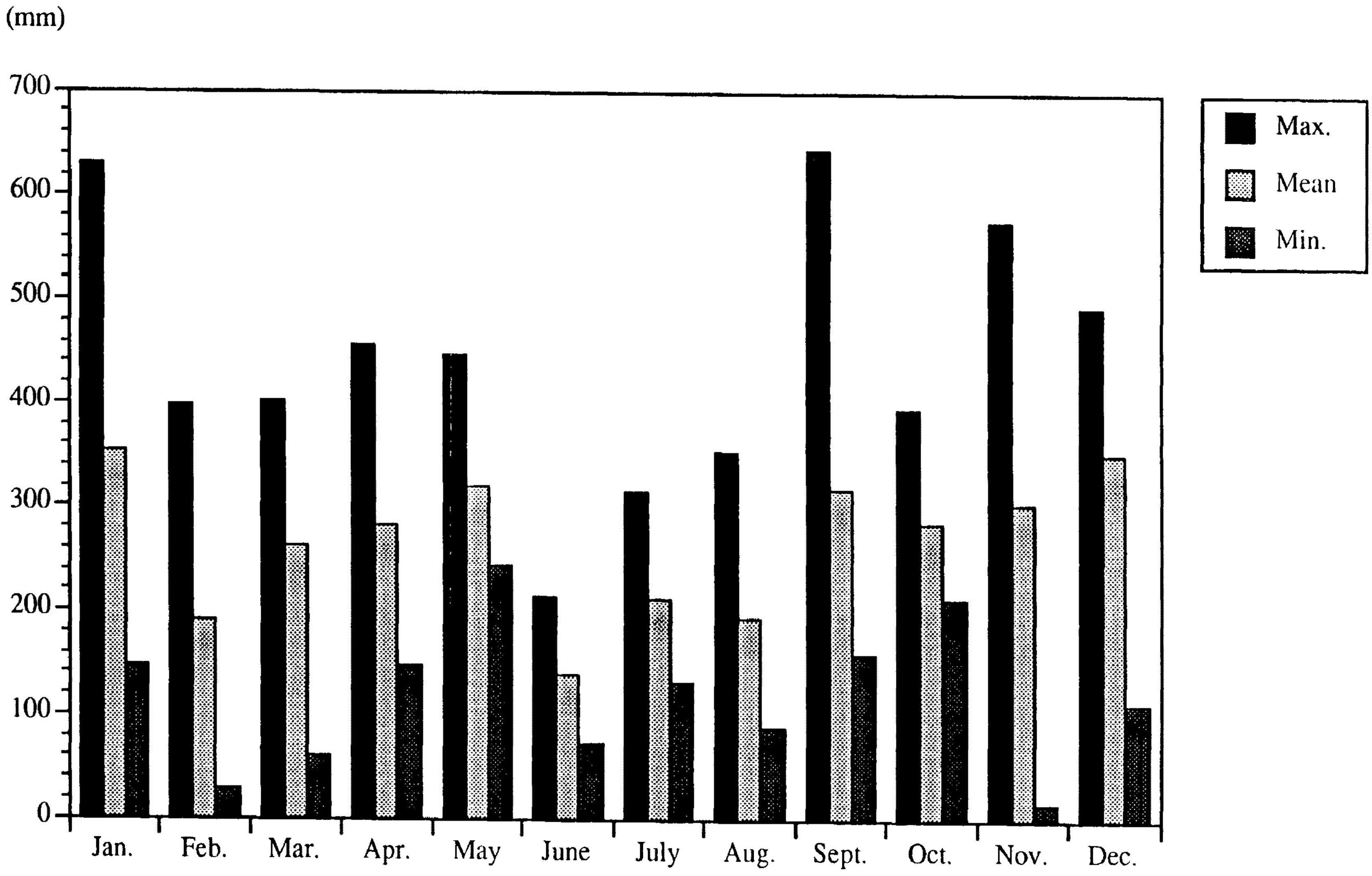


Figure 2. Mean, maximum and minimum monthly rainfall of the study area (1980-1985).

Leucaena with spacings of 1.2 m x 2.4 m. Plantations were 6.5 years of age at the time of study. The fourth rehabilitation treatment was fallow forest (natural regeneration), which was estimated to be between seven and ten years of age.

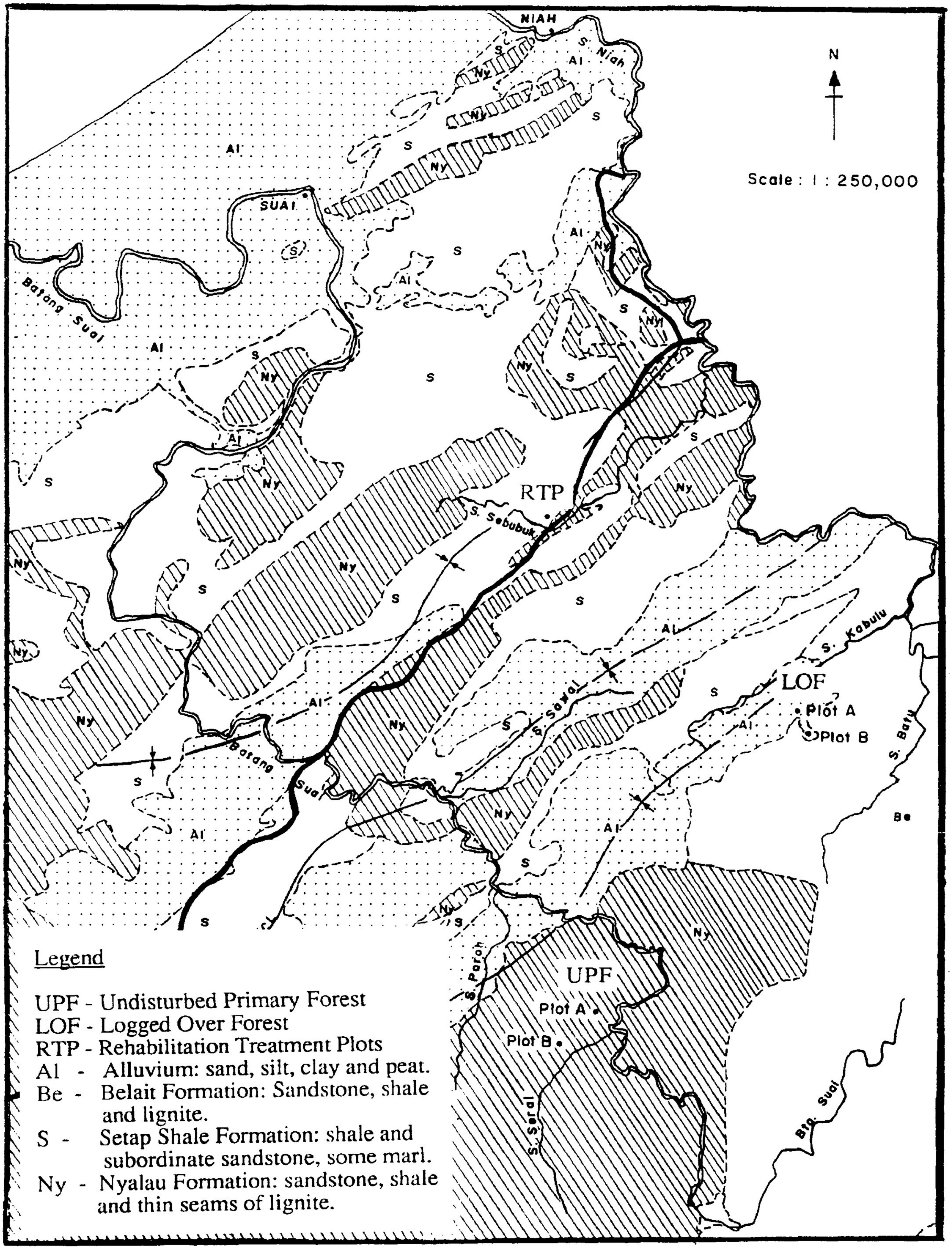
The plots were selected to form a chronosequence representative of shifting cultivation cycles that occur in Sarawak. The plots occur chronologically as follows: (1) UPF, (2) LOF, (3) two days after clearing and burning, (4) two weeks after clearing and burning, (5) one month after clearing and burning, and (6) 1.5 years after abandonment. There are four possible endings to this chronosequence which include the four rehabilitation treatments described above and completing the sequence as follows: (7a) *Acacia*, (7b) *Gmelina*, (7c) *Leucaena* and (7d) fallow forest. The chronosequence in this study is described in further detail in section 4.0.

3.5 Geology

The geological map of the Suai-Baram area (Haile, 1962) shows that plots for the silvicultural treatments in Niah F.R. lie over the Setap Shale Formation, bordering the Nyalau Formation (Figure 3). Haile (1962) describes the Setap Shale Formation as a thick monotonous succession of shale with subordinate sandstone and a few, mostly thin, lenses of limestone. The Niah Valley has slightly more sandy sedimentary layers occurring near the top of the formation, where locally some sandy marlstone and calcareous sandstone are interbedded in sandstone. The formation shows moderate folding. The estimated depth of the formation is 1200 m to 1500 m.

The logged over forest plots are mapped as lying over Alluvium and closely adjacent to the Belait Formation (Figure 3) which is composed of sandstone, shale and lignite. The sandstone is generally fine-grained and massive, the shale grey and often sandy, with lignite appearing as seams. The Alluvium Formation lies along a major syncline axis running in a southwest-northeast direction. From profile descriptions in the logged over forest plots, it appears more likely that the plots were located over the Belait Formation since there was no evidence of alluvial material. However, it should be noted that some Red-Yellow Podzolic soils do lie over old alluvial parent material (Tie, 1982). The Belait Formation occurs in synclinal basins and is more regularly and gently folded than the underlying Setap Shale Formation (Haile, 1962). The estimated thickness of the formation is 2560 m.

The undisturbed primary forest plots are mapped as lying over the Nyalau Formation. Haile (1962) describes this formation as being composed of sandstone and shale, commonly lignitic, with some impersistent beds and lenses of limestone and calcareous



Source: Haile (1962)

Figure 3. Geology of the study areas.

sandstone. The sandstones are often compact and massive, mostly fine to medium grained and white to greyish white. The subordinate interbedded shale is dominantly grey and strongly sandy. The formation has gentle to moderately steep dips and comparatively regular folding. The estimated depth of the formation is about 3000 m.

3.6 Topography

Sarawak is broadly classified into six topographic zones: (a) coastal mangrove and mudflats; (b) peat swamp; (c) recent marine beach deposits and alluvium; (d) recent riverine alluvium; (e) rolling and moderately steep hills; and (f) steep, dissected hilly and mountainous country (Hatch, 1982). The first four categories occupy approximately twenty percent of the land area in Sarawak. Rolling and moderately steep low hills (ranging from 15^{o} to 30^{o}) occupy about ten percent of the area while steep hilly and mountainous country (slopes in excess of 30^{o}) occupies over seventy percent of the land area (Hatch, 1982). It is in the latter two areas (eighty percent of the land area of Sarawak) where shifting cultivation predominates (Hatch, 1982).

3.7 Soils

The soils of Sarawak are classified into eleven local soil groups (Tie, 1982). These include: (a) organic, (b) skeletal, (c) Thionic, (d) gley, (e) arenaceous, (f) alluvial, (g) Podsols, (h) Andisols, (i) Oxisols, (j) Grey-White Podzolic and (k) Red-Yellow Podzolic (RYP) soils. All biomass plots in this study were situated on soils of the RYP soil group; the RYP soils are dominant in the uplands and are derived mainly from sedimentary rock (Scott, 1985). The distinguishing feature of RYP soils is a 'textural B' or 'argillic' horizon in the subsoil that has at least 1.2 to more than double the amount of clay found in the topsoil (Burnham, 1984). By definition RYP soils have a base saturation of less than 35 percent in the subsoil (Burnham, 1984). In general, parent materials are low in bases and have few easily soluble components. Base saturation is commonly below ten percent and averages less than thirty percent in the surface horizons. Exchangeable cations are highest in the topsoil and the topsoil generally shows a positive relationship between pH and the carbon-nitrogen ratio (Scott, 1985). There is generally some evidence of illuviation of clay in the B and C horizons and RYP soils are strongly affected by leaching.

The RYP group is further classified into several families based on texture and colour. The soils in this study are in the Merit, Bekenu or Nyalau families. The Merit family has a "fine" clayey particle-size class while the Bekenu family has a fine loamy or fine silty particle-size class and is derived from sedimentary rock. The Nyalau family has a coarse loamy or coarse silty particle-size class.

The Merit family is further divided into six soil series based on drainage, colour class, and cation exchange capacity. Merit family soils included in this study are classified as Merit, Begunan or Jakar series. The Merit series includes soils that have a cation exchange capacity greater than 24 me/100 g of clay in the major part of the B horizon and have a yellow colour class. The Begunan series is similar to the Merit series but has a red colour class. The Jakar series is not yet well defined and is described as other Merit family soils that have a red colour class. The Bekenu family is divided into three soil series, however, only the Bekenu and Sarikei series were found in this study. The Bekenu series soils are described as having a yellow colour class; a fine loamy particle-size class and are residual. The Sarikei series is the same as the Bekenu series, but has a red colour class. The Nyalau family is also divided into three series classes; however, only the Nyalau series was found in this study. Nyalau series soils are described as having a yellow colour class and a coarse loamy particle-size class.

The equivalent classification of Red-Yellow Podzolic soils, based on the FAO world soil map legend (FAO, 1974), is either Dystric Nitosols or Cambisols. However, these soils are correlated with Nitosols based on clay distribution patterns. Since many Sarawak soils have a cation exchange capacity of less than 24 me/100 g of clay they may be more closely correlated with Ferric Acrisols (Tie, 1982). Sanchez (1976) correlates them as Acrisols and Dystric Nitosols.

The USDA soil classification system (USDA, 1975) classifies Red-Yellow Podzolic soils as Ultisols of the subgroup Typic Paleudults or Inceptisols of the subgroup Dystropepts (Tie, 1982; Scott, 1985). The soil moisture regime is classified as "perudic" and the temperature regime is described as "isohyperthermic" (USDA, 1975).

4.0 METHODS

4.1 Treatments

The difficulty in monitoring long-term forest recovery in a single stand through the entire time span, from initial disturbance to completion of recovery, is that the recovery process is slow, thus requiring many years of study. Saldarriaga (1987) observed that a practical solution to this problem is to study a chronosequence of sites that appear to have been similar prior to disturbance. A chronosequence is a set of samples, taken at a single time, which represent several stages of succession or forest development. The assumption of this approach is that all of the study sites had relatively uniform soil and site conditions before the disturbance. The main limitation to this type of study is that treatments are confounded with sites; this may lead to problems in separating the differences due to treatment from inherent site differences. However, since time span was a problem in this study the chronosequence method was selected as the practical approach to use.

This study included plots representing ten conditions ranging from undisturbed forest conditions, logged over forest, areas subjected to clearing and burning, forest plantations and fallow forest (Table 2). Two types of control plots were included to represent areas that were not affected by shifting cultivation. The first type of control plots were in undisturbed primary hill dipterocarp forest (UPF) representing areas that have not been affected by man. The second type of control plots were in logged over hill dipterocarp forest (LOF) which had been harvested using the Malaysian Uniform System, seven years prior to commencement of this study. Both UPF and LOF are considered control plots because shifting cultivators may clear and burn either type for cultivation, although in recent years LOF has been more commonly used for cultivation. Inclusion of both plot types allows a comparison of either scenario.

Plots representing the shifting cultivation phase were located on forest sites that had been recently cleared and burned for cultivation including: two days after clearing and burning (2DAB), two weeks after clearing and burning (2WAB), and one month after clearing and burning (1MAB). Plots were established on sites 1.5 years after abandonment (1.5YAA) to represent site recovery conditions after cultivation had been abandoned. The 1.5YAA plots are also representative of site conditions present when the rehabilitation treatments were established. The purpose of these plots was to monitor changes in the soil due to clearing and burning of forest cover and abandonment after cultivation. Plots on sites during cultivation were not available.

Table 2. Soil type, slope and aspect of the study plots.

Treatment	Plot	Soil Type		Slope		Aspect
		Family	Series	Position	Steepness	
Undisturbed Primary Forest	A	Merit	Begunan	Mid-slope	11°	E
	B	Merit	Merit	Upper slope	20°	NNW
	C	Bekenu	Sarikei	Mid-slope	17°	SE
Logged Over Forest	A	Merit	Begunan	Upper slope	12°	NW
	B	Merit	Begunan	Upper mid-slope	5°	W
Two Days After Clearing & Burning	A	Merit	Jakar	Mid-slope	22°	SSE
Two Weeks After Clearing & Burning	A	Bekenu	Bekenu	Mid-slope	19°	NNE
One Month After Clearing & Burning	A	Merit	Jakar	Mid-slope	20°	SSW
	B	Bekenu	Bekenu	Mid-slope	20°	ENE
1.5 Years After Abandonment	A	Bekenu	Bekenu	Mid-slope	15°	NE
	B	Nyalau	Nyalau	Mid-slope	15°	NE
Acacia mangium	A	Merit	Begunan	Mid-slope	11°	NW
	B	Merit	Begunan	Mid-slope	19°	ENE
Gmelina arborea	A	Merit	Begunan	Mid-slope	11°	WSW
	B	Merit	Begunan	Mid-slope	21°	SW
Leucaena leucocephala	A	Merit	Begunan	Mid-slope	14°	NW
	B	Bekenu	Bekenu	Lower mid-slope	14°	NW
Fallow Forest	A	Merit	Begunan	Mid-slope	24°	ENE
	B	Merit	Begunan	Upper mid-slope	15°	W

Plots representing the recovery phase included plantations of *Acacia* and *Gmelina* at spacings of 3.7 m x 3.7 m, and *Leucaena* at a spacing of 1.2 m x 2.4 m; plantations were 6.5 years of age at the time of study. A fourth recovery condition was fallow forest (natural regeneration) which was estimated to have been abandoned between seven to ten years prior to this study. The plantations were fertilized with NPK (14-14-14) immediately after planting. Plantations were tended and fertilized three months, six months and twelve months after planting. Fertilizer was applied at a rate of approximately 60 g per tree in a radial trench that was 2 cm deep and had a radius of 15 cm from the tree stem. The *Acacia* and *Gmelina* were planted at a rate of 750 trees per ha, thus resulting in an application rate of 45 kg per ha. The *Leucaena* were planted at a rate of about 3500 trees per ha resulting in a much higher application rate of 210 kg per ha. Fallow forest did not receive any fertilizer or tending treatments.

The plots in this study are arranged chronologically as follows: (1) UPF, (2) LOF, (3) 2DAB, (4) 2WAB, (5) 1MAB, (6) 1.5YAA, (7a) *Acacia*, (7b) *Gmelina*, (7c) *Leucaena* and (7d) Fallow forest. Plots 7a through 7d represent four possible rehabilitation treatment options or conclusions to the chronosequence after shifting cultivation sites have been abandoned. Plantations were established one to two years after abandonment by cultivators; consequently, the purpose of the 1.5YAA plots is to represent the soil conditions at the time the plantations were established. The fallow forest plots were slightly older than the plantation plots in order to include the 1.5 year period of recovery that is left intact when sites are left to natural regeneration.

4.2 Plot Establishment and Layout

A topographic and general soil survey was carried out in the Niah Forest Reserve on the plantation and fallow forest sites, and in the Sawai Protected Forest on UPF and LOF sites in order to identify areas having similar soil types and slopes. The preferred location was at midslope with a slope ranging between 10^o and 25^o. Table 2 indicates the characteristics of the ten study areas.

A general soil survey was carried out by taking auger samples at tentative plot locations. Red-Yellow Podzolic soil of the Merit family was found to be the most common soil; therefore, it was selected as the soil type for study. A more intensive auger survey was then carried out within the identified areas, and biomass plots were established.

Plots were 10 m x 20 m in size with plots running parallel to plantation lines and where possible horizontally across the slope. Boundaries were marked with corner posts and string. Two replicates were established on each treatment site.

Control plots in UPF and LOF were established in the same manner in the Sawai Protected Forest. However, larger plots (100 m x 100 m in size) also were established for enumeration and estimation of tree biomass in the greater than 30 cm dbh class. Due to the large plot size and undulating topography, slope position could not be taken into account in the survey of the UPF and LOF plots.

4.3 Experimental Design

This project was planned as a case study in Sarawak; therefore, any conclusions will be limited to the area and sites where studies were carried out. Plantation plots were limited to replicates within the same plantations because these were the only plantations available for the selected age group. Plots were not established completely at random because of limited plantation sizes on the selected soil type and because plots were confined to areas having similar soil and slope position. In order to minimize the effects of external factors affecting growth rates plots were selected, as much as possible, within the following criteria: soil group was Red-Yellow Podzolic, in the Merit family, in the Merit or Begunan series; plots were to be located as close to midslope as possible and were within a slope range of 10^{o} to 25^{o}.

Since plots were not located completely at random valid statistical analyses could not be carried out. A further limitation to the chronosequence approach, as noted above, is that treatments are confounded with sites. The main assumption, when employing this type of study, is that all sites were similar prior to disturbance by man. However, this assumption may not always be valid under the existing soil conditions. The main difficulty in any chronosequence study lies in determining whether the results or effects are actually due to the treatments or whether they are due to inherent site differences. This difficulty has been reduced as much as possible, in this study, by way of careful site and plot selection.

All ten treatment plots were sampled for soil conditions to examine the effects of shifting cultivation and rehabilitation treatments on soil throughout the chronosequence. However, biomass and biomass nutrient content sampling were only carried out in the forest plots including UPF, LOF and the four rehabilitation treatments. Biomass studies were not done on the cleared and burned sites since there was little or no living biomass remaining. Biomass studies on the 1.5YAA plots were not carried out because they were considered an earlier stage of the fallow forest plots.

4.4 Biomass Sampling

4.4.1 Litter

A five percent survey was carried out within each 10 m x 20 m plot to measure the small-litter standing crop. The term small-litter standing crop is used to differentiate between annual litterfall, which is measured in litter traps at regular intervals, and the "litter standing crop" which is found on the forest floor at any given point in time (Proctor *et al.*, 1983b). Small-litter standing crop, in this study, refers to all litter, including dead branches ($\leq$ 3 cm diameter over bark), present on the forest floor at the time of survey. Ten 1 m x 1 m subplots were drawn on graph paper with subplot locations determined using random number tables. In the field, the litter subplots were marked on the ground with 1 m x 1 m wooden frames. All small litter was collected from each plot and taken to the laboratory for air-drying, sorting, oven-drying and weighing. Litter was sorted into the following categories: fruit and flowers, tree leaf litter, plant leaf litter, woody litter, and trash (trash refers to all unrecognizable material). Each category was oven-dried at 65° C to a constant weight and the oven-dry weight was recorded. Subsamples were also taken for nutrient analysis.

4.4.2 Undergrowth

A five percent survey was carried out on lower vegetation in each 10 m x 20 m plot using the same 1 m x 1 m subplots as in the litter survey. All vegetation was collected by cutting at ground level, and then sorted into the following categories: grass, ferns, rattans, non-woody plants, woody plants, non-woody vines and woody vines (all having a dbh < 1 cm where applicable). Each category was fresh weighed and subsamples were taken for oven-dry weight determination and nutrient analysis. Samples of each species were collected for identification.

4.4.3 Tree Understorey

In the case of fallow, logged and undisturbed primary forest plots, 10 m x 10 m subplots were randomly located in one half of each 10 m x 20 m plot for the purpose of harvesting woody vegetation having a diameter at breast height (dbh) of 1 to 3 cm. This woody vegetation was separated into categories of either saplings or vines and further separated into foliage and stem components. Each component was fresh weighed and subsamples were taken for oven-dry weight determination, nutrient analysis, and species identification. Understorey plots were not used in the plantation plots because tending treatments had removed this vegetation class.

4.4.4 Overstorey

All trees and vines with a dbh of > 3 cm within the 10 m x 20 m plot boundary were tagged and assigned a number. The dbh, stem identity class and mean crown diameter (by projection to the ground) were recorded. The location of each tree was mapped on graph paper for future reference. Smaller trees were harvested first to prevent damage by larger trees during felling. All trees were cut to ground level; no roots were harvested.

Small trees were cut directly at ground level and then separated into vegetative components for fresh weighing. However, for large trees, this was done in stages. Before felling, a tree climber ascended the tree and removed dead branches which were collected and weighed. The climber would then proceed to remove live branches, in stages, for up to eighty percent of the tree depending on the type of crown and foliage. Branches were collected, separated into vegetative components and fresh weighed. This method was used to maintain a higher level of accuracy per individual tree in determining total fresh weight. Advantages, in contrast to directly felling the tree, were that each tree sustained less damage and there was less confusion as to where fallen leaves and branches had originated. Separating the tree into vegetative components was a very time consuming process; therefore, harvesting in stages reduced the amount of air-drying and sap loss from branches and stem sections prior to determining fresh weight.

Once a tree was felled, the total height, crown length and stem diameter at mid-height were recorded. The tree was then separated into the following components:

1) Fruit and flowers - all reproductive parts
2) Foliage - including petiole
3) Twigs - less than 1 cm dob
4) Small Branches -1 to 3 cm dob
5) Large Branches - greater than 3 cm dob
6) Dead branches
7) Stem

The fresh weight of each vegetative component was determined directly after separation was completed. Bark weight was estimated by separating wood and bark in the stem subsamples, weighing separately and calculating percent weight of the total stem sample.

Subsamples of each component were taken for determination of oven-dry weight, nutrient analysis and species identification. The method of taking subsamples differed for some treatments due to variation in tree size and the number of trees and species per plot. For *Acacia* and *Gmelina* , subsamples were taken for each component of one dominant, one suppressed and three average trees. Status was based on tree height, dbh and crown size. Nutrient samples were likewise taken except that only one average tree was sampled and composite samples were made up of the three subsamples (i.e. one dominant, one suppressed and one average tree).

Composite samples were taken in the *Leucaena* plots because of small tree size and poor growth rates due to suppression by the undergrowth. Composite samples also were taken in the fallow, logged and undisturbed primary forest plots because of the large number of trees per plot and the great variation in number and species of trees. No sampling was done after rainfall or when vegetation was wet with dew.

Fresh weights were taken to the nearest 10 g for small component parts using a 10 kg x 10 g capacity spring scale. Stem sections and large branches were weighed to the nearest 100 to 500 g using Salter spring scales with capacities of 100 kg x 500 g or 50 kg x 200 g. Subsamples for oven-dry weight determination were taken to 0.1 g using an Ohaus triple beam balance, 2610 x 0.1 g. The number of subsamples taken for each component varied with availability but generally three samples were taken for leafy vegetation and five samples for woody components. For tree components in nonplantation treatments, five or more composite subsamples were taken because of the variation in species and tree size. One subsample was taken for fruit and flowers if available. The minimum weight for foliage, twig and dead branch subsamples was 500 g while all other subsamples were a minimum of 1000 g.

Subsamples were kept in paper envelopes and stored in a field oven for drying until they could be transported back to the laboratory for oven drying and nutrient analysis.

4.4.5 Extension Plots

Extension plots of 100 m x 100 m in size were located in logged and undisturbed primary forest for enumeration of larger trees. All trees > 30 cm dbh were tallied and given a number. Data collected for each tree included total height, crown length, dbh or diameter above the buttress, buttress height, stem identity class and species name. Biomass of trees in extension plots were determined by using several empirically validated regression equations for foliage, branches and stem (Kato *et al.*, 1969; Kira, 1978; Anon *et al.*, 1978). Biomass of stem wood, stem bark and different branch categories was estimated using percentage biomass values determined from biomass samples and multiplying by total biomass of the appropriate category.

4.5 Nutrient Analysis of Plant Tissue

Subsamples, with fresh weights of approximately 600 g, were collected for each vegetative component for nutrient analysis. Foliage samples were washed and allowed to air-dry before storing in paper envelopes in a field oven. Woody vegetation and litter components were placed directly into paper envelopes and stored in the same manner.

Samples were ground in a Wiley mill to pass through a 1.0 mm mesh sieve and the percent moisture content at 65° C was calculated. Analytical methods (Black *et al.*, 1965) were as follows:

Total P - H_2SO_4/HNO_3 digestion
Total N - Kjeldahl method
Total C - Walkley and Black method
Total K, Ca and Mg - Dry ashing and extraction by dilute acid (HCl)

The weight of nutrients in each treatment was calculated by multiplying the appropriate percent nutrient concentration by the component weights.

4.6 Soil Sampling

4.6.1 Field Sampling

Soil samples were collected to determine the nutrient status of the soil within each biomass plot. A soil pit was dug at approximately the centre of each 10 m x 20 m plot, to a depth of one metre. Soil samples were collected from each major horizon for physical and chemical analysis, and for bulk density determination. A soil profile description was recorded for each pit.

4.6.2 Analytical Procedures

The analyses were carried out in the Soils Laboratory of the Sarawak Forest Department, Research Section. Soil samples were air-dried and ground to pass through a two millimetre mesh sieve prior to analysis.

4.6.2.1 Physical Analysis

Physical properties that were analyzed included sand, silt and clay percentages, loss-on-ignition, bulk density, porosity and moisture content. Bulk density was determined by taking two undisturbed core samples of a known volume from each soil horizon.

Methods used for analysis of physical properties are described by Chin (1986), adapted from Black *et al.* (1965).

4.6.2.2 Chemical Analysis

The methods used for chemical analysis (Black *et al.*, 1965) were as follows:

1) pH was measured using both 1:2.5 soil:water and 1:2.5 soil:KCl mixtures.
2) Total organic carbon by Walkley and Black titration method.
3) Total nitrogen by the Kjeldahl digestion method.
4) Total phosphorus by perchloric acid digestion with vanado-molybdo-phosphoric reaction.
5) Cation exchange capacity by leaching with ammonium acetate at pH 7.
6) Exchangeable cations K, Na, Ca and Mg by ammonium acetate method at pH 7 extract, using a flame photometer for K and Na; atomic absorption for Ca; and spectrophotometer for Mg.
7) Exchangeable Al and H by KCl/sodium fluoride method and titrations using NaOH and HCl solutions.

It should be noted that the method of P analysis for UPF plots A and B was the same as for the other plots in the chronosequence; however, the results of the two UPF plots were determined in percent values and were only taken to two decimal places. When converted to ppm these values are expressed in units of 100 and are somewhat broader than values determined for the other plots (Appendix IV).

5.0 RESULTS

5.1 Soils

5.1.1 Profile Descriptions

The majority of plots were located on the Merit soil family with most plots in the Begunan soil series (Table 2). Only two plots were in the Jakar soil series and one in the Merit soil series. Five plots were on the Bekenu soil family, four in the Bekenu soil series and one in the Sarikei soil series. One plot was located on the Nyalau soil family in the Nyalau soil series. The different characteristics of these soils have been described in section 3.7 and the family and series for each plot are summarized in Table 2. Definitions of these soil families and series are given in the glossary. It would have been preferable to locate all treatments within the same soil family and series; however, some treatments were not available on Merit soils. Profile descriptions of soil pits for each plot are given in Appendix II.

In the chronosequence the UPF appeared to have a thinner litter layer than other plots. The litter layer appears to be thicker in LOF, but this completely disappeared after clearing and burning and was replaced with a thin layer of ashes. The litter layer reappeared in the chronosequence of plots after burning with the return of biomass in the 1.5YAA plots. Depth of the litter layer appeared to vary slightly with rehabilitation treatments (plantations and fallow plots).

The majority of plots had A horizons with a sandy clay loam (SCL) texture, although there were also sandy loam (SL), clay loam (CL) and very fine sandy loam (VFSL) textures. In general, the texture of all soil profiles changed to CL and then to C with profile depth. The exceptions to this were the 1.5YAA plots which had a VFSL texture for all soil horizons. The C horizon in all profiles was at a depth greater than 100 cm and was not exposed in any of the profiles. The structure of the A horizons was mostly moderate medium crumb on plots with vegetation, while on the burned plots it was moderate medium subangular blocky. Structure in the upper B horizons was generally moderate medium subangular blocky, or was weak fine subangular blocky becoming moderate medium subangular or moderate medium angular blocky with soil depth. In some cases soils were structureless and massive near the bottom of the profile. Generally, the A horizons had many roots, the upper B horizons had frequent roots, and the lower B horizons had very few or no roots. Fine roots were generally found to a depth of about 50 cm, but a few roots were often found in the lowermost horizon of a profile.

5.1.2 Physical Analysis

This section and section 5.1.3 describe differences in soils associated with specific plots. The following results do not necessarily indicate changes occurring with time or treatment because some differences may be inherent to specific sites or soil type and, therefore, may have existed before disturbance or treatment. As noted in section 4.3 valid statistical analyses could not be done. Therefore, the problem of whether the following results were inherited or due to treatment or disturbance will be discussed in section 6.0.

Results of the physical analysis for each soil profile are given in Appendix III; textural classes have been described in the previous section. Generally, sand content in the A horizons was 40 to 60 percent. However, plot B of the UPF had a very low sand content of 27 percent while the 1.5YAA plots had sand contents of nearly 70 percent. Silt content ranged from 14.1 to 31.8 percent; however, most profiles were between 18.2 and 24.8 percent. Clay content ranged from 17.7 to 40.7 percent. The percentage of sand decreased with soil depth in all profiles while percent clay increased. Changes in percent silt content varied with profile depth and from pit to pit.

Bulk density in the A horizon, for all profiles, ranged from 0.92 to 1.46 g/cm^3. Generally, bulk density increased with soil depth to a range of 1.33 to 1.66 g/cm^3, with most profiles attaining at least 1.45 g/cm^3 somewhere within the B horizons (Appendix III). In most profiles bulk density was highest in the B horizons and then decreased slightly in the lowermost horizons ranging from 1.30 to 1.56 g/cm^3. In the chronosequence, the topsoil in the 2DAB plot had the lowest bulk density followed by the UPF plots. The LOF plots had a higher mean bulk density than UPF plots by 0.21 g/cm^3 in the uppermost horizon. Bulk density in the 2WAB plot was lower than that found in the LOF plots. However, mean bulk density was slightly higher in the 1MAB and 1.5YAA plots than in the LOF plots. Plantation and fallow plots were similar to LOF plots with the exception of *Acacia* which had a higher mean bulk density, in the topsoil, than all other plots.

In the mid horizons, the UPF had variable bulk density ranging from 1.25 to 1.66 g/cm^3; LOF plots had less variation ranging from 1.41 to 1.55 g/cm^3 (Appendix III). Bulk densities in the plantations and fallow forest were similar to the LOF plots. The highest bulk densities were found in the 1.5YAA plots. In the lower horizons there was little difference between UPF and other plots except for the 2WAB plot which had a lower bulk density and the 1.5YAA plots which had higher bulk densities.

The greatest topsoil porosity was found in the UPF plots at a mean of 61.7 percent (Appendix III). The LOF plots were slightly lower at a mean of 57.4 percent. Porosity was generally lower in the cleared and burned plots and in the 1.5YAA plots ranging from 45.7

to 59.7 percent with the lowest porosity occurring in the 1MAB plots. Rehabilitation treatments all had greater porosity than that found in the 1.5YAA plots; the fallow forest and *Gmelina* plots had slightly greater porosity than the *Acacia* and *Leucaena* plots.

Porosity showed less variation at mid profile than in the upper horizons. There was no apparent difference between UPF and LOF plots; however, porosity was lower in all the cleared and burned plots and generally greater in the rehabilitation plots. The trend was similar for the lowermost horizons except that the LOF plots had a greater mean porosity than the UPF plots.

5.1.3 Chemical Analysis

5.1.3.1 Soil pH

Results of the soil chemical analysis are given in Appendix IV. Soil pH was measured in both distilled water and KCl solutions. All topsoils in the chronosequence plots are classified as extremely acid (pH < 4.5) with the exception of the *Leucaena* plots (Plot B) and the 1MAB plots (Plot B) which were classified as very strongly acid and strongly acid, respectively. The pH (H_2O) of the topsoil in the 2DAB plot was similar to the UPF and LOF plots, although the pH of ash lying on the soil surface was 9.8 (Appendix IV). However, the 2WAB plot had a slightly higher pH, and the 1MAB plots had the highest pH in the chronosequence. The 1.5YAA plots had a higher pH than the UPF and LOF plots, but a lower pH than the 1MAB plots. *Leucaena* and *Gmelina* plots had higher pH values than the UPF and LOF plots but *Acacia* and fallow plots had pH values similar to the LOF plots. The pH (KCl) values for all plots were slightly more acidic than pH (H_2O) values but trends were similar (Appendix IV).

The highest pH levels in the mid horizons were observed in the 1.5YAA plots and in the cleared and burned plots. The plantation and fallow forest plots had mid horizon pH values similar to those of the LOF plots. All mid profile horizons were classed as extremely acidic. In the lowermost horizon pH was also highest in the 1.5YAA plots and in the cleared and burned plots. The major difference in the lower horizons, along the chronosequence, appears to be that UPF and LOF plots were less acidic than the four rehabilitation treatment plots.

5.1.3.2 Organic Carbon

The highest organic C concentration in the topsoil was found in the UPF plots at a mean of 4.0 percent followed by the LOF plots at 2.7 percent (Appendix IV). The lowest C concentration was found in the 2DAB plot. Percent C appeared to be higher in the remaining plots but was at least 1.5 percentage points lower than the UPF plot mean. Mid and lower horizons indicated a similar trend with the lowest levels occurring in the cleared and burned plots and 1.5YAA plots. Percent C was higher in the rehabilitation phases but did not attain the levels in UPF or LOF plots. Within individual profiles there was a decrease in C content with soil depth in all plots.

Percentage or concentration values do not always give an accurate view of the C or nutrient status of a soil because they do not take into account differences in bulk density (Brown and Lugo, 1990); therefore, C and nutrients have been converted to kg/ha. The amount of C in the top 30 cm of soil (Figure 4) shows little difference among UPF, LOF, *Acacia* , *Gmelina* and fallow plots. The lowest amounts of C were observed in the 2DAB and 1.5YAA plots. Carbon in the 2WAB and 1MAB plots was similar to the UPF and LOF plots. All rehabilitation treatments had similar amounts of C, approaching UPF levels, with the exception of the *Leucaena* plantation which had amounts comparable to that in the 1.5YAA plots.

5.1.3.3 Total Nitrogen

The highest percent N content in the top horizon, along the chronosequence, was observed in the UPF plots followed by the LOF plots (Appendix IV). The lowest percent N was observed in the 2DAB plot. Percent N was also low in the 1.5YAA plots at about half that found in the UPF plots. Nitrogen content in the top horizon was higher in the rehabilitation phases than in the 1.5YAA plots. In the subsoil the highest percent N was also found in the UPF and LOF plots. Percent N was lower in the cleared and burned plots but its lowest level was observed in the 1.5YAA plots. Nitrogen levels in the subsoils of the rehabilitation plots did not appear to be higher than that in the 1.5YAA plots.

Figure 4 indicates that the LOF plots had about 800 kg/ha more N than the UPF plots, in the top 30 cm of soil. Nitrogen levels in the 2WAB and 1MAB plots were similar to UPF plots, while the lowest levels were observed in the 2DAB and 1.5YAA plots. Nitrogen content was higher in the rehabilitation plots than in the 1.5YAA plots, but to varying degrees.

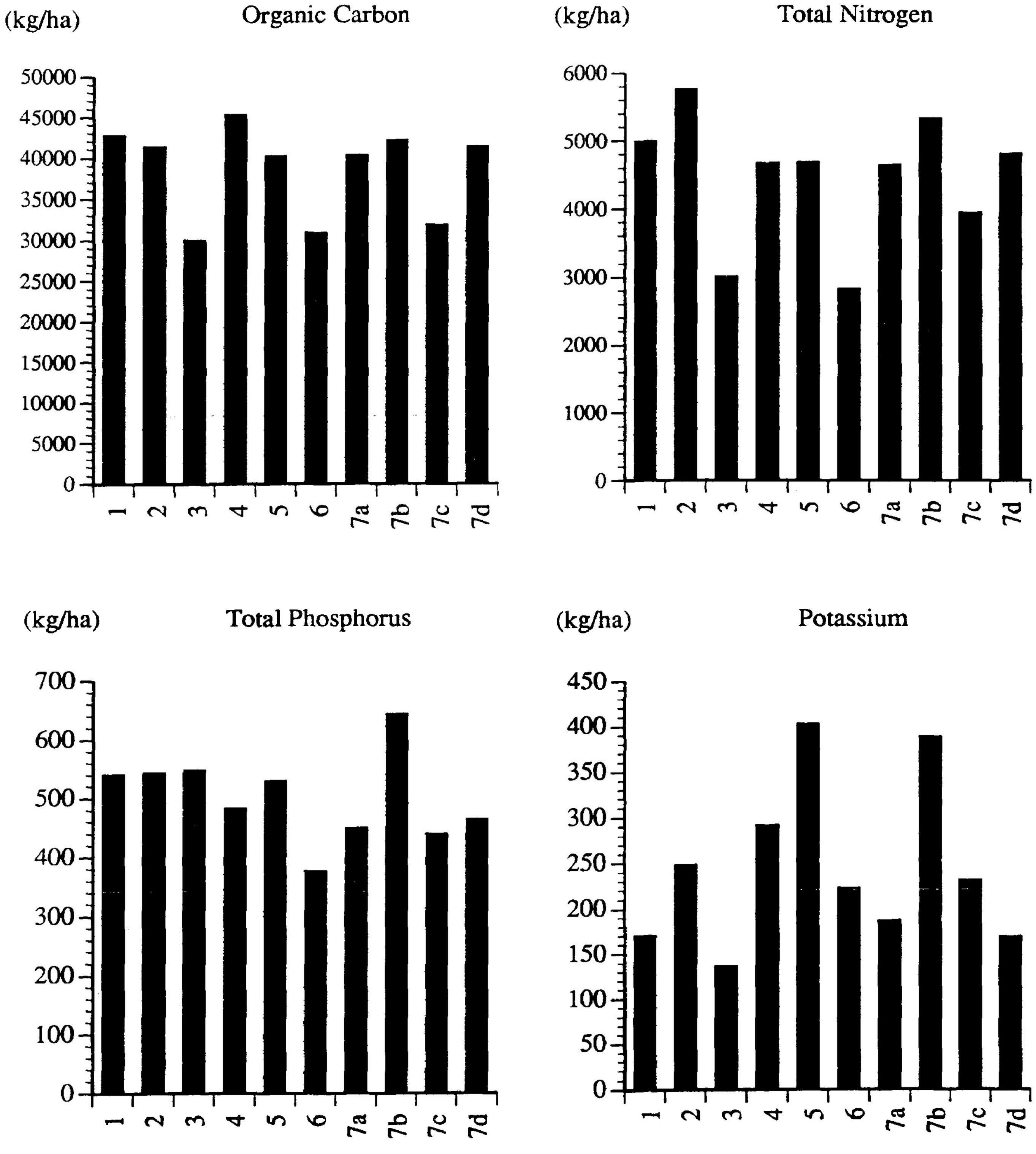


Figure 4. Stocks of C, N, P, K, Ca, Mg, Al and H in the top 30 cm of soil (kg/ha).
Sites include: (1) UPF; (2) LOF; (3) 2DAB; (4) 2WAB; (5) 1MAB;
(6) 1.5YAA; (7a) *Acacia*; (7b) *Gmelina*; (7c) *Leucaena*; (7d) Fallow Forest.

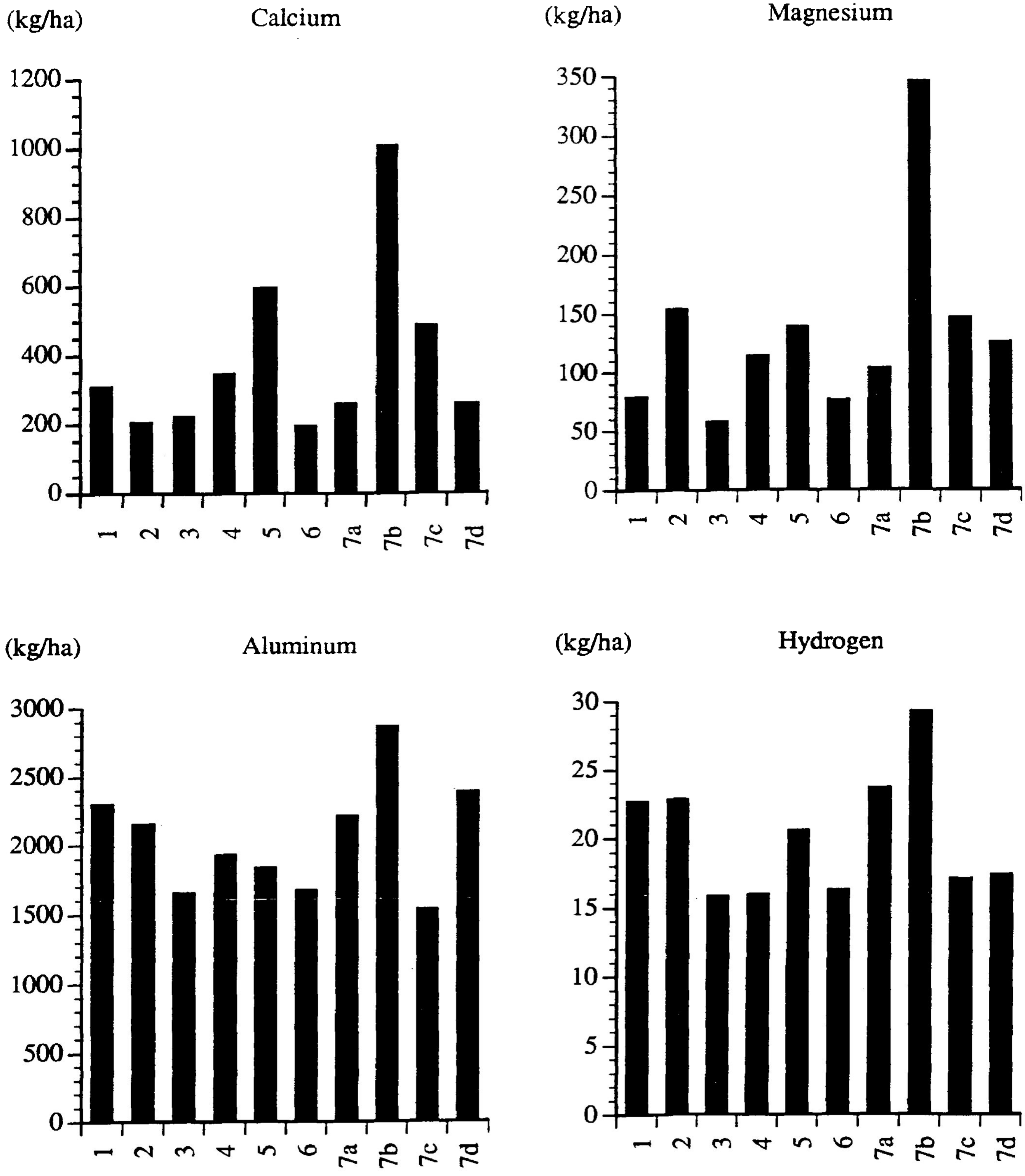


Figure 4. *Continued.*

5.1.3.4 Carbon-Nitrogen Ratio

The carbon nitrogen ratio (C:N) was highest in the topsoil for all plots, but there appeared to be no trend in the chronosequence (Appendix IV). The highest C:N ratios were found in the 1.5YAA and UPF plots while the lowest were observed in the *Acacia* plantation. The C:N ratio generally decreased with soil depth in most profiles, although there were increases in the lowermost horizon of some profiles. The C:N ratio in the lower horizons varied considerably within treatments and there did not appear to be a trend.

5.1.3.5 Total Phosphorus

Phosphorus concentrations were highest in the topsoils of all plots, decreasing with soil depth and then increasing slightly in the lowermost horizon in most profiles (Appendix IV). The highest mean P concentrations were in the top horizon in the LOF and 1MAB plots; the lowest concentrations were observed in the 1.5YAA plots. Phosphorus concentrations in the topsoil were variable and do not suggest a trend between UPF through to the 1MAB plots. However, P was at its lowest level in the 1.5YAA plots; the *Acacia*, *Leucaena* and fallow plots had slightly higher levels of P than the 1.5YAA plots, while the *Gmelina* plot had noticeably higher levels (Appendix IV). Figure 4 shows a similar trend except that the *Gmelina* plot had a higher P content than all other plots. Mid horizons showed a stronger trend with the highest P concentrations occurring in the 2DAB plot. Concentrations were lowest in the 1.5YAA plots but were slightly higher in the rehabilitation treatment plots. *Gmelina* was the only rehabilitation treatment in which P levels exceed that of UPF. The lowermost horizons showed a similar trend to that of the mid horizons.

5.1.3.6 Exchangeable Bases

The highest CEC was found in the UPF plots while the lowest occurred in the cleared and burned plots and 1.5YAA plots, ranging from 9.6 to 9.8 me/100 g (Appendix IV). The CEC appeared to be greater for the plantation and fallow plots, ranging from 14.9 to 16.0 me/100 g, which was similar to the LOF plots but lower than the UPF plots. Similar trends were found in the mid and lower horizons with the exception of the *Gmelina* profile which had a CEC higher than all other plots.

Potassium concentrations in the LOF and 2DAB plots were slightly lower than in the UPF plots, in the upper horizons. The highest K concentrations were observed in the 1MAB plots; the lowest concentrations were observed in the 1.5YAA plots (Appendix IV).

Concentrations in the rehabilitation plots were generally slightly higher than in the 1.5YAA plots. Mid horizon concentrations did not show a strong trend but appeared to be slightly higher in the 2WAB, *Gmelina* and *Leucaena* plots. Figure 4 shows the amounts of K in the top 30 cm of soil in kg per ha. The most noticeable feature of Figure 4 is the higher K content in the 1MAB and *Gmelina* plots.

Calcium content in the upper horizon showed a great deal of variation within some plots (Appendix IV); thus, it is difficult to make meaningful comparisons with some treatments. There were no apparent differences between the UPF and LOF plots except that UPF Plot B had a comparatively high Ca concentration which was probably inherent to the site. Calcium content in ash on the soil surface, in the 2DAB plot, was very high at 45.3 me/100 g (Appendix IV), yet Ca in the underlying topsoil was at one of the lowest levels in the chronosequence at 0.45 me/100 g. In contrast to the 2DAB topsoil, Ca concentrations were 1.4 times higher in the 2WAB plot; 3.4 times higher in the 1MAB plots; and 2.2 times higher in the 1.5YAA plots. Compared to the 1.5YAA plots, Ca concentrations in the *Acacia* and fallow plots were generally similar, while *Leucaena* was 2.7 times higher and *Gmelina* was 3.4 times higher. Mid and lower horizons showed a similar trend but had less variation within plots. Calcium concentration appeared to be higher in the cleared and burned plots but was at its lowest levels in the 1.5YAA plots. Calcium stocks in the top 30 cm of soil generally show a similar trend (Figure 4).

Trends in Mg concentrations in the upper horizons were similar to those of Ca (Appendix IV). Magnesium in mid and lower horizons showed a similar trend to that of Ca within the same horizons. The *Gmelina* plot almost consistently had the highest Ca and Mg concentrations compared to all other plots. These trends generally hold true for the amounts of Ca and Mg in the top 30 cm of soil (Figure 4).

Base saturation in the topsoil of the chronosequence plots was variable, even within treatments. However, it appeared to be higher in the cleared and burned plots with the highest base saturation being observed in the 1MAB plots (Appendix IV). Base saturation was lower in the 1.5YAA plots but was generally higher than base saturation in the UPF and LOF plots. The *Gmelina* and *Leucaena* plots had comparatively higher base saturation than the 1.5YAA plots, while the *Acacia* and fallow plots had lower base saturation. Mid horizons had higher base saturation in the cleared and burned plots, while the lowest levels were observed in the 1.5YAA plots. All rehabilitation phases had higher base saturation than the 1.5YAA plots but *Acacia* and fallow had lower base saturation than the other rehabilitation plots. A similar trend was found in the lower horizons with the lowest base saturation occurring in the 1.5YAA plots while higher values were observed in the rehabilitation plots.

Aluminum concentration in the upper horizon of soil was generally highest in the UPF plots, with the exception of fallow forest which had a relatively high Al concentration (Appendix IV). The cleared and burned plots and the 1.5YAA plots generally had slightly lower Al concentrations than the UPF and LOF plots. *Acacia* plots had similar Al concentrations to those found in the 1.5YAA plots. The *Gmelina* and *Leucaena* plots, however, had the lowest Al concentrations in the upper horizon of soil (Appendix IV). Aluminum capital in the top 30 cm of soil generally shows a similar trend (Figure 4), with the exception of *Gmelina* which had higher amounts of Al than all other plots. This difference is due to the high Al concentration in the B21 horizon of the *Gmelina* soil profile. Hydrogen generally showed a similar trend to that of Al (Figure 4).

5.2 Stand Growth Characteristics

Mean growth characteristics of each stand are given in Table 3. Mean height of trees within the 10 x 20 m UPF plots (trees $> 3 \leq 30$ cm dbh) was 10.2 m; mean dbh was 7.2 cm. The 10 x 20 m LOF plots had a slightly lower mean height and dbh of 9.0 m and 7.0 cm, respectively. The mean height and dbh values for the UPF and LOF plots are misleading because they suggest that trees in these plots are smaller than those found in the *Acacia* and *Gmelina* plantations. However, the ranges (Table 3) indicate that large trees were present in these plots. The mean values are low because all trees within the plots were used in the calculation of means and there were a large number of suppressed trees in these plots. The one hectare extension plot data for UPF and LOF plots, shown in parenthesis, give a better indication of tree size in the overstorey. Mean height and dbh of trees in the UPF extension plots were 34.8 m and 49.0 cm, respectively. Mean height and dbh of trees in LOF extension plots were 25.8 m and 43.6 cm, respectively. The best growth rates for treatments after shifting cultivation were found in the *Acacia* stand with a mean height of 19.7 m and a mean dbh of 18.7 cm. *Gmelina* followed closely at 16.6 m in height and 17.3 cm dbh. Fallow forest and the *Leucaena* mean heights were well below these at 10.4 m and 4.6 m, respectively. The corresponding mean dbhs were 8.5 cm and 3.4 cm, respectively. However, the range of heights and dbhs (Table 3) indicate that relatively large trees were present in the fallow plots.

Table 3. Mean growth characteristics of the study plots.

Forest type	Primary forest (UPF)	Logged forest (LOF)	*Acacia mangium*	*Gmelina arborea*	*Leucaena leucocephala*	Fallow forest
Mean height (m)	10.2 (34.8)*	9.0 (25.8)	19.7	16.6	4.6	10.4
Range (m)	3.2-39.0 (8.8-57.4)	2.0-25.2 (10.6-51.6)	9.7-26.2	9.4-20.4	0.4-7.4	3.1-23.0
DBH (cm)	7.2 (49.0)	7.0 (43.6)	18.7	17.3	3.4	8.5
Range (cm)	3.0-29.4 (30.0-136.8)	3.0-26.6 (30.2-110.6)	6.0-25.0	7.5-25.3	0.0-7.1	3.0-29.8
Mean crown diameter (m)	3.2 (10.9)	2.8 (8.2)	4.9	5.6	2.0	3.3
Mean crown length (m)	4.2 (12.7)	3.6 (10.6)	11.7	6.0	3.1	4.5
Trees/plot	58.5 (94.5)	67.0 (63.5)	14.5	16.5	24.2	60.5
Lianas/plot	1.5	4	0	0	0	0.5
Palms/plot	2	0	0	0	0	1.0
Epiphytes	0	1	0	0	0	0
Trees/ha	2925 (94.5)	3350 (63.5)	725	825	1210	3025

* Numbers in parenthesis are means of 1 ha extension plots (trees > 30 cm dbh).

5.3 Biomass

5.3.1 Litter

Mean biomass of the small-litter standing crop is shown in Figure 5; data and percentage values are given in Appendix V. Fallow had the greatest litter biomass at 7.43 t/ha followed by UPF at 6.94 t/ha and *Acacia* at 6.5 t/ha. Logged over forest produced about one t/ha less litter biomass than UPF. *Gmelina* and *Leucaena* produced the lowest small-

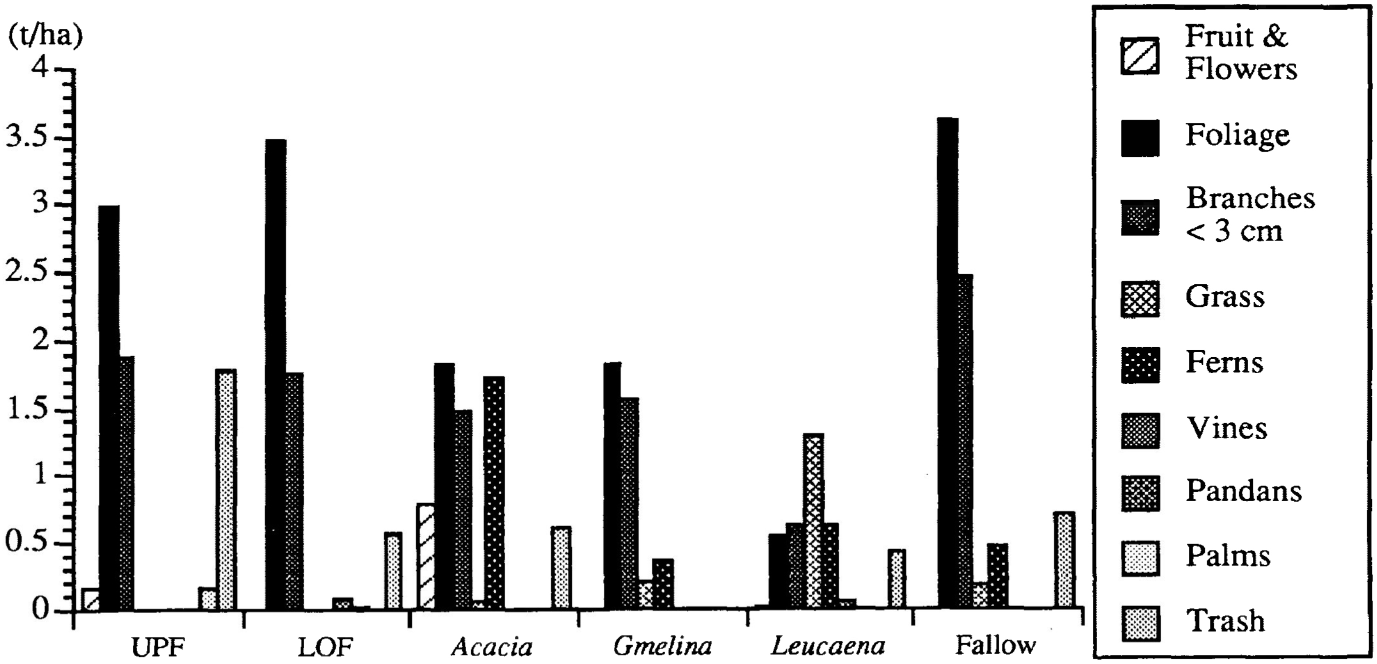


Figure 5. Mean biomass of small-litter standing crop (t/ha).

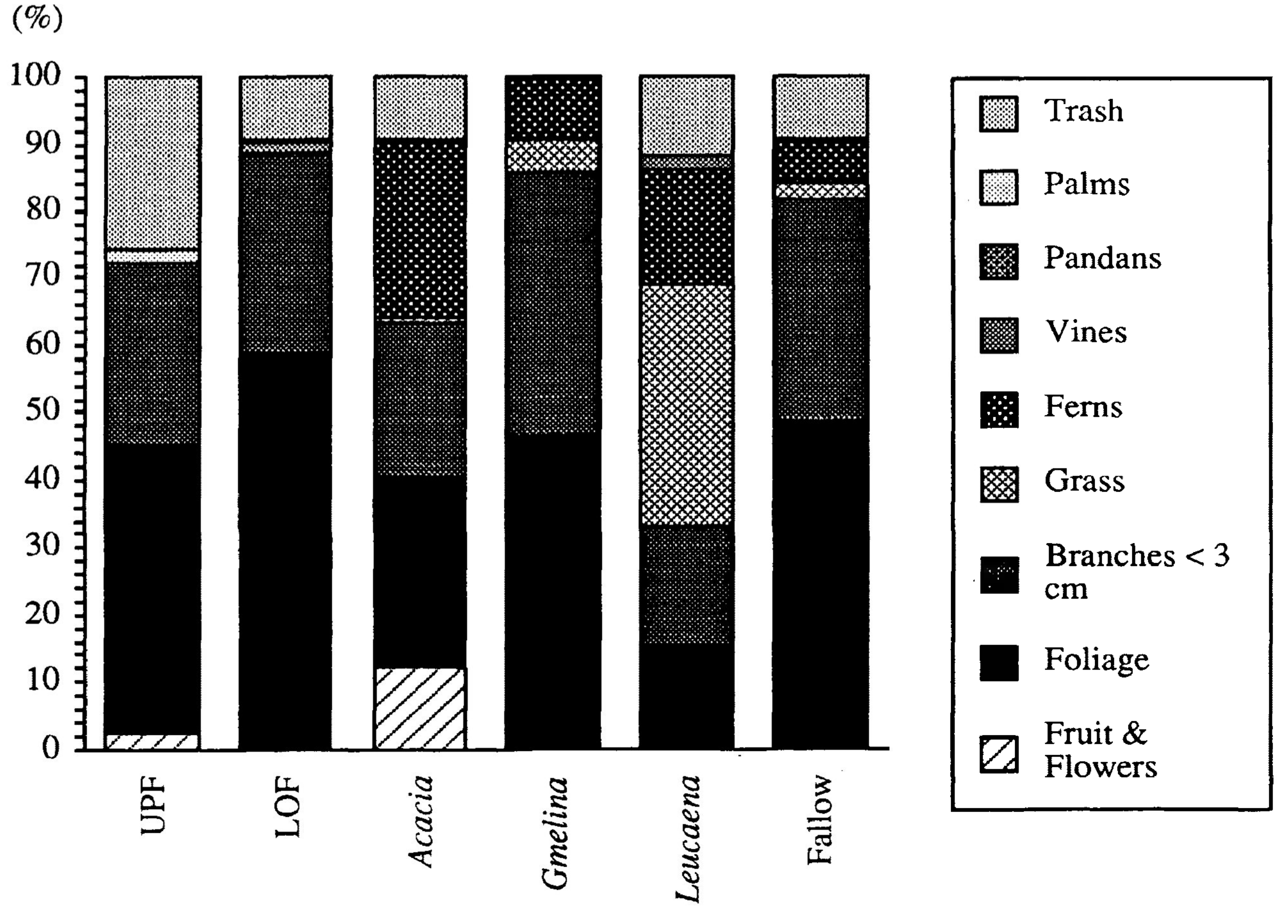


Figure 6. Mean biomass of small-litter standing crop (%).

litter standing crops at less than four t/ha each.

Figure 5 also shows differences in the types of litter material found under each forest type. No grass litter was found on UPF or LOF plots. The remaining plots all contained grass and fern litter but no pandan or palm litter and very little vine litter, with the exception of the *Leucaena* plots.

Foliage litter comprised the largest percent biomass for all plots except *Leucaena* (Figure 6). The range for foliage litter was 15.2 percent for *Leucaena* to 58.9 percent for LOF. Grass produced the greatest amount of litter in *Leucaena* plots at 36 percent. Branches (< 3 cm dob) contributed the next highest percentage to litter biomass, ranging from 17.4 percent in the *Leucaena* plots to 39.4 percent in the *Gmelina* plots. Percent distribution of different litter components is shown in Figure 6. The differences in percent trash (unrecognizable material) were mainly due to differences in transporting and the amount of handling prior to sorting.

5.3.2 Undergrowth

Mean biomass production of undergrowth is shown in Figure 7; data and percentage values are given in Appendix VI. *Leucaena* had the greatest undergrowth biomass at 8.1 t/ha, which was about the same weight as the overstorey biomass; fallow had the lowest undergrowth biomass at 2.2 t/ha. There was little variation among the remaining plots which ranged from 3.2 to 3.6 t/ha.

The dominant undergrowth vegetation in UPF, LOF and fallow forest was almost entirely woody plants making up 77 to 100 percent of the undergrowth biomass (Figure 8). In contrast, the dominant undergrowth vegetation under *Acacia* and *Gmelina* was ferns, ranging from 64 to 75 percent. *Leucaena* undergrowth was predominantly grass and ferns. No grass or fern undergrowth was found in the UPF or LOF plots. The lack of fern and grass undergrowth in the fallow plots contradicts litter data where grass and fern litter were found. Visual observation of the plots confirmed that grass and ferns were present in the undergrowth, but their presence was very patchy rather than evenly distributed as in the plantation plots. These vegetation types do not appear in the fallow undergrowth because they did not fall within the five percent survey of randomly placed subplots or because their biomass was not significant enough to show up in the results. Figure 8 illustrates the percent biomass distribution of the undergrowth; percentage data are given in Appendix VI.

Biomass on burned sites was not determined because generally all living biomass was destroyed by the fire. Biomass of the 1.5YAA sites was not determined experimentally

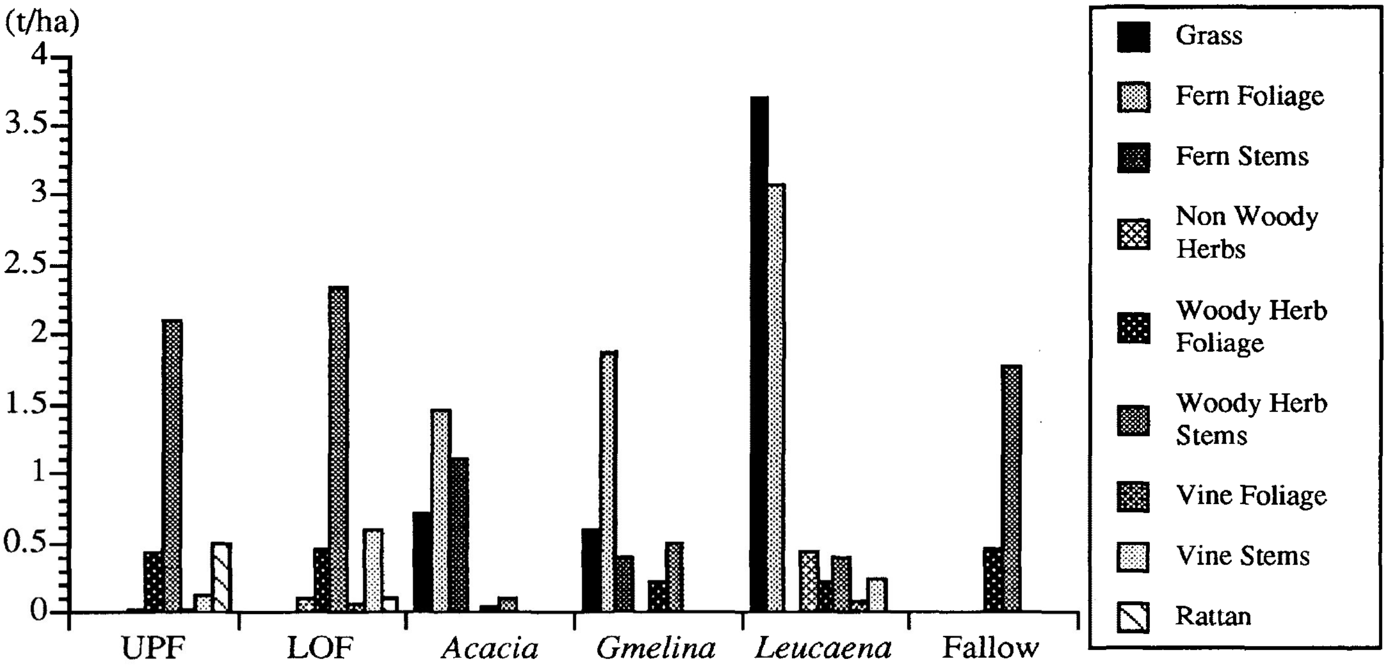


Figure 7. Mean biomass production of the undergrowth (t/ha).

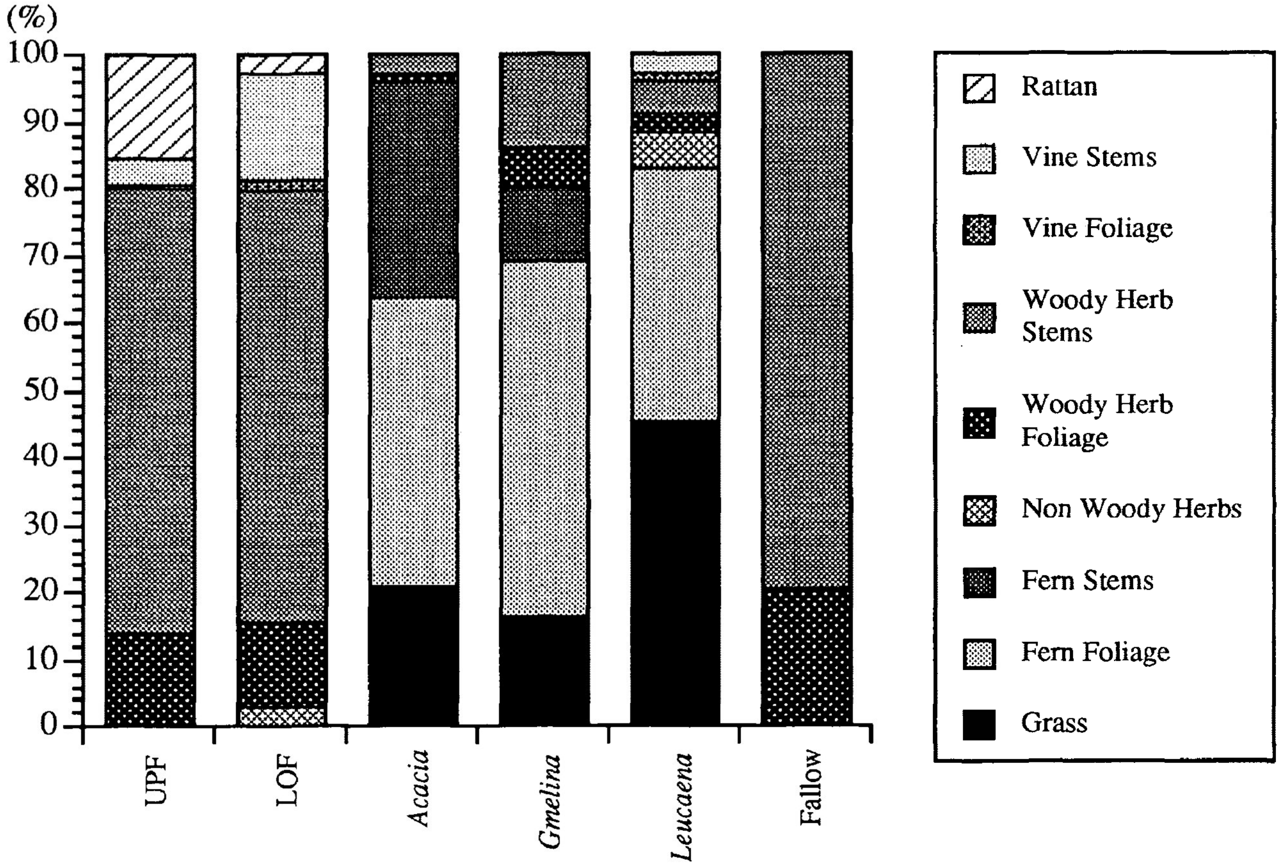


Figure 8. Mean biomass production of the undergrowth (%).

but was estimated visually to be 5 to 10 t/ha. This estimate is supported by results of other studies (Nakano, 1978; Uhl *et al.*, 1982a,b; Williams-Linera, 1983; Uhl *et al.*, 1988).

5.3.3 Overstorey

Figure 9 shows biomass distribution, by vegetation type, in tonnes per ha. Undisturbed primary forest had the greatest overstorey biomass at 465.7 t/ha, while LOF had about half that at 218.5 t/ha (Appendix VII). *Acacia* had the greatest overstorey biomass of the rehabilitation treatments at 123 t/ha while *Leucaena* had the poorest biomass production at 8.4 t/ha. *Gmelina* and fallow had similar biomass at 85 and 87 t/ha, respectively.

Figure 10 shows the percent biomass distribution of the overstorey by vegetation type. Stems made up the largest proportion of biomass ranging from 54.4 to 79.0 percent of total overstorey biomass among treatments. The greatest proportion of stems was comprised of stemwood, ranging from 47.9 to 68.5 percent while bark comprised 6.5 to 10.7 percent. The next largest portion of biomass was large branches (> 3 cm dob), followed by small branches (1-3 cm dob). Undisturbed primary forest , LOF and *Leucaena* had larger proportions of twigs (< 1 cm dob) than foliage while *Acacia*, *Gmelina* and fallow had larger proportions of foliage than twigs in their respective total biomasses. Fruit and flowers made up the smallest biomass proportion or was absent in some treatments at the time of harvest.

5.3.4 Total Biomass

Total aboveground biomass distribution of each forest type is given in Table 4. Total biomass of the UPF was 475.8 t/ha comprising 96.9 percent overstorey, 1.4 percent litter, 1.0 percent dead trees and branches, and 0.7 percent undergrowth. Total biomass of LOF was about half that of UPF, but the overstorey comprised a similar proportion of the overall biomass at 95.3 percent and slightly higher amounts of litter and undergrowth at 2.6 and 1.6 percent, respectively. Total biomass of rehabilitation treatments ranged from a high of 134.1 t/ha for *Acacia* to a low of 20.1 t/ha for *Leucaena*. The distribution of biomass, for rehabilitation treatments, ranged from 4.2 to 17.9 percent for litter; 2.3 to 40.3 percent for undergrowth; 0.0 to 2.5 percent for dead standing trees and 41.8 to 91.9 percent for overstorey. *Leucaena* data increased the extent of litter and undergrowth ranges for the rehabilitation treatments because of its much larger proportions of these vegetation types than the other treatments.

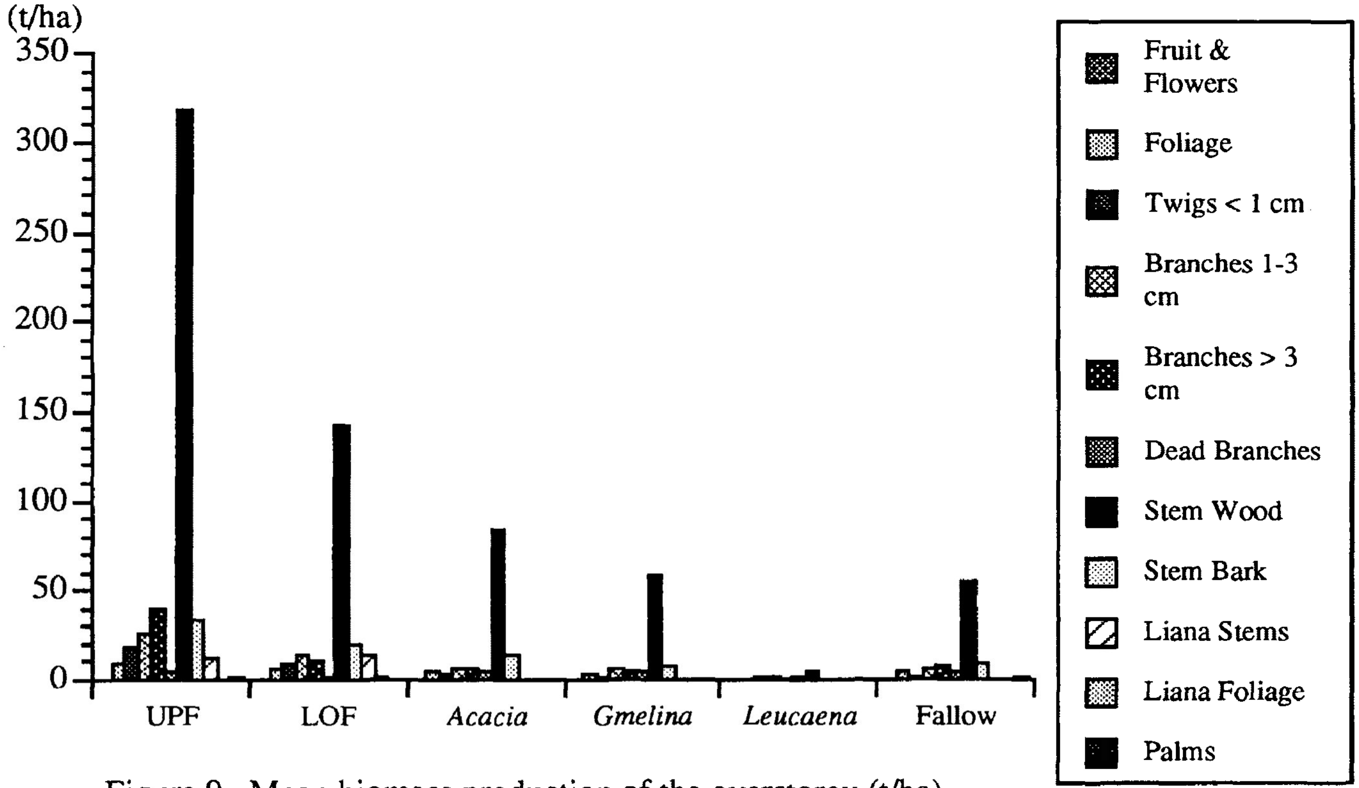


Figure 9. Mean biomass production of the overstorey (t/ha).

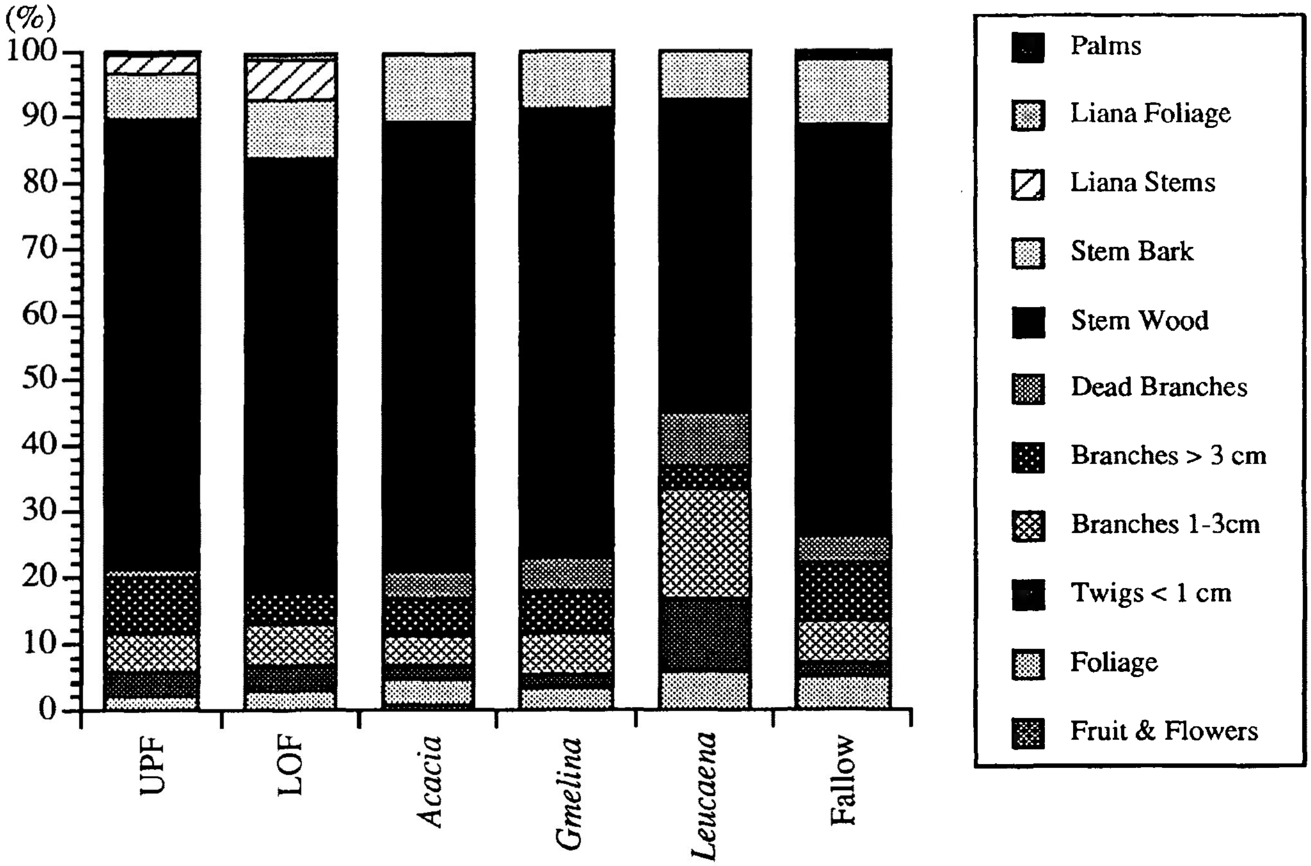


Figure 10. Mean biomass production of the overstorey (%).

Table 4. Total mean aboveground biomass production.

Vegetation type	Primary forest		Logged forest		*Acacia mangium*		*Gmelina arborea*		*Leucaena leucocephala*		Fallow forest	
	t/ha	%	t/ha	%	t/ha	%	t/ha	%	t/ha	%	t/ha	%
Litter	6.9	1.4	5.9	2.6	6.5	4.9	3.9	4.2	3.6	17.9	7.4	7.6
Undergrowth	3.2	0.7	3.6	1.6	3.4	2.5	3.6	3.5	8.1	40.3	2.2	2.3
Overstorey	461.1	96.9	217.3	95.3	123.2	91.9	85.0	92.3	8.4	41.8	85.0	87.6
Dead trees and branches	4.6	1.0	1.2	0.5	1.0	0.7	0.0	0.0	0.0	0.0	2.4	2.5
Total	475.8		228.0		134.1		92.5		20.1		97.0	

5.4 Nutrients in Aboveground Biomass

5.4.1 Litter

Nutrient content in litter biomass is illustrated in Figure 11; data are given in Appendix VIII. Differences in the amounts of nutrients in litter are influenced mainly by litter biomass and composition. Nitrogen content of litter in the LOF plots was similar to that in the UPF plots; however, *Acacia* and fallow phase plots had levels greater than that in UPF and LOF (Figure 11). In contrast, N content in the *Gmelina* and *Leucaena* plot litter was somewhat lower. Phosphorus levels were consistently low for all plots, but were somewhat lower for the plantation plots. Fallow was the only rehabilitation phase having similar levels of P in litter to that in UPF and LOF plots. Potassium levels in the LOF plots were about half that in the UPF plots; K levels in other plots were slightly higher with the exception of *Gmelina* litter which had about one third the amount of K found in UPF litter. Calcium levels in the UPF plots were less than in the LOF, *Acacia*, *Gmelina* and Fallow plots; the *Leucaena* plots had levels lower than that in UPF litter. Magnesium levels in the UPF plots were higher than in the LOF plots; *Acacia* and *Leucaena* plots were both lower in Mg than UPF and LOF plots. *Gmelina* and fallow plots had similar amounts of Mg in litter but had greater amounts than the other two plantation plots.

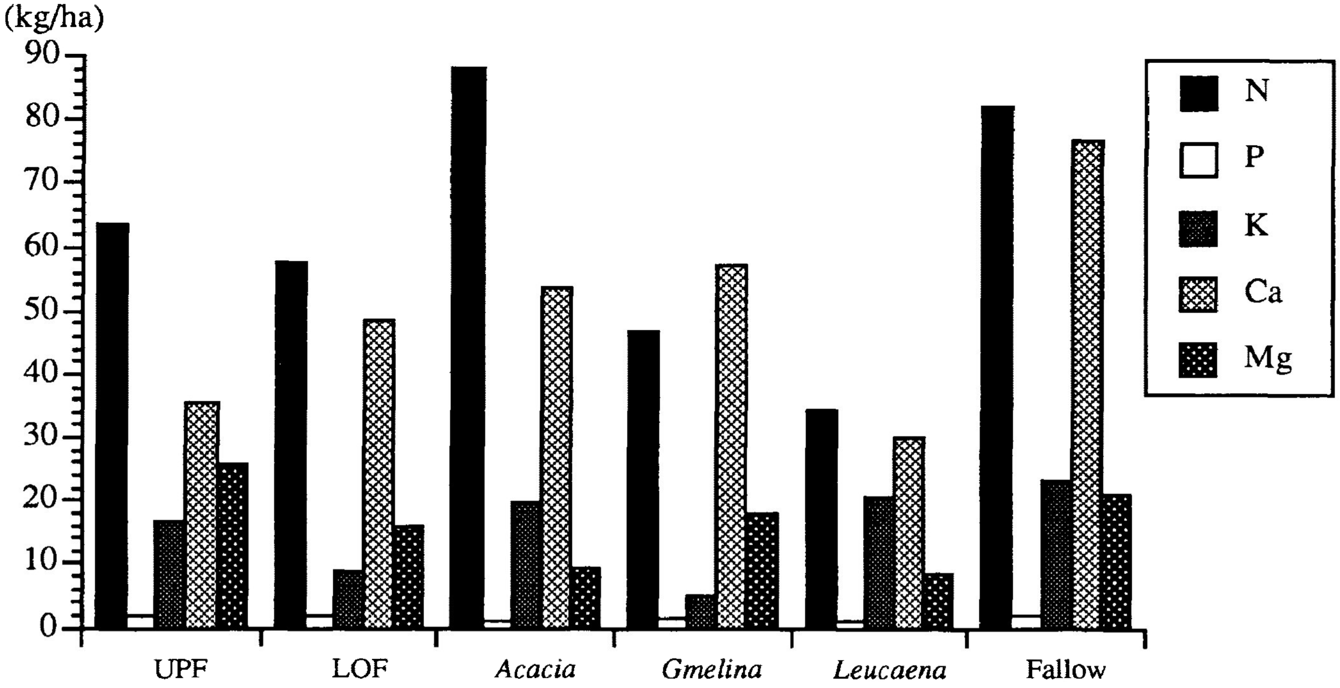


Figure 11. Nutrient content in small-litter standing crop (kg/ha).

5.4.2 Undergrowth

Nutrient contents in undergrowth biomass is shown in Figure 12; data are given in Appendix VIII. There were differences in nutrient concentrations in different types of undergrowth; however, differences in total amounts of nutrients in undergrowth, on a given site, are influenced by total biomass as well as the concentration per unit weight of biomass. There was little difference in total nutrient content in undergrowth between UPF and LOF plots. The amounts of N, P and K in the plantation phases were greater than in UPF, LOF and Fallow forest plots. The amounts of Ca and Mg in *Acacia* and Fallow undergrowth were lower than that of LOF, while *Gmelina* had similar amounts and *Leucaena* had greater amounts. *Leucaena* undergrowth contained very high amounts of nutrients especially N and K compared to undergrowth of other treatments. *Leucaena* undergrowth also contained greater amounts of P than other treatments ranging from 2.9 to 11.0 times more.

5.4.3 Overstorey

Nutrient contents in overstorey biomass are illustrated in Figure 13; data are given in Appendix VIII. Undisturbed primary forest contained the largest amounts of nutrients compared to other overstories. Logged over forest contained the next largest amounts of nutrients, with the exception of N, which was found in a slightly greater quantity in the

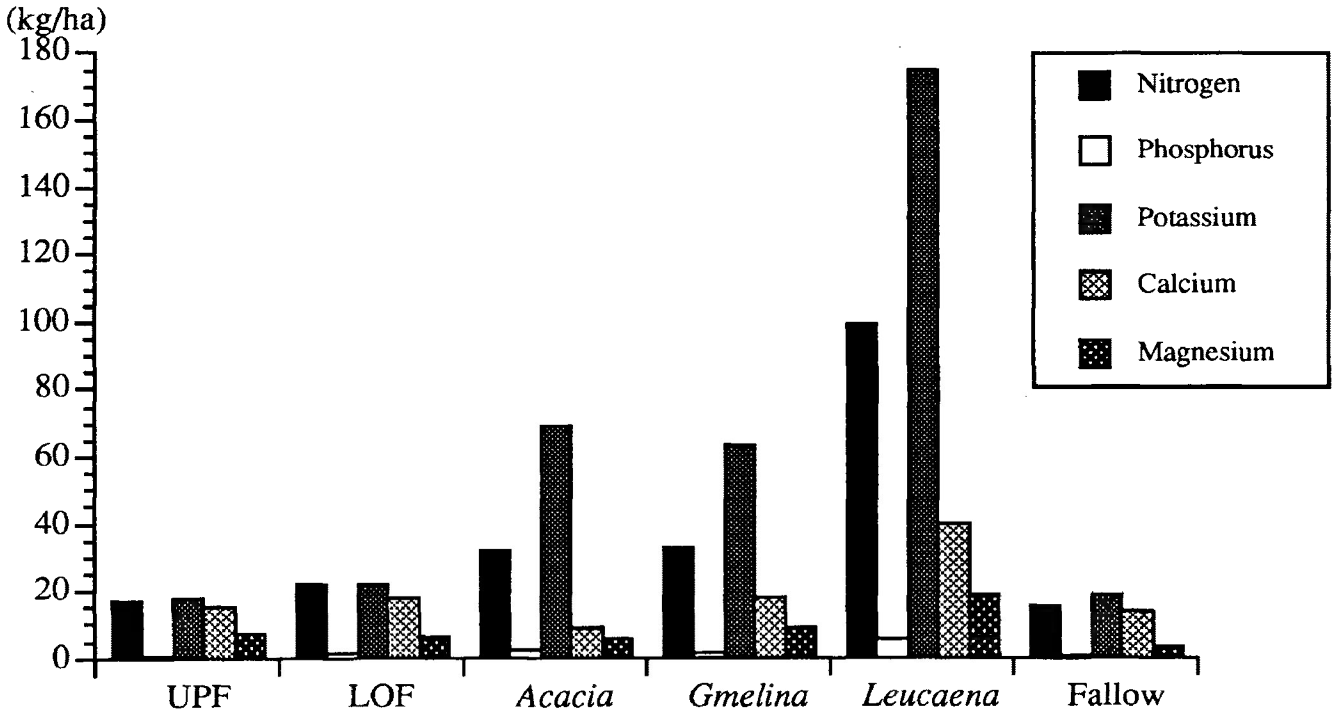


Figure 12. Nutrient content in undergrowth biomass (kg/ha).

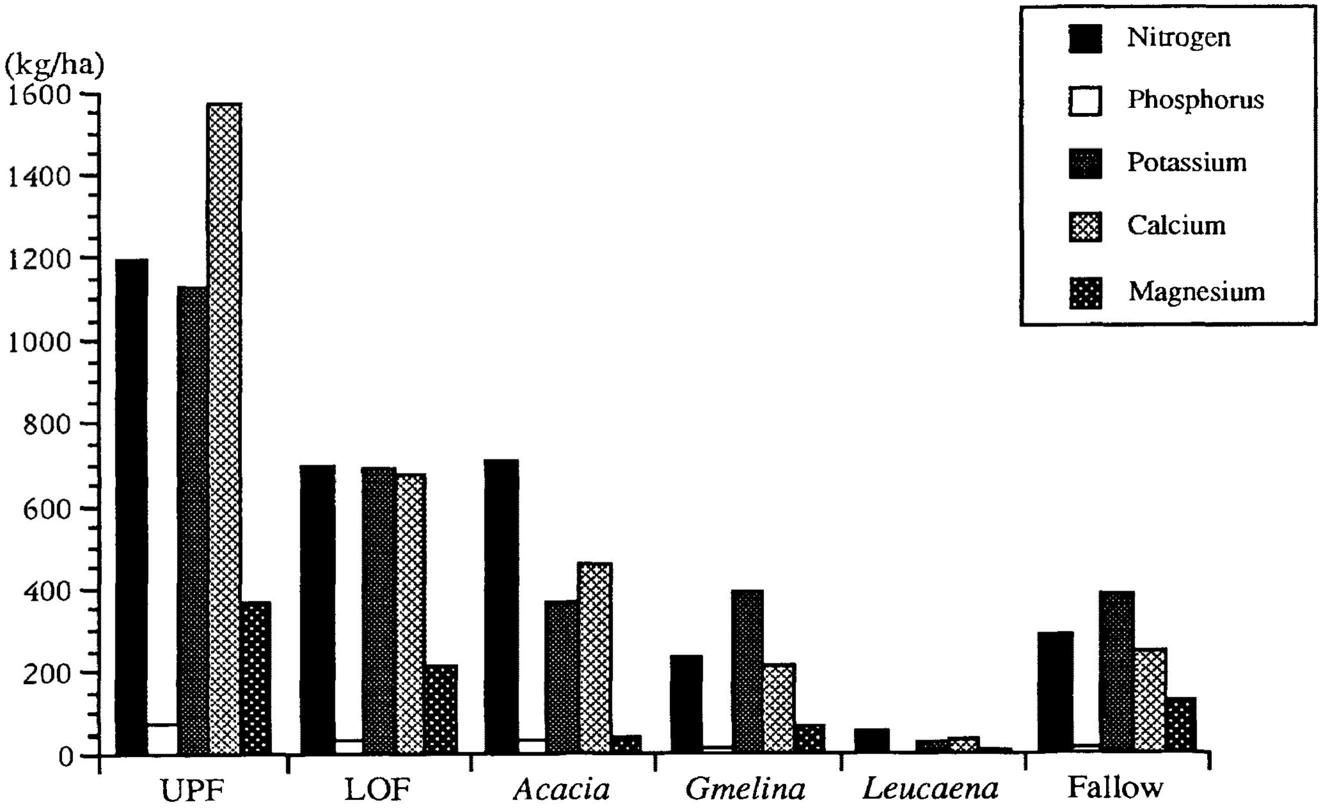


Figure 13. Nutrient content in overstorey biomass (kg/ha).

Acacia overstorey. This slightly greater amount of N in the *Acacia* overstorey is significant because the *Acacia* biomass was almost 95 t/ha lower than the LOF biomass (Table 4). *Leucaena* had fewer nutrients than the other forest types due to its low biomass. Nitrogen content in the biomass ranged from a low of 57.5 kg per ha in the *Leucaena* plantation to a high of 1191 kg per ha in the UPF. Potassium and Ca also had broad ranges from 29 to 1126 kg per ha and 35 to 1573 kg per ha, respectively. The ranges for P and Mg were much smaller at 2.6 to 72.6 kg per ha and 7.5 to 369 kg per ha, respectively. Among rehabilitation treatments there was considerable variation in nutrient content. *Acacia* had the highest overall content of N, P and Ca; *Gmelina* had the highest K content; and fallow the highest Mg content.

Differences were observed in the amounts of specific nutrients taken up within each forest type suggesting preferential immobilization of some nutrients among the various forest types. Nitrogen was the most abundant nutrient within the LOF, *Acacia* and *Leucaena* overstories and the second most abundant in the remaining forest types (Figure 13). Calcium was taken up in greater amounts than other nutrients within the UPF, while K was taken up in greater amounts within the *Gmelina* plantation and fallow forest. Phosphorus was taken up in the smallest amounts within all forest types.

Nutrient distribution in the aboveground overstorey biomass, by vegetation type, is shown in Figure 14; data are given in Appendix VIII. The largest amounts of nutrients were generally immobilized in stem wood except for Ca, which was contained in greater amounts in stem bark for all treatments except UPF, which had larger amounts in stem wood (Appendix VIII D). Other exceptions to this were the *Leucaena* plantation which had greater amounts of nutrients in foliage and branches; and the *Gmelina* plantation which had greater amounts of Mg in stem bark (Appendix VIII E). Amounts of nutrients in other components varied with nutrient and forest type and showed no apparent trend. It is also noteworthy that lianas contained considerable amounts of N, P and K in the UPF and LOF plots, exceeding that of the entire *Leucaena* overstorey (Figure 14).

Percent nutrient concentration was generally highest in fruit, flowers and foliage for N, P and K and next highest in stem bark. The highest percent nutrient concentrations of Ca and Mg were found in stem bark followed by foliage. The next highest nutrient concentrations were found in twigs (< 1 cm dob), branches (≥ 1 cm dob) and stem wood, in that order. Where fern and grass undergrowth were present they usually had the highest concentrations of K compared to all other vegetation types.

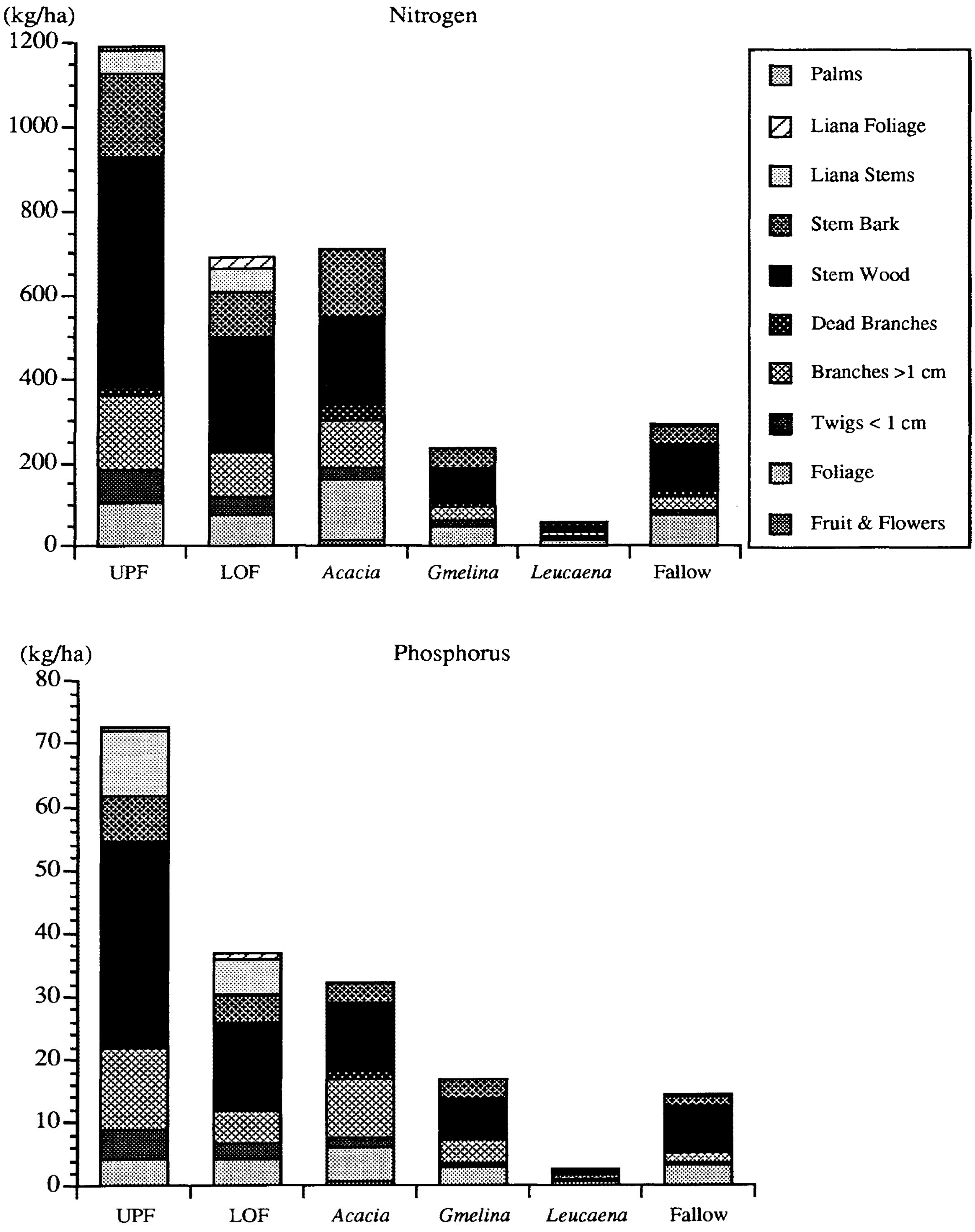
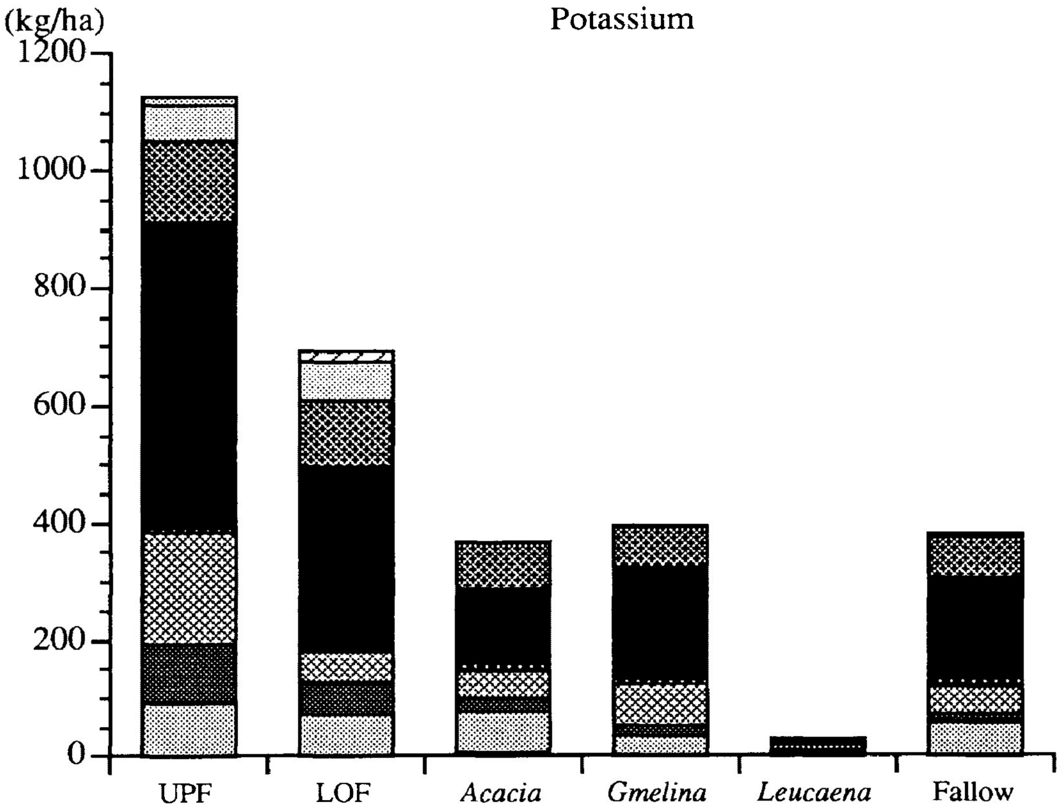


Figure 14. Nutrient distribution in the overstorey biomass (kg/ha).



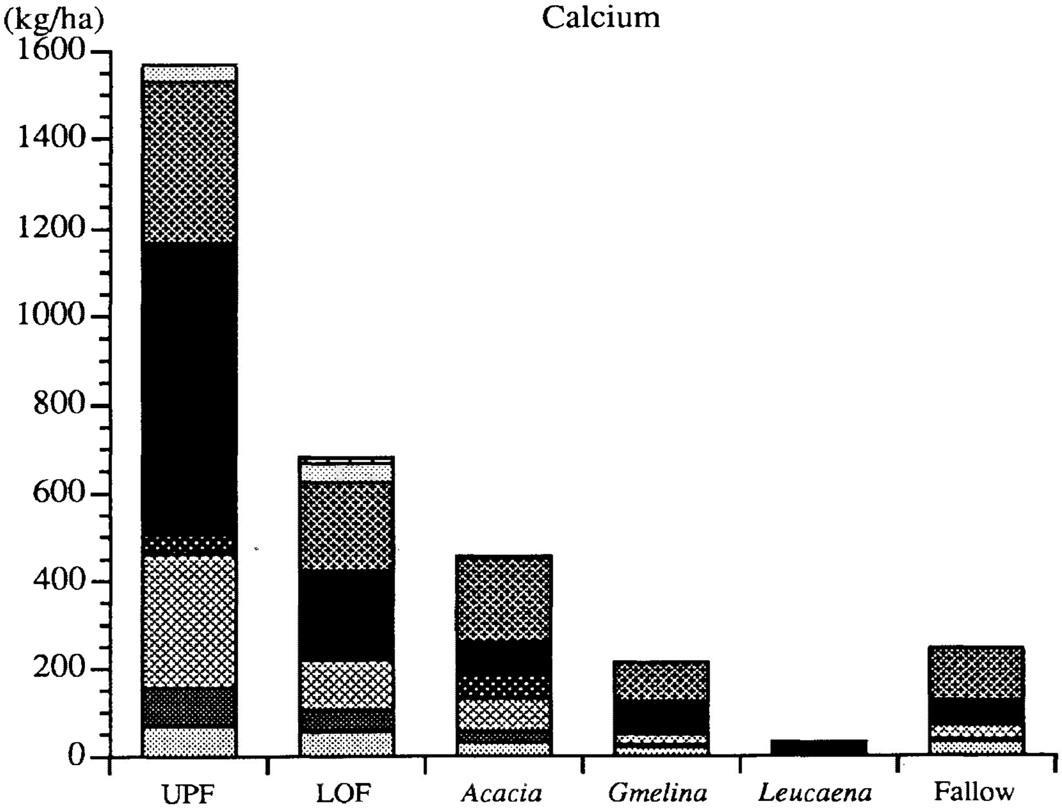


Figure 14. *Continued*.

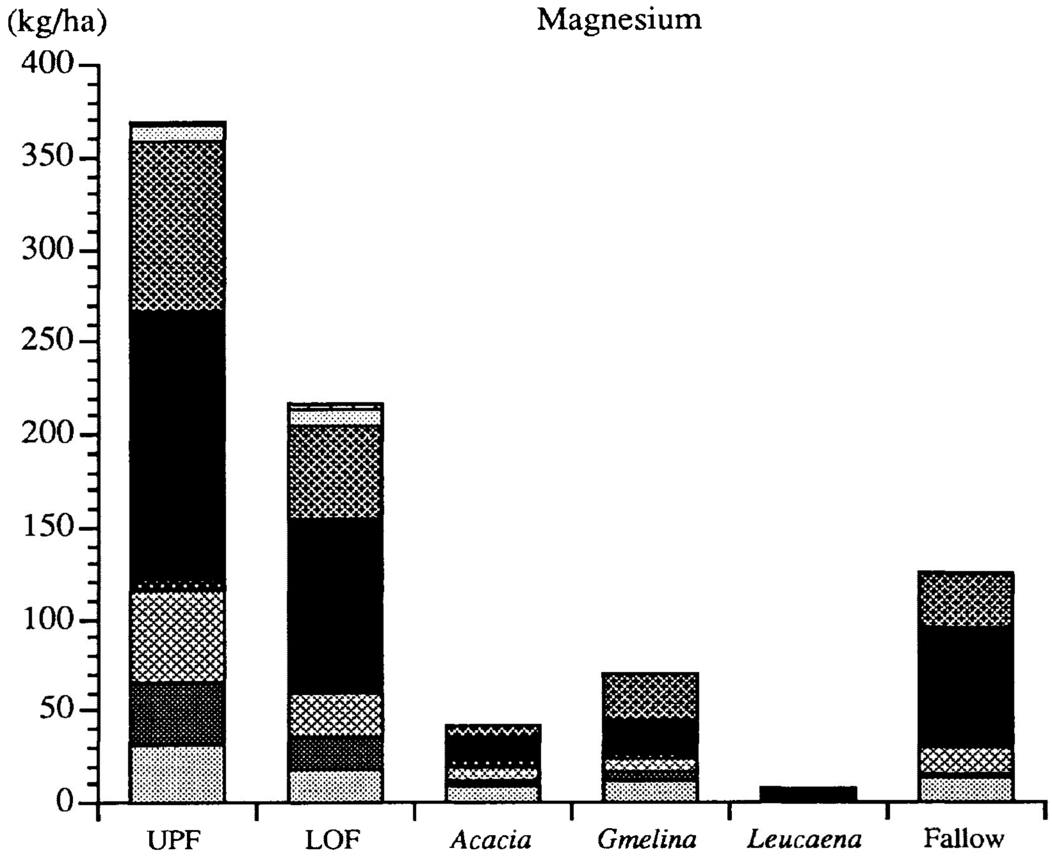


Figure 14. *Continued*.

5.5 Nutrient Capital in Biomass and Soil

Nutrient capital does not include amounts in roots since no data on root biomass or root nutrients were collected. Plots after clearing and burning are not included because biomass was nil or insignificant. Plots after abandonment have not been included because no biomass or nutrient data were collected. Figure 15 shows the relative amounts of nutrients in litter, undergrowth, overstorey and soil of each treatment site, in kg per ha.

The majority of N and P capital was held in the soil; for N the range was 80 % (UPF) to 95 % (*Leucaena*); for P the range was 88 % (UPF) to 98 % (*Leucaena*). Within the biomass, UPF contained the largest amounts of N and P compared to other treatments. Among rehabilitation treatments *Acacia* had the largest amounts of N and P in the aboveground biomass; these amounts were similar to that of LOF even though LOF had almost twice the biomass of the *Acacia* plantation. The other rehabilitation treatments contained considerably smaller amounts of N and P in their biomasses.

Most N and P was contained in the overstories except for the *Leucaena* plantation where undergrowth contained about twice the amount of that in the overstorey. The amounts of N and P in litter and undergrowth appeared insignificant in all plots. Overall, litter contained between 0.8 and 1.6 percent of total N capital and 0.2 to 0.4 percent of total P capital. Amounts in undergrowth were 0.3 to 2.4 percent and 0.1 to 1.2 percent for N and P, respectively.

The proportion of K was greater in aboveground biomass than soil for all forest types except the *Leucaena* plantation (Figure 15) which had 51 percent of its K stocks in the soil. The remaining plots contained 54 to 87 percent of K stocks in the aboveground biomass, with the largest amount in UPF. The overstories contained the largest amounts of K, with the exception of the *Leucaena* overstorey which contained only 6.4 percent of the total stocks on site. Amounts in litter ranged from 0.6 to 4.5 percent, while undergrowth held 1.3 to 38.4 percent, the latter amount being contained in *Leucaena* undergrowth.

Larger amounts of Ca were found in the aboveground biomass than in the soil of UPF, LOF, *Acacia* and fallow forest plots, ranging from 56 to 84 percent. *Gmelina* and *Leucaena* plantations had only 22 and 18 percent of Ca in their respective aboveground biomasses. The quantity of Ca in *Gmelina* biomass, in percentage terms, appears small; however, this is due to the large amount of Ca in the *Gmelina* soils. Figure 15 indicates that *Gmelina* biomass contained similar amounts of Ca to that of fallow forest biomass. Overstories contained 5.9 % (*Leucaena*) to 81.3 % (UPF) of all Ca stocks, while litter contained 1.8 to 12.8 percent and undergrowth contained 0.8 to 6.7 percent.

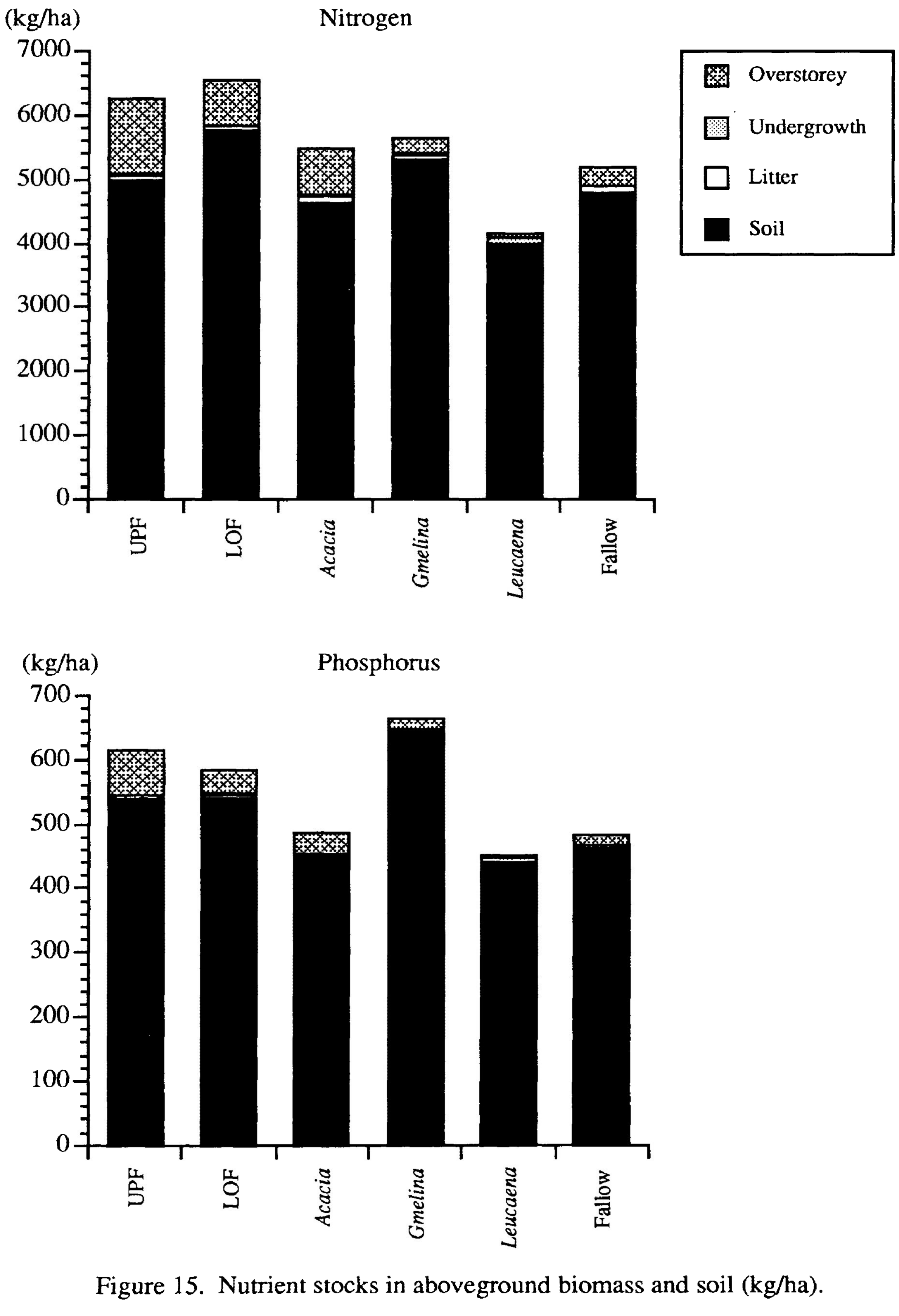


Figure 15. Nutrient stocks in aboveground biomass and soil (kg/ha).

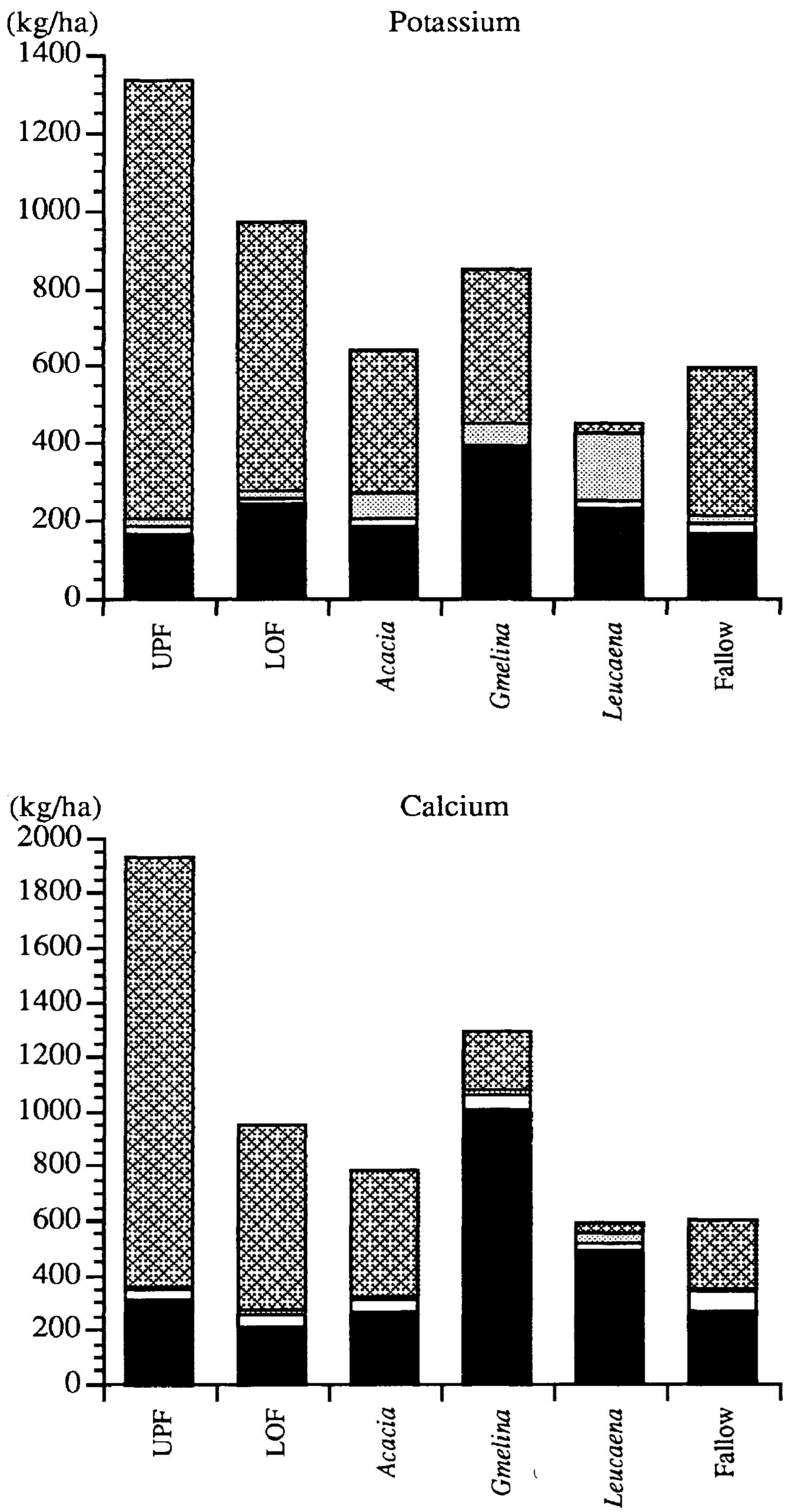


Figure 15. *Continued.*

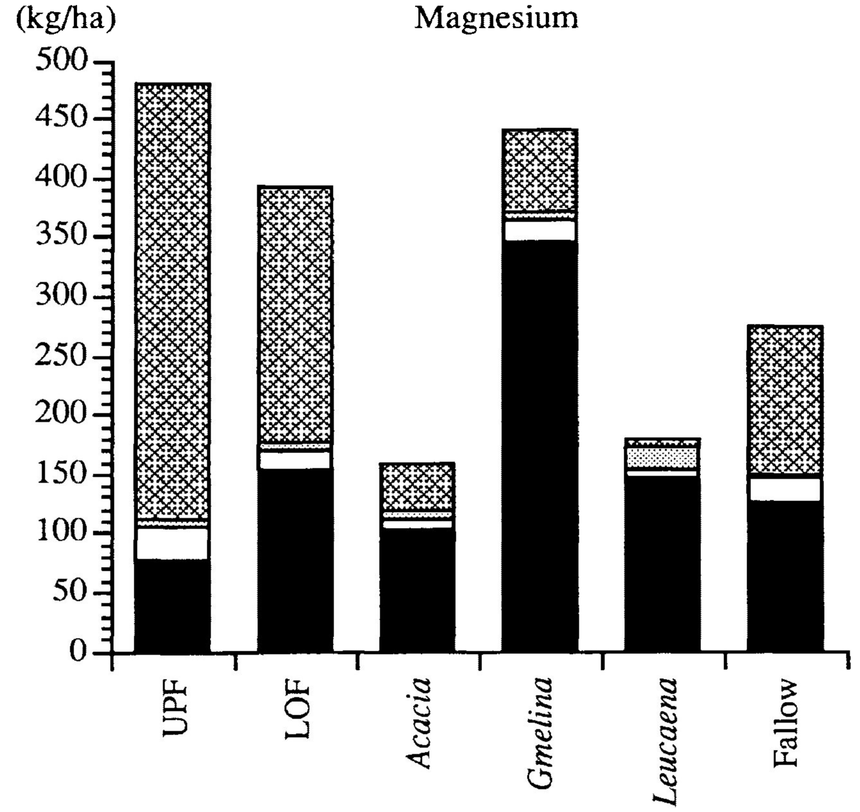


Figure 15. *Continued.*

Undisturbed primary forest, LOF and fallow forest had larger proportions of Mg in aboveground biomass than in soil (Figure 15), ranging from 54 to 84 percent. Plantations had smaller amounts of Mg in biomass ranging from 19 to 35 percent. Overstories contained the largest amounts of Mg, with the exception of *Leucaena*, which had larger amounts in undergrowth biomass. Litter contained 4.0 to 7.7 percent while undergrowth contained 1.2 to 10.2 percent of total Mg stocks. The amount of nutrients in aboveground biomass did not appear to affect amounts in the soil.

5.6 Species Composition

A list of the undergrowth species found in the 10 m x 20 m plots is given in Appendix IX. Undergrowth species in LOF plots were not recorded, but undergrowth in the UPF plots was comprised mainly of trees and shrubs (≤ 3 cm dbh), non-woody plants and climbers. No grass or fern species were found in the UPF plots; however, these plots had the greatest species richness in the undergrowth, with a combined total of over 190 species in the two biomass plots (Plots A and B). Due to the large number of species in the UPF plots a separate species list for trees and shrubs (≤ 3 cm dbh) is given in Appendix IX B. In contrast to the UPF plots, undergrowth in the plantation plots was composed mainly of fern and grass species with a few non-woody plants and small climbers (Appendix IX A). Only two of the species in the rehabilitation treatments (*Anisophylea disticha* and *Vitex pubescens*) were present in the UPF plots.

A list of the overstorey species (trees > 3 cm dbh) found in the UPF, LOF and fallow forest plots (both the 10 m x 20 m and 1 ha extension plots) is given in Appendix X. In the 10 m x 20 m plots the UPF had the greatest species richness with a mean of 51 species; LOF had a mean of 48 species. Fallow forest had a much lower species richness with a mean of 18 species. A total of 98 species was found in the two 10 m x 20 m UPF plots; only 5 of these species were observed in both plots. The LOF plots had a total of 84 species with 12 species observed in both plots. Fallow forest plots had a total of 27 species, 9 of which were found in both plots.

Species richness in the one hectare extension plots (trees > 30 cm dbh) was also greater in the UPF plots at a mean of 54 species, while the LOF plots had a mean of 39 species. Of the 299 tree species and 3 liana species listed in Appendix X only 3 tree species in the UPF plots were also observed in the fallow plots including *Gironniera nervosa*, *Pentace curtisii* and *Pleiocarpidia enneandra*. Only four species found in the LOF plots were also observed in the fallow plots including *Alstonia angustifolia*, *Ficus stolonifera*, *Macaranga hosei* and *Shorea pauciflora*. Of the 280 tree species observed in the UPF and LOF plots only 32 were common to both forest types; the 3 liana species were all found in the UPF plots. Several lianas were also found in the LOF plots; however, the species were not identified.

6.0 DISCUSSION

6.1 Soils

6.1.1 Physical Analysis

Results of the soil analysis show that there was a large variation in sand, silt and clay content between some plots (Appendices II and III). This variation in particle-size distribution can affect soil chemical and physical conditions, thus causing differences between plots that are not due to treatments or disturbance by shifting cultivators. Soils with a high clay or humus content are capable of adsorbing larger amounts of nutrients and water than soils with large amounts of sand (Brady, 1990). An example of this may be in the topsoil of UPF, Plot B, where sand and clay content were 27.5 percent and 40.7 percent, respectively (Appendix III). This clay content was considerably higher than the other two UPF plots and base saturation and exchangeable cations in Plot B were found to be 1.7 to 7.6 times greater than in the topsoil of the other two plots that had less clay (Appendix IV). Soils with the highest sand content (the 1.5YAA plots) might be expected to have the lowest amount of exchangeable bases and base saturation not only as a result of shifting cultivation activity but also due to their coarser soil texture.

This illustrates a major disadvantage of chronosequence studies in that the nutrient status of a soil prior to disturbance or treatment is unknown. However, chronosequence studies assume that all soils are similar before disturbance or treatment and, further, that differences observed on the various plots are due only to treatment or disturbance. However, chronosequences are advantageous in that long-term studies of up to 80 years or more can be carried out in a relatively short period of time (e.g. Saldarriaga, 1987). The soils in this study are assumed to have had a similar nutrient status to that of UPF at the beginning of the chronosequence, except where inherent soil physical characteristics may be the dominant cause of differences in nutrient status.

The main physical soil attributes likely to be affected by logging and shifting cultivation activity probably are bulk density and porosity. Compaction and increased bulk density in the LOF plots was expected as a result of machinery brought on site to harvest trees. Compaction as a result of logging has been reported by numerous authors (Abdulhadi *et al.*, 1981; Incerti *et al.*, 1987; Kamaruzaman, 1988). Malmer and Grip (1990) found that harvesting in Sabah was associated with compaction in the top five centimeters of clay soils where bulk density increased from 0.82 to 1.28 g/cm^3. The increase in topsoil bulk density in the LOF plots was comparable to these changes even though soil sampling was carried out seven years after logging.

The relatively low bulk density found on the 2DAB and 2WAB plots may be an indication of recovery due to the absence of human activity since the actual logging operations. However, more samples would be required to make any concrete conclusions. It is also possible that soil on burned sites was not exposed to direct impact of rain after disturbance long enough to affect compaction, especially if there was little or no rain since burning. Increased bulk density 1.5 years after abandonment may be due to the continued effect of human activity during cultivation as well as the impact of rain on exposed soil. Significant changes in bulk density due to clearing and burning, and shifting cultivation have been observed by several authors (Arimitsu, 1985; Eden *et al.*, 1991; Martins *et al.*, 1991). Intensive rainfall accompanied by a rapid decline in organic matter is considered one of the main reasons for compaction and decreased porosity (Sanchez, 1976).

Bulk density in the rehabilitation treatments was generally higher than that of UPF indicating that soil structure may not have recovered to normal undisturbed levels. Meijer (1970) reported that areas of intensive soil disturbance could be traced as far back as 40 to 45 years; therefore, recovery of soil structure and macroporosity is expected to be relatively lengthy. Increased bulk density reduces water infiltration, soil aeration and root development. Thus, bulk density is important in terms of site rehabilitation because it may result in reduced site productivity if compaction becomes too severe.

Decreased soil porosity in the LOF plots was probably the result of exposing bare soil. Cunningham (1963) reported that exposure of bare soil due to logging resulted in a decrease from 15 percent to 10 percent in macropores and a small but significant decrease in total porosity. In addition, silt and clay content decreased in the A horizon and increased in the B horizon. It was suggested that this movement of clay reduced porosity by clogging large pores. Movement of clay was attributed to a large drop in organic carbon content and a loss of soil aggregation as a result of exposure. Porosity in this study appeared to decrease in the upper horizons by seven to eleven percent from the LOF plots to the 2WAB and 1MAB plots (Appendix III). Cunningham (1963) reported similar decreases in total porosity from 52 to 43 percent after clearing tropical forest and a three year period of cultivation.

Clearing and burning results in increased exposure of bare soil and, hence, a further decrease in soil porosity. Rapid decomposition and disappearance of organic matter, as a result of clearing and burning, exacerbates the problem because organic matter is correlated with aggregate stability and plays a cementing role between primary mineral particles (Lugo-Lopez and Juarez, 1959; Briones and Veracion, 1965; Brady, 1990). Hudson

(1984) reported that bare topsoil has reduced infiltration rates due to compaction from raindrops and the resulting loss of structure and soil aggregation. Reduced infiltration results in increases in runoff which in turn leads to erosion and nutrient losses (Kang and Lal, 1981; Lal, 1986), thus furthering site quality degradation.

Porosity was not measured during cultivation; however, macropores probably were greatly reduced throughout the cultivation period. Grohmann (1960) reported that cultivated Ultisol soils in Brazil had a decrease in soil aggregates larger than 2 mm by about half and, conversely, a very large increase in aggregates less than 0.21 mm. These aggregates can easily clog macropores and reduce water infiltration. Assuming that percent macropores decreased below the 46 percent in the 1MAB plots (Appendix III), as a result of two or three years of cultivation, it would appear that percent porosity increases after abandonment. The higher porosity in the 1.5YAA plots and in the rehabilitation treatments was probably the result of reduced soil exposure and increases in organic matter content. Figure 4 indicates that organic C was increasing during the rehabilitation treatments, with all but *Leucaena* approaching UPF levels. Fallow forest had the greatest porosity compared to other rehabilitation plots (Appendix III) probably because it was not disturbed after abandonment as were the plantation plots.

6.1.2 Chemical Analysis

6.1.2.1 Soil pH

Soil pH was measured in both water and KCl solutions. Measurement of pH in KCl solution gives an indication of the potential or exchange acidity due to the presence of Al and H ions adsorbed on exchange surfaces of soil colloids. In contrast, pH of a water solution is only an estimate of the pH of the soil solution. Exchangeable Al is generally considered the dominant cation associated with soil acidity (Sanchez, 1976). The general rise in pH after clearing and burning (Appendix IV) results from the addition of bases contained in the ash from burned biomass. The ash, which had a pH of 9.8, did not appear to have an immediate effect on soil pH, but did result in increased pH two weeks after burning by which time it, along with exchangeable bases, had sufficient time to leach into the soil profile (Appendix IV). Kumada *et al.* (1985) also found increases in pH after clearing but prior to burning and suggested that this was due to bases leaching out of felled vegetation through rainwash. The advantage of increased pH following burning is that base saturation is increased and more nutrients become available to plants.

After burning and during cultivation, however, nutrients are also lost from the site, mainly because the biomass and root systems have been burned or killed and can no longer capture and keep nutrients within the nutrient cycle. Cations are leached or eroded away, and organic matter is rapidly decomposed and is not readily replaced. Decreased pH and lowered nutrient availability results, and may be one of the main causes of abandonment to fallow. This appeared to be the case in this study where pH levels in the cleared and burned plots and 1.5YAA plots were higher than in the UPF and LOF plots, but were lower in the 1.5YAA plots than in the 1MAB plots. The trend appeared to continue in the *Acacia* and fallow plots which had lower pH values than the 1.5YAA plots. *Gmelina* and *Leucaena* topsoils, however, had similar pH levels to the 1.5YAA plots; probably the result of higher levels of exchangeable bases on these sites. Burning affects pH in a similar manner throughout the depth of the profiles, although the effect becomes less pronounced with soil depth. Similar effects of clearing, burning and cultivation on soil pH were observed by Zinke *et al.* (1978) and Jordan (1987).

6.1.2.2 Organic Carbon

There did not appear to be a significant change in the amount of C in soil after logging indicating that eight years may be a sufficient period of time for LOF to recover to UPF carbon levels (Figure 4). However, two days after burning there was a sharp drop in C to its lowest level in the chronosequence. Decreases in C immediately after burning have been reported by Kumada *et al.* (1985) and Brown and Lugo (1990). Kumada *et al.* (1985) observed that burning resulted in insignificant direct losses of C, and he attributed these losses mainly to erosion which continued for up to ten months after burning. Sanchez (1976) also noted that sharp decreases in C after burning were probably associated with erosion losses from topsoil. Burning volatilizes almost all of the C present in the biomass (Palm *et al.*, 1986) but has little effect on soil organic matter because soil temperatures usually are not high enough for a sufficiently long period to result in combustion (Sanchez, 1976). However, in this study, C levels were greater two weeks after burning than immediately after burning and did increase above UPF and LOF levels (Figure 4). Other studies (Nye and Greenland, 1964; Seubert, 1975; Andriesse, 1977; Zinke *et al.*, 1978) also have observed increases in C after burning. Sanchez (1976) attributes increases in C after burning to incomplete combustion of biomass and the measurement of charcoal particles (which may have been carried into the soil following rain) as organic carbon. The difference between the two sites (two days and two weeks after clearing and burning), in this study, also may have been caused by differences in the quality of burn between the sites, as well as differences in previous site use or inherent site characteristics. The difference may also be related to sample size and further replication of plots would be required to determine what actually occurs immediately after burning on these sites. However, it appears clear that the trend two weeks after burning is a decrease in C towards 1.5 years after abandonment.

These observed decreases in C two weeks after burning until 1.5 years after abandonment may in part be due to erosion, as mentioned above, but is also likely to be the result of increased rates of organic matter decomposition. Tulaphitak *et al.* (1985) observed that the rate of decomposition was twice as rapid in the first year of slash-and-burn agriculture compared to that in undisturbed forest, and that nearly thirty percent of the total soil organic matter was decomposed within the first year of cultivation. Andriesse's (1977) study on soil nutrients, during a twenty year shifting cultivation cycle in Sarawak, also indicated decreases in soil organic matter after cultivation. Similar results were also reported by Zinke *et al.* (1978) and Cerri *et al.* (1991).

The overall loss of C is due to an imbalance between C losses and inputs. Agricultural crops do not produce enough biomass to balance the increased rate of organic matter decomposition and losses through erosion. This loss of C is critical because soil organic matter contains nutrients and is the main nutrient exchange surface in the humid tropics (Brady, 1990; Cerri *et al.*, 1991). However, as biomass increases during the fallow period soil organic matter is eventually replenished (Nye and Greenland, 1960; Popenoe, 1960; Zinke *et al.*, 1978). Rates of carbon-increase, among different studies, vary with site characteristics and conditions. Carbon in this study increased in the rehabilitation treatments, approaching UPF and LOF levels, with the exception of *Leucaena* which, due to poor biomass production, did not show much improvement in soil C content (Figure 4).

6.1.2.3 Total Nitrogen

Total soil N is related to soil organic matter and, therefore, is correlated to soil carbon content (Butt and Ting, 1983). The results (Figure 4) indicate that N levels generally follow the same trend as C levels along the chronosequence. The lower amount of soil N two days after burning, in this study, is related to the low soil C levels in the same soil. However, the N content in the UPF and LOF is somewhat greater than that in plots affected by clearing and burning. This is probably an indirect result of the fire. Nye and Greenland (1960) observed that burning results in nearly all N in the biomass being lost to the atmosphere as ammonia, gaseous N or the oxides of N; therefore, little addition of N was expected from ash. Nitrogen in soil organic matter, however, was not affected by burning (Nye and Greenland, 1960).

The explanation for N losses may involve effects of increased soil pH after burning on increased soil microorganism populations (Corbet, 1934), thus resulting in increased nitrification (Stock and Lewis, 1986). Montagnini and Buschbacher (1989) reported increased nitrification rates after clearing and burning that were up to 3.6 times that observed in undisturbed forest soils and resulted in increased losses of N through leaching. Increases in N leaching are explained by Bormann *et al.* (1968) who observed that clear cutting a forest ecosystem in New Hampshire reduced transpiration, thus increasing gravitational water flow and resulting in greater leaching of soil nutrients, including soil N. Root surfaces which absorb nutrients are lost through clearing and burning; thus, more N and other nutrients are lost by leaching.

However, some studies have reported increases in N from ash deposits (Stock and Lewis, 1986) or from organic N being converted to a soluble nitrate form (Guha, 1969; Adedeji, 1984; Jordan, 1987). These increases are very short lived and any excess in N is rapidly lost through leaching as soluble nitrate or through volatilization. Guha (1969) found that as much as 750 kg per ha of ammonium sulfate leached from the top 30 cm of soil in approximately three weeks as a result of clearing and burning. Bormann *et al.*, (1968) observed that 57 kg per ha of nitrate N was lost in stream water after clearcutting a hardwood forest in New Hampshire. Herrera *et al.* (1981) also attributed the rapid loss of N to the solubility of nitrate N. Losses from volatilization have been estimated to be about twelve percent of total losses on uncropped soils (Allison, 1955). Whether increases or decreases in soil N are observed, after clearing and burning, appears to be a matter of when the sampling is done; however, the end result appears to be an overall decline in soil N.

Nitrogen levels continued to decline until after abandonment (Figure 4), presumably because of limited root surface area on the abandoned sites, and because increased oxidation of organic matter resulted in increased leaching and volatilization of nitrogen. Nitrogen levels increased during the rehabilitation phases; however, levels remained lower than that in UPF and LOF soils. Adedeji (1984) also observed that N levels in a six year old fallow forest remained lower than levels in undisturbed forest. This was thought to be due to higher leaching and run-off losses because young successional forests have not yet attained the "closed" cycle of a mature forest.

It is somewhat surprising that N levels in *Acacia* soils (Figure 4) were not higher considering the large amount of nitrogen rich litter the overstorey produces (Figure 11). This may be an indication that, in addition to N losses, *Acacia* rapidly and efficiently takes up N soon after it is mineralized. Nye and Greenland (1960) noted that the expected increase in soil N in a ten year old fallow forest would be about 400 kg/ha or 40 kg/ha/year in the top 30 cm of soil. In this study all rehabilitation treatments had soil N levels that were more than 1000 kg/ha greater than in the 1.5YAA soils suggesting mean annual increases of 100 to 154 kg/ha..

6.1.2.4 Carbon-Nitrogen Ratio

The C:N ratio gives an indication of the rate of decay of organic matter and the availability of nitrogen (Brady, 1990). The C:N ratios are narrow throughout the chronosequence (Appendix IV) indicating that soil organic matter is well decomposed and is relatively stable compared to fresh organic matter. The C:N ratio is somewhat more narrow after burning due to the loss of C, but becomes wider 1.5 years after abandonment as organic matter is added by the return of biomass to the site. A narrow C:N ratio after burning indicates there is a greater amount of N available for crops, exceeding the needs of soil organisms involved in organic matter decomposition (Zinke *et al.*, 1978). However, Mouttapa (1974) observed little variation in the C:N ratio between cultivation and fallow periods, stating that this was due to increases in N being proportional to increases in C. The low C and N levels in the soils throughout the chronosequence are typical of tropical soils (Sanchez, 1976) and are thought to be a result of rapid decomposition associated with the prevailing high temperatures and rainfall (Andriesse, 1972).

6.1.2.5 Total Phosphorus

There was little apparent change in P in the top 30 cm of soil among UPF, LOF and the cleared and burned plots (Figure 4). Jordan (1987) also reported little change in soil P throughout a seven year shifting cultivation and fallow cycle. He attributed this to P remaining immobile and fixed in the soil; and found that only two percent of total P in the soil was in an exchangeable form. Charley and McGarity (1978) observed that P does not leach appreciably because it quickly forms insoluble iron and aluminum compounds by precipitation and adsorption reactions. Jordan (1987) found that soluble P was not leached because of fixation by iron and aluminum oxides that are common in tropical soils. Phosphorus in these insoluble compounds is not readily available to many crop plants and as a result P deficiency is a common problem in tropical agriculture (Olson and Engelstad, 1972). Thus, P deficiencies are probably a contributing factor to eventual abandonment of many tropical soils.

In contrast, in Sarawak, Andriesse (1977) found significant increases in available P, of thirty to forty times, on newly burned sites compared to that in unburned forests. However, these P levels were found to decrease almost to their initial values after cultivation. Zinke *et al.* (1978) observed increases in soluble P after clearing and burning that were 5.5 times the amount in an unburned forest, but these levels also decreased after the first year of fallow. It is rather surprising that the high P content in ash (1233 ppm) in this study (Appendix IV) did not increase the amount of total P in the top 30 cm of soil between two weeks and one month after burning. However, this may be attributed to the type of chemical analysis; an increase may have been observed if soils had been analyzed for available P.

In this study, the most notable difference in total P was 1.5 years after abandonment where it was at the lowest level in the chronosequence (Figure 4). Popenoe (1960) also observed a large decrease in P two years after abandonment. Decreases in P after abandonment may be related to decreases in organic matter. Andriesse (1977) states that organic matter build-up and decomposition are related to the P content of organic matter, and the ability of a soil to keep exchangeable nutrients within the cycle. Consequently the greater amounts of organic matter in the rehabilitation treatments may be related to the respective build up of P. The high P content in the *Gmelina* plantation soil may be related to the high Ca and Al levels in that soil (Figure 4). Soils high in Ca and Al have been found to show rapid P-fixation (Andriesse, 1977). The higher level of exchangeable bases also results in increased pH. This results in iron and aluminum becoming less soluble; hence, phosphates complexed with iron and aluminum at low pH become soluble and available for the agricultural crop that will follow (Jordan, 1985). However, Figure 4 shows values for total P; thus, the *Gmelina* plantation may still have relatively low amounts of available P.

Nye and Greenland (1960) observed that during fallow it is expected that organic P will increase in the soil at a rate of 1.3 to 3.4 kg/ha/year in the top 30 cm of soil. All rehabilitation treatments in this study appeared to have surpassed this rate of accumulation, above the amounts in the 1.5YAA plots for total P; however, only *Gmelina* has attained and surpassed UPF and LOF levels.

6.1.2.6 Exchangeable Bases

The decreases in K and Mg in the topsoil two days after burning was probably the result of leaching losses during the period between forest clearing but prior to burning (Ewel *et al.*, 1981; Jordan, 1985). After clearing, sites are left to dry for one month or longer. During this time biomass dies, begins to decompose, and no longer takes up nutrients; thus, exchangeable cations in the soil are easily leached away. Ewel *et al.* (1981) found significant losses of nutrients due to tree harvesting and to leaching after cutting but prior to burning. Similar losses were reported by Andriesse (1977) on slash-and-burn sites prior to burning, and by Bormann *et al.* (1967) in temperate forests that had been clear cut. This may also be the cause of higher concentrations of Ca, in this study, in the mid and lower horizons two days after burning (Appendix IV). Potassium and Mg concentrations, however, do not appear to increase in the lower horizons. This may be due to K and Mg being more water soluble and more loosely held by soil colloids than Ca; hence, they may have been more easily leached from the soil profile.

The increases in exchangeable bases in soil two weeks and one month after burning (Figure 4) were probably due to nutrients leaching into the soil from the overlying nutrient rich ash. Exchangeable base content in ash two days after clearing and burning was very high at 70.5, 45.3 and 39.4 me/100 g for K, Ca and Mg, respectively (Appendix IV). Downward movement of relatively soluble Ca and Mg is made favourable because permanent exchange sites on mineral and organic colloids become saturated with Ca and Mg and displace exchangeable Al (Sanchez, 1976). Downward movement of Ca and Mg is fairly easy due to the well aggregated porous nature of the soils, and due to high rainfall. This increase in exchangeable base nutrients results in increased soil pH and base saturation which results in increased nutrient availability. However, at 1.5 years after abandonment, Ca and Mg levels generally were similar to or below UPF and LOF levels (in the top 30 cm of soil); in the mid and lower horizons Ca and Mg were at the lowest levels in the chronosequence (Appendix IV). Potassium levels were also lower but were still higher than that in UPF soils. The overall decline in exchangeable bases is due to the effects of organic matter decomposition, leaching, erosion and nutrient removals in the crop harvest. Decreases in exchangeable bases results in increased soil acidity which further reduces the availability of nutrients, especially to crop plants.

Exchangeable bases in the top 30 cm of soil generally were higher in the rehabilitation plots than in the 1.5YAA plots, although somewhat variable (Figure 4). Potassium, in fallow and *Acacia* soils, was the only nutrient that was lower than levels at 1.5 years after abandonment. In both fallow and *Acacia* just over seventy percent (428 and 454 kg/ha, respectively) of all K on each site was contained in the vegetation (Figure 15) with the remaining amount in the exploitable soil (to 30 cm depth). The K levels in soils under the *Acacia* treatment may be lower, in contrast to *Gmelina*, due to rapid forest growth and the consequent greater nutrient demands. Thus, build-up of nutrients in soil is dependant on a balance between the addition of nutrients through litter fall, atmospheric inputs, rainwash and weathering, and losses due to uptake by vegetation and leaching into the subsoil (Nye and Greenland, 1960).

The length of recovery time is also dependant on the history of the site including the number of times it has been cultivated and the length of intervening fallow phases. Sites that have been cultivated for many years may have greater loss of nutrients associated with leaching and with crop removal; therefore, nutrient build-up in soil will take longer. It is possible that the rehabilitation sites may have different site histories. It should also be noted that plantation treatments had an advantage over fallow forest in that they were fertilized (NPK; 14-14-14) immediately after planting and then tended and fertilized three, six and possibly twelve months afterwards. These fertilization treatments were not, however, expected to have had an effect on the nutrient levels shown in Figure 4 because the last treatment was given five and a half to six years prior to this study. In addition the plantation areas also were cleared and burned prior to planting. Lundgren (1978) observed that the effects of burning on soil subside after about seven years under tropical conditions. Since plantation treatments were 6.5 years old at the time of study their soils may still have been influenced by the fire. In contrast, the fallow forest, being slightly older, would be less influenced by fire, at the time of study.

Among rehabilitation treatments *Gmelina* had the highest exchangeable base content and base saturation of all treatments in the topsoil and in most of the mid and lower horizons (Appendix IV). Since there was only one *Gmelina* soil profile it was uncertain whether this was an effect of the *Gmelina* plantation, an inherent effect due to better site characteristics, or possibly due to sampling error. However, Russell (1987) also found dramatic increases in soil Ca in an 8.5 year old *Gmelina* plantation in Brazil. He cites unpublished data (Jordan, 1983) which indicated that additional Ca may represent Ca bound in recalcitrant humic compounds. These results further indicated that exchangeable Ca, determined with dilute double acid method, represents only about fifty percent of total Ca in the upper horizons and ten percent or less in the lower horizons. Chijioke (1980) also found higher levels of exchangeable bases, especially Ca, in soils underlying *Gmelina* plantations and suggested that this was probably an indication that *Gmelina* has a greater recycling efficiency than other plantation species.

Acacia and fallow forest generally had lower levels of exchangeable bases in the topsoil than *Gmelina* and *Leucaena* (Figure 4). This suggests that the *Acacia* and fallow treatments take up more exchangeable bases than they return through litter fall and rainwash. Russell (1987) observed that soil P, K, and Ca decreased with increasing rotation age in pine plantations in Brazil, due to nutrient uptake by trees. This also appeared to be the case for N, P, Ca and Mg in *Gmelina* plantation soils in Nigeria (Chijioke, 1980). Decreases in P, Mg and Ca also were observed in Nigeria in one to six year old fallow forest soils, approaching the lower undisturbed forest levels, while K decreased well below undisturbed levels (Adedeji, 1984). The *Acacia* and fallow soils in this study had P, K and Ca levels similar to or lower than those in UPF and LOF soils (Figure 4). If the above observations are true for the rehabilitation treatments then continued nutrient uptake in *Acacia* and fallow plots should result in decreased nutrient levels below UPF and LOF levels.

Decreased soil nutrient levels would appear to contradict the purpose of the rehabilitation treatments, since the soils would be more depleted of nutrients than prior to clearing and burning. However, rapid nutrient uptake, resulting in low soil nutrient status, retains nutrients within the ecosystem which might otherwise be lost through leaching. Furthermore, Chijioke (1980) observed that immobilization of nutrients in the standing biomass decreased with increasing tree age; Wells and Jorgensen (1979) reported that decreases in soil nutrients occurred only for the first five to fifteen years after plantation establishment in temperate forests. It would, therefore, be expected that as the age of rehabilitation treatments increase, growth rates will slow, as will nutrient uptake. Nutrient inputs from litter, rainwash and the atmosphere also may eventually balance the nutrient budget or even result in nutrient increases in the soil, thus returning soil nutrients to UPF levels. Adedeji (1984) noted that after a sufficiently long period, fertility levels in soil will be restored to nearly the original levels. This is probable in the near future since *Acacia* and most fallow forest species are relatively short lived. As the trees mature, nutrient uptake will slow and when trees eventually die, nutrients in the standing biomass will be released into the soil through decomposition. The *Gmelina* and *Leucaena* soils do not appear to be as seriously depleted of nutrients because they were above or similar to UPF or LOF levels.

6.2 Stand Growth Characteristics

Growth characteristics (Table 3) in the UPF, LOF, *Acacia* and *Gmelina* plots were generally within the ranges reported in other studies cited in the Literature Review section. In contrast, the *Leucaena* plots had much poorer growth rates than most other reported areas; however, these poor growth rates were comparable to reports for other areas having extremely acidic soils. Other authors (NRC, 1984) have indicated that *Leucaena* is not a good species for reforestation on acidic soils. The fallow forest in this study had somewhat better growth rates than those reported for another fallow forest in Sarawak (Chai, 1981).

6.3 Biomass

6.3.1 Litter

The differences in small-litter standing crop (Figures 5 and 6) reflects the different growth rates (Table 3) and also suggests different rates of litter production and/or different rates of decomposition found on the various plots. The low litter biomass under *Leucaena* is not surprising since its total aboveground biomass was very low (Table 4). Tree biomass contributed only 1.2 t/ha, while the remaining litter was contributed by undergrowth (Figure 5). The low litter biomass under *Gmelina* (Table 4) may be attributed to its low overstorey foliage biomass of 2.5 t/ha (Figure 9) since foliage contributed 46 percent of the total litter biomass. Foliage biomass of the *Gmelina* overstorey appeared to be low due to insect defoliation during the study period.

It is surprizing, however, that the remaining plots do not have a greater variation in litter biomass considering the large differences in overstorey biomass (Table 4). The largest proportions of litter were contributed by overstorey foliage and branches (< 3 cm dob), with the exception of *Acacia* which had large contributions from ferns. The large differences in overstorey biomass (Figure 9) between these forest types would suggest a larger variation in litter standing crop, yet fallow forest, which had the lowest overstorey biomass in these categories (except for *Leucaena*), had the largest small-litter standing crop (Table 4). Ewel *et al.* (1976) observed that successional forests of different ages produced different amounts of litter; however, they also reported that 10 to 12 year old fallow forest had similar litter fall production to that of a mature forest. It has also been observed that litter from successional species decomposed more rapidly than that of mature forest species. Brown and Lugo (1990), in a review of tropical secondary forests, reported that litter production rates are 12 to 13 t/ha/year by age 12 to 15 years; and that litter production is a higher fraction of net primary production than stemwood biomass production. This agrees with the observation that litter production of the fallow forest in this study (Figure 5) is relatively high.

The small-litter standing crops estimated for UPF and LOF in this study (Figure 5) were within the range of those found in other mature tropical forests at 3.2 to 7.2 t/ha (Ogawa, 1978; Anderson *et al.*, 1983; Proctor *et al.*, 1983b). Observations of fallow forest in this study also agree with studies of other fallow forests ranging from 3.4 to 7.4 t/ha (Nye and Greenland, 1960; Koopmans and Andriesse, 1982). The *Acacia* litter in this study was slightly lower than the 7.1 t/ha reported by Lim (1988). *Gmelina* litter observed in this study was much lower than the 10 to 22.7 t/ha reported for 5.5 to 12.5 year old *Gmelina* plantations in Brazil (Chijioke, 1980; Russell, 1987), but higher than the 0.7 to 1.9 t/ha reported for *Gmelina* of the same age in Nigeria (Chijioke, 1980).

6.3.2 Undergrowth

Undergrowth ranged from 0.7 % (UPF) to 40.3 % (*Leucaena*) of the total biomass (Figure 8). Although this percentage range is broad the actual weight of undergrowth (Figure 7) does not vary much between UPF, LOF, *Acacia* and *Gmelina* plots, ranging only from 3.2 to 3.6 t/ha. Undergrowth in the plantations appeared much thicker and heavier than that in UPF and LOF yet the biomass did not differ significantly, with the exception of *Leucaena.* This may be explained by the composition of the undergrowth. The UPF and LOF undergrowth was comprised of just over 80 percent woody stems, while in plantations grass and ferns made up 80 to 96 percent of the biomass. Oven-dried leafy vegetation lost more moisture than woody vegetation; thus, an equivalent fresh weight biomass of these two categories would result in a lower dry weight biomass for leafy vegetation. It is noteworthy that although the type of undergrowth vegetation was different in *Acacia* and *Gmelina* plantations, the biomass production was still similar to UPF and LOF.

The large undergrowth biomass in the *Leucaena* plantation was due to the low overstorey biomass (Figure 9) and to the openness of the canopy. Ewel *et al.* (1983) point out the importance of establishing a good stocking of tree species early in succession, before the site is captured by vegetation that produce less wood. Lambert *et al.* (1990) observed that increased dominance of grass tends to prevent establishment of other species due to its extensive root systems. The *Leucaena* was apparently unable to overcome the dense grass, fern and vine undergrowth, even after tending treatments, and consequently suffered high tree mortality. Anon (1977) observed that establishment of *Leucaena* requires weed free conditions. In contrast, fallow forest had a high rate of tree species establishment resulting in rapid crown closure, hence the lower undergrowth biomass (Figure 7). Low undergrowth biomass, especially grasses and ferns, in fallow forest may also be attributed to differences in pretreatment. Plantations were established by clearing and burning the existing vegetation and then planting, while fallow forests were simply abandoned after crop harvest. Sim and Nykvist (1991) observed that burning prior to plantation establishment resulted in increased undergrowth biomass especially grasses. The fallow forest in this study had not been burned after abandonment and had almost no grass in the undergrowth.

Studies of undisturbed forests report a range of undergrowth biomass from 4 to 10.8 t/ha (Edwards and Grubb,1977; Proctor *et al.*, 1983a; Rai and Proctor, 1986a). Undergrowth biomass in UPF and LOF in this study are slightly below this range. The main reason for differences in undergrowth biomass between studies is in the methodology used. The studies cited above used either a larger dbh class or tree height to identify undergrowth. In this study a maximum dbh of 3 cm was used in order to remain consistent with the rehabilitation treatments. The percentage of biomass that undergrowth comprised was similar to other studies, ranging from 0.6 to 1.7 percent. Sim and Nykvist (1991) reported undergrowth biomass on selectively logged rain forest in north Borneo, similar to the LOF undergrowth in this study, at 3.3 to 5.1 t/ha.

Undergrowth biomass is generally not reported in plantation biomass studies because of its relatively low weight compared to total biomass, and because the main interest is usually in cellulose production. However, Sim and Nykvist (1991) report undergrowth biomass ranging from 1.1 to 6.3 t/ha for a 1.5 year old *Acacia* plantation. Studies of successional forests often make some reference to undergrowth. Ewel *et al.* (1983) reported that undergrowth biomass of 4.5 to 9.5 year old fallow forests in Sarawak ranged from 5.1 to 10.2 t/ha, comprising 13 to 48 percent of the total aboveground biomass. Undergrowth made up a small proportion of biomass on more productive sites, but made up almost half the total biomass on the least productive sites. The *Leucaena* plantation in this study had an undergrowth biomass comparable to that found on the least productive sites where undergrowth accounted for 40 percent of the biomass. The general trend in the chronosequence is that the greater the total aboveground biomass the smaller the proportion of undergrowth biomass, although actual undergrowth biomass may not differ significantly among treatments (Table 4).

6.3.3 Overstorey

Overstorey biomass of all treatments (Figure 9) was generally within the ranges reported in other studies. Reports on undisturbed primary forests on similar soils, in West Malaysia and Borneo, range from 422 to 873 t/ha (Kato *et al.*, 1978; Kira, 1978; Kira and Ogawa, 1971; Proctor *et al.*, 1983a; Yamakura *et al.*, 1986). Rain forest biomass in other tropical areas ranged from 290 to 649 t/ha (Ogawa *et al.*, 1961; Kira and Ogawa, 1971; Klinge *et al.*, 1975; Edwards and Grubb, 1977; Rai and Proctor, 1986a). Overstorey biomass production of the UPF in this study was 466 t/ha which is at the lower end of the range for other forests in Borneo but near the middle of the range for other tropical areas. Selectively logged forests in Sabah, Malaysia were estimated to have an overstorey biomass of 240 to 273 t/ha (Sim and Nykvist, 1991). The LOF in this study was below this range by 22 t/ha, although both forests were logged at the same time. The difference may be explained by differences in logging and the number of merchantable species per ha within the selected plot areas. However, it may be said that logging resulted in removal of about 50 percent of the overstorey biomass. Logged over forests in Puerto Rico have been reported at lower biomasses of 148 to 197 t/ha (Briscoe and Wadsworth, 1970; Ovington and Olson, 1970). It is obvious that logging removes large amounts of biomass; thus, shifting cultivators have much of their workload reduced when they select logged sites rather than undisturbed forests for clearing and this would, in part, explain their preference for using logged over forests.

Acacia had the best overstorey biomass production of the rehabilitation treatments (Figure 9). Production was slightly above the average (based on MABI), for other *Acacia* plantations in Malaysia (Lim, 1985, 1986, 1988; Lim and Basri, 1985). Compared to studies in other tropical areas (Djazuli *et al.*, 1985; Sudjadi *et al.*, 1985; NRC, 1983; Voss *et al.*, 1987) *Acacia* , in this study, appeared to be about average based on MAHI and MADI. Better biomass production of *Acacia* relative to other rehabilitation treatments may be attributed, in part, to the nitrogen-fixing ability of *Acacia*.

Gmelina had the next highest overstorey biomass production (Figure 9) of the plantations, but this was about 30 percent lower than the *Acacia* biomass. Compared to other *Gmelina* biomass production in Malaysia and elsewhere in the tropics *Gmelina* in this study was below average for most areas (Freezailah and Sandrasegaran, 1966; Chijioke, 1980; Akachuku, 1981; Tan and Sim, 1986; Russell, 1987). However, there are reports showing areas with much lower biomass production of 3 to 6 t/ha/year (Schmidt, 1981). The broad range in growth rates is an indication that *Gmelina* is site specific. Tan and Sim (1986) found that *Gmelina* growth rates were greatly affected by site quality in Sabah. Chijioke (1980) also found broad ranges in *Gmelina* biomass production due to soil type in Nigeria and Brazil. Butt and Sia (1982) observed that *Gmelina* grows on a wide variety of soils, provided they are well drained; the best growth rates are attained on deep, fertile soils. The *Gmelina* in this study were planted on abandoned shifting cultivation sites; thus, soil fertility was probably lower than required for optimum *Gmelina* growth. However, this was probably compensated for, to some extent, by the fertilizer treatments added to all plantations. If *Gmelina* is as site specific as other studies indicate, it may be questionable as to whether it should be used for rehabilitation of abandoned shifting cultivation sites because these sites are generally low in nutrients. However, *Gmelina* biomass production in this study was satisfactory. In addition, there is some indication that the *Gmelina* plantation may improve soil nutrient contents and, therefore, may have a positive effect on site recovery and rehabilitation.

Leucaena had very poor overstorey biomass production compared to the other rehabilitation treatments (Figure 9). Clearly productivity had not been restored to the site and *Leucaena* appears to have had a negative effect on site recovery. This is indicated by comparing *Leucaena* to the fallow forest. If the *Leucaena* site had been left to regenerate naturally, biomass would probably be similar to that of the fallow forest which had about ten times greater biomass production than *Leucaena*. Further proof of this was in the natural vegetation found growing along the boundaries of the *Leucaena* plantation where natural regeneration had a stand structure comparable to that found in the fallow plots. The poor *Leucaena* growth rates may be attributed to soil acidity and the species' limitations. *Leucaena* is known to be intolerant of acidic soils (Oakes, 1968; Durst, 1987), or soils high in Al. Height growth after two years has been reported to be as much as 5 to 9 m lower for more acid soils (Ahmad and Ng, 1981). Anon (1977) also observed that *Leucaena* was a slow starter requiring weed free conditions for establishment. Since the Red-Yellow Podzolic soils in Sarawak are typically very acid to extremely acid and generally high in Al content (Andriesse, 1972) it is clear that these are poor sites for *Leucaena*. *Leucaena* was first introduced as a rehabilitation species in Sarawak because of its nitrogen-fixing ability, but clearly this is outweighed by its intolerance of acidic soils. There is overwhelming evidence in the literature that *Leucaena* has not and will not grow well under the soil conditions that predominate in Sarawak; therefore, *Leucaena* should not be considered a viable species for planting on most sites in Sarawak.

Fallow forest overstorey biomass production was about 30 percent lower than *Acacia*, but comparable to that of *Gmelina* (Figure 9). However, biomass production was more than 2.5 times the overstorey biomass of other similar-aged fallow forests in Sarawak (Koopmans and Andriesse, 1982; Ewel *et al.*, 1983). These differences may be attributed to differences in soil type, the number of times sites have been cultivated, and to the length of the intervening fallow periods. The two studies cited above were located in more densely populated areas and, therefore, have probably undergone more disturbance by shifting cultivators. Sites that have been cultivated more often or for longer periods of time may be more severely depleted of nutrients (Sabhasri, 1978; Asamoa, 1980; Adedeji, 1984) resulting in lower biomass production (Uhl *et al.*, 1988). There is a broad range of overstorey biomass production reported for fallow forests in other tropical areas, ranging from 11 to 140 t/ha (Bartholomew *et al.*, 1953; Ewel, 1971; Aweto, 1981; Saldarriaga *et al*, 1988; Uhl *et al.*, 1988). The fallow forest in this study had average or slightly better biomass production than those reported in other areas.

A major difference between the four rehabilitation treatments is that plantations are expensive to establish, while there is no cost involved in allowing abandoned sites to revert to fallow forests. Since the fallow forest had comparable or better biomass production than two of the three plantations the question arises whether some plantations are worth establishing. There is no doubt that fallow forest would be preferable to *Leucaena* plantations in Sarawak. However, which system should be selected where biomass production is almost equal? Synnott and Kemp (1976) recommend that whenever there is doubt regarding the selection between natural regeneration and more intensive methods, the long-term security and robustness of natural regeneration should be given the benefit of the doubt, unless other types of management can be proven better. However, the problem is more complicated than simply selecting the best biomass producing treatment. A main drawback to natural regeneration is that it tends to give an impression of disinterest in the forest, thus leaving lands open to claims by shifting cultivators or even excision by the government for other agricultural purposes (Lee, 1981).

A further argument is that, while plantation species have a commercial value most fallow forest species are not merchantable and will be of no future use. However, through the successional process, primary species have been found to re-establish under the canopy of secondary forests (Kochummen, 1966; Kochummen and Ng, 1977; Crow, 1980; Ewel *et al.*, 1983; Saldarriaga *et al.*, 1988). Primary species were also found in the fallow forest in this study (Appendix X). The establishment of primary species is generally slow and dependent on the extent to which a site has been degraded and the distance from a seed source. Estimates of the length of time an abandoned site will take to return to primary forest biomass range from fifty years to hundreds or even thousands of years (Kochummen, 1966; Uhl *et al.*, 1982; Saldarriaga *et al.*, 1988). If there is any basis to the latter figure, it is probably an unacceptable rotation period for most tropical foresters and they would, therefore, opt for plantation establishment. However, even though commercially valuable, it is debatable whether in the long run these plantation treatments, or at least the plantation species presently used, will serve the purpose of site rehabilitation.

Although the plantations were initially established for rehabilitative purposes, they have been established on permanent forest estates. At present many plantations are still in experimental or trial stages, but there is no doubt that eventually the plantation trees will be required for timber production, as is the case in Sabah and West Malaysia. The plantation species in this study are relatively short lived. Chijioke (1980) states the rotation for *Gmelina*is five to six years, while Lim (1988) states that most species planted in Malaysia have rotations of fifteen years or less. However, many trees in the *Acacia* plots in this study were already affected by heart rot, or by black stain on exposure to air (stain-fungi); several had dieback due to pink disease (*Corticium salmonicolor*) and several trees in the *Acacia* plantation had already been killed by the disease. This plantation, at 6.5 years of age, was already showing signs of decline. Lim (1991) observed that *Acacia* growth rates decline rapidly after three or four years and is almost zero by the eighth or tenth year.

The management choice appears to be to either let nature take its course or to log the *Acacia* and salvage the wood. If the plantation is left as it is, secondary species will probably eventually dominate the stand as is indicated by secondary tree species in the encroaching undergrowth; the end result probably will be a fallow forest. Thus, it may have been pointless to establish the *Acacia* plantation because a young fallow forest was already in place prior to plantation establishment. If the second alternative of logging the plantation is taken, the rehabilitative effects of the *Acacia* plantation may be lost. Several studies have indicated that six to seven years is not a sufficient period of forest regrowth to restore site fertility after shifting cultivation (Sabhasri, 1978; Zinke *et al.*, 1978; Adedeji, 1984). It has been shown, in this study, that soil nutrient levels and soil structure have not returned to predisturbed levels. Furthermore, logging would result in additional nutrient removals from the site as well as physical damage to the soil. Figure 14 indicates that nutrient removals in the *Acacia* stems can be significant; therefore, logging would not be advisable using such a short rotation.

The solution to this problem may lie in the selection of longer-lived species. Successful plantations using *Shorea* species were established in Semengoh F. R., Sarawak, as far back as the 1920s and still exist today. Longer lived species offer a longer period of site recovery as well as a more valuable end product. If *Shorea* or *Durio* species were planted there would also be the benefit of the interim crops i.e. illipe nut and durian fruit.

6.4 Nutrients

6.4.1 Litter

The lower amounts of K and Mg in the litter of LOF, compared to UPF, (Figure 11) appears to be mainly the result of a lower litter biomass in the LOF plots by about one tonne per ha (Table 4). Calcium was the only nutrient found in larger amounts in LOF litter. As a result it might be expected that there would be a larger proportion of branch litter in the LOF plots since branches tend to have higher Ca concentrations than other types of litter. However, there was only three percent more branch biomass in the LOF litter. The difference may have, in part, been due to different species contributing to litter (Stark, 1971b; Rai and Proctor, 1986b).

There was considerable variation in litter nutrient contents among rehabilitation treatments. Much of this was due to the large difference in total litter biomass, the maximum difference being 3.8 t/ha (Table 4). This may in part explain the lower amounts of N in *Gmelina* litter and the smaller amounts of N, P, Ca and Mg in *Leucaena* litter (Figure 11); however, there are other factors that influence litter nutrient content. Stark (1971b) and Rai and Proctor (1986b) noted that some differences between undisturbed forests may be caused by the varying contribution of different species. Clearly this would be an influence in monoculture plantations, which often take up nutrients at different rates. *Acacia* had a lower small-litter standing crop biomass than both UPF and fallow forest, yet it had the highest N content in litter. This may be attributed to *Acacia*'s nitrogen-fixing ability, which was also reflected in a higher N content in the overstorey biomass. The relatively high Ca content in *Gmelina* litter also appears to be an effect of the overstorey species. Studies have noted dramatically different behavior of Ca in *Gmelina* plantation soils (Chijioke, 1980; Russell, 1987). This may be associated with the relatively high Ca content in litter since nutrients contained in litter will leach into the soil as the litter decomposes.

Differences in nutrient content may also be related to differences in the proportions of the various litter fractions contributed (Nye, 1961; Stark, 1971b; Rai and Proctor, 1986b). This may, in part, contribute to the high Ca content in *Gmelina* litter (relative to low litter biomass) and fallow litter, both of which had the highest branch fractions in litter, ranging from 33 to 39 percent of total litter biomass (Figure 6). The high K content in *Leucaena* litter, relative to its low litter biomass, appears to be due to its high grass and fern fraction which made up 53 percent of the total litter biomass. Kanapathy (1976) noted that leafy vegetation, such as grass and ferns, have higher concentrations of K than other forms of vegetation.

Differences in nutrient content in litter may also be caused by differences in leaching rates or increases in concentrations during decomposition (Rai and Proctor, 1986b). Anderson *et al.* (1983) observed that P showed small increases of approximately ten percent in the last two months of litter decomposition, in Sarawak. This may have been due to P leaching more slowly than litter was decomposing. It also has been observed that different species lose nutrients from litter at different rates (Ewel, 1976; Anderson *et al.*, 1983). Ewel (1976) also observed that K was lost very rapidly from litter in various successional forests. Potassium is rapidly leached from organic matter because it does not enter into covalent bonds with organic compounds (Phang, 1987). Anderson *et al.* (1983) also noted rapid losses of K from undisturbed forest litter, while N and P were conserved. Edwards (1982) observed that N, P and Ca were lost more slowly from litter. These differences in nutrient loss rates may explain the lower amounts of K than Ca in litter even though living biomass, especially foliage and undergrowth, contained larger amounts of K than Ca (Figures 14 and 15). The generally larger amounts of N than K in litter, in relation to the amounts in biomass, suggests that N is conserved or lost more slowly from litter, in all plots along the chronosequence.

Overall, fallow forest followed by *Acacia* appeared to have more nutrients in litter than most of the other plots, while *Gmelina* appeared to have relatively large amounts of Ca

Ca and Mg. Brown and Lugo (1990) have observed that secondary forests have a higher nutrient turnover in litter especially in the early stages when nutrients are in high demand by rapidly growing vegetation.

6.4.2 Undergrowth

Nutrient content in undergrowth is generally not reported or it is combined with the overstorey because of the insignificant amount of undergrowth biomass compared to total biomass; therefore, comparisons to other studies cannot be made. However, there are some aspects regarding nutrients in undergrowth, along the chronosequence, that should be discussed.

There is a difference between nutrients taken up by plantation undergrowth and that taken up by UPF, LOF and fallow undergrowth. Undergrowth in the three latter plots were mostly tree species (Figures 7 and 8); therefore, most nutrients will remain in the undergrowth biomass and continue to accumulate as the seedlings and saplings mature, unless they become suppressed and die. However, plantations had large proportions of grass and fern species in the undergrowth which are generally short lived. Lambert and Arnason (1986) observed that herbaceous plants play an important role in early site recovery by rapidly accumulating nutrients which would otherwise be lost due to leaching; herbaceous plants also contribute organic matter, thus improving the moisture and nutrient holding capacity of the soil. Rapid uptake of K by plants is especially important because K is highly susceptible to leaching and runoff losses during early regrowth (Toky and Ramakrishnan, 1983a, 1983b; Lambert and Arnason, 1986). However, nutrients taken up by this type of undergrowth are only temporarily immobilized and should be considered part of the mobile nutrient pool. When the undergrowth dies nutrients are released into the soil and are mineralized through decomposition of organic matter and, thus, should be available for uptake. For *Acacia* and *Gmelina* these amounts were not great; however, in the *Leucaena* plantation undergrowth accounted for 38 percent of all K (175 kg/ha) in the entire ecosystem, excluding roots (Figure 15). The amounts for Ca and Mg were much lower at 7 % (40 kg/ha) and 10 % (18 kg/ha), respectively. When vegetation dies some of these nutrients may be susceptible to leaching out of the ecosystem because disturbed sites tend to have more open nutrient cycles (Adedeji, 1984). Losses may be further exacerbated by high rainfall and the low total biomass. In the case of *Leucaena* it is apparent that undergrowth has outcompeted the overstorey for nutrients and may have contributed to the negative effect on overstorey biomass production.

6.4.3 Overstorey

The greater amounts of nutrients contained in UPF (Figure 13) is mainly due to its much greater biomass accumulation (Figure 9). Actual concentrations of N, P and K were generally lower than those found in the plant components of rehabilitation treatments. However, Ca concentrations in stemwood of UPF were generally higher than in the stemwood of other treatments and this, along with the large stemwood biomass (Figure 9) resulted in a comparatively large Ca content in the UPF overstorey. The LOF overstorey and stem biomass were 53 % (244 t/ha) and 54 % (191 t/ha) lower, respectively, than the overstorey and stem biomass of UPF (Appendix VII). This translated to 57 % (893 kg/ha) less Ca and 49 % (36 kg/ha) less P in LOF overstorey biomass (Figures 13 and 14). However, total immobilization of N, K and Mg were only about 40 percent lower. This may, in part, be due to differences in forest structure. The LOF had slightly larger proportions of foliage, bark and small branches than UPF (Figure 10) and these vegetation types generally had higher concentrations of N, K and Mg. In addition, LOF had secondary species growing in the gaps created by logging. Nutrient concentrations have been found to differ among different tree species (Tanner, 1977) and in vegetation of different ages (Grubb and Edwards, 1982). Other studies have indicated that short-lived or secondary species have higher nutrient concentrations than longer lived species (Williams-Linera, 1983; Uhl and Jordan, 1984; Uhl, 1987). The presence of secondary species and the higher proportion of younger trees in LOF are probably the main contributing factors that reduce differences in N, K and Mg content (Figure 13), relative to differences in biomass (Figure 9). Grubb and Edwards (1982) also observed that older stemwood had higher concentrations of Ca than younger stemwood. The large amounts of stemwood and bark removal during logging may account for the lower Ca content in the LOF overstorey, relative to the amount of biomass removed.

Acacia contained the largest amounts of N, P and Ca among rehabilitation treatments (Figure 13). This was probably due to its more rapid growth rate and greater biomass accumulation. It has been observed that trees with rapid growth rates take up more nutrients than slower growing trees (Chijioke, 1980; Lambert *et al.*, 1990). The high N content in the *Acacia* overstorey was also due to its nitrogen-fixing ability. *Acacia* biomass was about 45 percent (95 t/ha) lower than that of LOF (Appendix VII), yet total N content was 2 percent (17 kg/ha) higher (Figure 13). *Leucaena* also is nitrogen-fixing and in fact had the highest N concentrations in most plant components, compared to other treatments. However, overstorey biomass was so low that total N content was low compared to other treatments (Figure 13).

Gmelina biomass was about 30 percent (38 t/ha) lower than that of *Acacia* (Appendix VII), yet it contained somewhat larger amounts of K and Mg (Figure 13). However, Verbenaceae have been reported to show preferential immobilization of basic nutrients (Nwoboshi, 1972; Chijioke, 1978). This may explain the relatively high K and Mg contents in the *Gmelina* in this study; however, it is surprizing that Ca content was not higher. Fallow forest had similar nutrient contents to that of *Gmelina* which was expected because of the similar biomass. Golley *et al.* (1975) have reported preferential immobilization in other tropical hardwoods which may have occurred in the fallow forest in this study. However, the results may also indicate that *Acacia* either requires less K and Mg than the other two treatments or it is less efficient in taking up these nutrients.

Differences in the amounts of nutrients in different overstorey components among treatments (Figure 14) occurs for various reasons. For example, foliage generally had larger proportions of N, P, Ca and Mg in the rehabilitation plots than in the UPF and LOF plots. This is partly due to the higher nutrient concentrations found in the foliage of the rehabilitation treatments. Higher nutrient concentrations in foliage of fallow forests compared to mature forests have been observed in other studies (Bartholomew *et al.*, 1953; Uhl and Jordan, 1984; Lambert *et al.*, 1990). Lower nutrient concentrations in the biomass of mature forest species are thought to be a reflection of the highly weathered and nutrient depleted nature of the soil (Herrera *et al.* 1978); while higher concentrations in secondary species may be a result of their ability to rapidly take up nutrients released after cutting and burning (Uhl and Jordan, 1984). The smaller proportion of nutrients in foliage in UPF and LOF is also a reflection of the increasing stemwood biomass which results in foliage making up a smaller proportion of the total overstorey biomass (Lambert *et al.*, 1990; Wang *et al.*, 1991) and, hence, a smaller proportion of nutrients. Sim and Nykvist (1991) suggested that higher amounts of nutrients in younger forests, relative to biomass, were due to the comparatively small amount of wood biomass, which also had the lowest nutrient concentrations. Therefore, as stem biomass increases in the rehabilitation treatments, foliage may contain proportionally fewer nutrients relative to total nutrient uptake.

The largest amounts of Ca were contained in stem bark with the exception of UPF. This was partly due to lower Ca concentrations in stem bark of UPF trees. However, like foliage the percent proportion of bark biomass decreases with forest age as a result of increased stemwood biomass (Grubb and Edwards, 1982; Wang *et al.*, 1991); this was also evident in this study (Figures 9 and 10). As mentioned earlier, it has been observed that older stemwood has higher concentrations of Ca than young stemwood; therefore, as trees age the higher proportion of old wood further contributes to larger amounts of immobilized Ca in stemwood. Figure 14 indicates that the amounts of Ca in LOF stemwood is approaching the levels found in LOF bark. As stemwood biomass of the LOF increases towards UPF levels it is expected that stemwood will immobilize larger amounts of Ca than stem bark. However, this is not expected to occur in the rehabilitation treatments because species such as *Acacia*, *Gmelina*, and *Leucaena* do not have the potential to accumulate large amounts of wood biomass comparable to the UPF.

The remaining differences in nutrient contents may be attributed to differences in stand structure, species characteristics and morphology. The way in which nutrients accumulate affects site rehabilitation; this depends on the quantity of nutrients accumulated and the components in which they are contained. This will be discussed in section 6.5.

The nutrient content of the UPF and LOF plots in this study was within the ranges reported for other tropical rain forests, both undisturbed and logged over (Zinke *et al.*, 1978; Grubb and Edwards, 1982; Adedeji, 1984; Uhl and Jordan, 1984; Sim and Nykvist, 1991). There was a great deal of variation among studies and biomass did not always reflect total nutrient content (Table 5). Nutrient accumulation patterns, however, were as follows: Ca>N> K>Mg>P with the exception of the forest in Thailand (Zinke *et al.*, 1978) which contained larger amounts of K than N. The large variation in nutrient content, among different forests, is probably a combination of differences in site fertility, species composition, forest structure, biomass age and climate. These differences would be reflected in the effects of shifting cultivation on different sites. Sites having very high nutrient accumulation in the biomass might expect to have larger additions of nutrients from ash or by leaching from unburned decaying tree trunks, if the site were cleared and burned. This would account, in part, for the broad range of results from studies observing nutrient dynamics associated with the various conditions and successional stages of shifting cultivation. Table 5 shows biomass and nutrient accumulation of various forest types in the tropics.

Data on nutrient uptake by *Acacia* is scarce; however, a study on 18 month old *Acacia* in Sabah was carried out by Sim and Nykvist (1991). The amounts reported were generally much higher per unit biomass than the *Acacia* in this study (Table 5). This is probably due to the more rapid growth rates and higher nutrient concentrations generally found in younger trees. Trends in the order of nutrient uptake by *Acacia* cannot be determined because Sim and Nykvist (1991) omitted data on N content. However, it appears that N is contained in the greatest amounts among the nitrogen-fixing species listed in Table 5. *Gmelina* nutrient content fell within the range reported for *Gmelina* in other studies (Chijioke, 1980; Russell, 1987); however, there was considerable variation among sites and the order in which N, K and Ca were taken up. Differences were probably related to site fertility, although biomass accumulation did not always reflect total nutrient contents.

Table 5. Nutrient uptake of overstories for different forest types in the tropics.

Forest type	Age (yrs)	Biomass (t/ha)	N	P	K (kg/ha)	Ca	Mg	Source
Undisturbed	-	408	1189	143	951	2140	333	Adedeji (1984)
"	-	323	747	43	681	1372	194	Grubb & Edwards (1982)
"	-	391	1800	236	2452	2816	795	Zinke *et al.* (1978)
"	-	465	1191	73	1126	1573	369	This study
"	-	282	1073	32	248	212	58	Uhl & Jordan (1984)
Logged	-	260	519	17.4	419	637	136	Sim & Nykvist(1991)
"	-	218	694	36.9	693	680	217	This study
Fallow	5	40	168	8.4	79	96	27	Uhl & Jordan (1984)
"	8	217	576	15.1	437	201	130	}Buschbacher *et al.*
"	8	31	114	2.8	34	167	15.9	} (1988)
"	8	6.1	10	0.2	3.7	15.9	3.2	} "
"	10 +	32	124	6	189	113	22	}Koopmans &
"	25 +	80	509	29	374	919	131	}Andriesse (1982)
"	7-10	87	290	14.5	387	248	125	This study
Plantations								
Acacia	1.5	2.3	d.o.*	6	94	41	11	}Sim & Nykvist (1991)
"	1.5	10	d.o.	8	115	47	22	} "
"	6.5	123	711	32	365	460	41	This study
Gmelina	8	120	322	32	300	435	d.o.	Russell (1987)
"	5.5 -12.5	56-170	128-408	22-63	93-1039	42-774	39-79	} Chijioke (1980)**
"	6.5	85	236	17	394	214	69.5	} This study
Leucaena	5.5	48	370	39	220	330	60	Wang *et al.* (1991)
"	5.5	33	210	23	127	190	39	"
"	6.5	8.4	58	2.6	29	35	7.5	"

* Data omitted.

** Range for several plantations.

Nutrient content of *Leucaena* in this study fell well below those reported in other studies (Halliday and Somasegaran, 1983; Wang *et al.*, 1991) mainly due to large differences in total biomass (Table 5). The amounts of nutrients taken up per unit biomass, in this study, were also lower than those in other studies except for N, which was similar to other studies. The low amounts of P, Ca and Mg, per unit biomass, may explain the low biomass production of the *Leucaena* plots in this study. Hutton (1983) observed that deep root penetration, by *Leucaena*, is prevented by very acidic soils and soils that have high Al content. It has been shown that Ca uptake is antagonized by high Al content in Oxisols (Hutton, 1983). Mengel and Kirkley (1978) state that roots must be able to absorb Ca efficiently in order to continue to grow. The *Leucaena* soils in this study were very to extremely acid; thus, it is probable that root growth was inhibited. This may explain the low nutrient uptake by *Leucaena* and, hence, the low biomass production. Wong and Devendra (1983) noted that poor *Leucaena* growth in acid soils has been attributed to Al and Mn toxicity, the effect of H ions, and Ca deficiency.

A broad range of nutrient contents has been reported for fallow forests throughout the tropics (Table 5). Differences in nutrient contents are due to differences in species composition, biomass production, fallow age, site fertility and site history. Nutrient content of the fallow forest plots in this study fell within the range reported in other studies and appeared to be above the average uptake suggesting that previous nutrient depletion, in this study, was not overly severe. There were differences in the order in which N, K and Mg were accumulated; however, it appears that as fallow age increases the nutrient accumulation pattern approaches that of undisturbed forests. This is probably due to changes in species composition and forest structure which begins to resemble that of undisturbed forest with increasing age.

6.5 Biomass and Soil Nutrient Relationships

Amounts of N and P along the chronosequence were always found in much larger quantities in soil than in biomass. This has also been reported in other studies for different forest types (Zinke *et al.*, 1978; Grubb and Edwards, 1982; Buschbacher, 1987; Jordan, 1987; Russell, 1987; Saldarriaga, 1987; Brown and Lugo, 1990). This suggests that total amounts of N and P are in abundance in the soil; however, not all soil N and P are in forms available for uptake by vegetation. Brown and Lugo (1990) and Zinke *et al.* (1978) observed that available P was found in smaller quantities in soil than in biomass, including litter. Other studies report that P is low or the limiting factor in tropical ecosystems (Sanchez; 1976; Vitousek, 1984; Buschbacher, 1987). The variability in amounts of K, Ca and Mg in soils and biomass among treatments in this study may be due to differences in biomass, forest structure and species-specific requirements. Brown and Lugo (1990) observed that no general pattern is exhibited for K, Ca and Mg in secondary forest ecosystems. However, several studies indicate that as biomass increases the amounts of K, Ca and Mg held in vegetation is greater than the amounts held in soil (Nye and Greenland, 1960; Sabhasri, 1978; Zinke *et al.*, 1978).

Several authors have suggested that the immobilization of large amounts of nutrients in undisturbed forests is a nutrient conserving mechanism in tropical ecosystems having nutrient poor soils (Jordan, 1985, 1989; Golley, 1983). Similarly, secondary forests have been described as nutrient sinks (Vitousek and Reiners, 1975; Vitousek, 1984; Brown and Lugo, 1990). The function as a nutrient sink is particularly important in early forest regrowth because young trees tend to accumulate nutrients, whereas, old trees tend to recycle them (Bowen and Nambiar, 1984). Nutrients contained in biomass are less susceptible to being lost from the ecosystem through leaching and erosion. However, immobilization of large amounts of nutrients in the overstorey biomass may result in large amounts of nutrients being removed from the ecosystem when trees are removed by logging.

Logging of undisturbed primary forest resulted in removal of about 50 percent (244 t/ha) of the biomass, mostly in the form of stem wood and bark (Figure 9). Data in Figure 15 indicate that this resulted in the removal of a large proportion of nutrients in the biomass. These removals would have relatively little effect on total N and P because most of their total capital is in soil (Figure 15). However, for K, Ca and Mg most of the capital is in the biomass, particularly in the stems; thus, much greater proportions of these nutrients are subject to removal in logged trees. The effects on soil after logging appear to be increases in N, K and Mg and decreases in Ca and organic C. However, the overall amounts of nutrients in the ecosystem as a whole were lower than in the UPF, with the exception of N which was slightly higher. The loss of N through biomass removal appears to have been replaced by increases in the soil. Overall decreases of P, K, Ca and Mg in the ecosystem are also shown to be due to biomass removal. However, K and Mg are increased in the soil while Ca in soil decreases. Increases of K and Mg are possibly due to nutrients leaching out of decomposing slash. Decreases in Ca may be due to the large proportion of wood and bark removed from the site; thus, slash remaining after logging would not be of components in which Ca was the most highly concentrated.

Clearing and burning removed all living biomass and, as indicated in Figure 4, resulted in a transfer of some nutrients from biomass to soil. However, when there is little or no biomass to absorb nutrients a large proportion of nutrients may be leached and eroded from the ecosystem. Stark (1971a) noted that clearing and burning results in an accelerated decline in nutrient levels in a tropical ecosystem because large amounts of nutrients, that may have been held in biomass for thousands of years, are suddenly made soluble and subject to leaching losses. The return of vegetation, such as the rehabilitation treatments of this study, again establishes a nutrient sink which is the only means of immobilizing and recycling nutrients within the ecosystem.

As mentioned earlier the amounts of N and P are found in greater amounts in the soil than in the biomass (Figure 15). This was also true for the rehabilitation treatments; however, the amounts in each ecosystem (treatment site) varied. *Leucaena* had the lowest amounts of both N and P overall. This is partly due to the small amounts accumulated in the biomass, but the main cause is lower amounts in the soil. However, the lower amounts in soil may be due to leaching and erosion as a result of the low biomass production. The large amount of N in the *Acacia* biomass is not reflected in the soil; thus, it did not significantly improve N content in the ecosystem as a whole over that in *Gmelina* or fallow forest (Figure 15). DeBell *et al.* (1985) observed that nitrogen-fixing trees did not alter the amount of N in soils of mixed plantations of *Eucalyptus* and leguminous trees in Hawaii. This was thought to be due to better N uptake by trees and higher biomass production. The *Gmelina* ecosystem had the largest amounts of P, exceeding that of even UPF and LOF. Russell (1987) observed that *Gmelina* appears to be able to mobilize insoluble P from the soil and this may have contributed to the overall higher levels of P in the *Gmelina* ecosystem. However, as mentioned in section 6.1.2.5 the higher P levels in the soil may also be related to high Ca and Al levels in the soil.

The *Gmelina* plantation ecosystem also had the highest amounts of K, Ca and Mg among rehabilitation treatments (Figure 15). It contained the largest amounts of K in biomass; K content in the soil also was higher than all other treatments. The amounts of Ca and Mg in biomass were smaller; therefore, slightly higher levels might be expected in the soil due to lower rates of uptake. However, the amounts of these nutrients in soil were disproportionately higher suggesting that the *Gmelina* may be adding large amounts to the topsoil through litter fall. High nutrient content in the *Gmelina* soils may be an inherent site characteristic; however, similar behavior of soil Ca has been noted in other *Gmelina* plantations (Russell, 1987). Chijioke (1980) also observed higher levels of exchangeable bases in *Gmelina* topsoils and attributed this to greater nutrient recycling efficiency by *Gmelina*. The large amounts of nutrients in the *Gmelina* soils suggest some interesting plantation management possibilities since *Gmelina* appears to have increased the amounts of exchangeable bases in the soil. One possibility would be to interplant *Gmelina* with another species that could make use of the apparently excess nutrients. This might also be advisable since excessive amounts of nutrients in the soil are susceptible to leaching and erosion losses in areas having high rainfall.

The fallow forest ecosystem generally contained amounts of nutrients similar to that in the *Acacia* plantation ecosystem with the exception of Mg, which was much lower in the latter treatment (Figure 15). However, the proportions of nutrients above and below ground varied. Fallow had smaller proportions of N, P and Ca; similar proportions of K and larger proportions of Mg aboveground. These differences may be due to a species-specific effect of the *Acacia* monoculture as well as differences in biomass and biomass proportions between treatments. However, it is noteworthy that the thirty percent lower biomass of the fallow forest did not appear to affect the overall amount of nutrients in the ecosystem, when compared to the *Acacia* plantation. This is probably due to the ability of the natural forest to conserve available nutrients by trapping them into an almost closed nutrient cycle. However, a study on nutrient losses from these sites would be required to confirm this.

6.6 Species Composition

The great species richness observed in the UPF and LOF plots (Appendix X) was expected since MDFs in Sarawak are characterized by a large number of species (Scott, 1985) and are reported to have their greatest species richness in Sarawak and Brunei (Whitmore, 1984). Over 200 species per ha have been observed in Malaysia and Kalimantan (Wyatt-Smith, 1966; Kartawinata *et al.*,1981). By comparison, the UPF and LOF 1 ha plots in this study appeared to have much fewer species at 54 and 39 species, respectively. However, this is due to the selected trees having a dbh limitation of > 30 cm, while other studies included all trees or had limitations of ≥ 10 cm dbh or smaller. The 10 m x 20 m UPF plots showed great species richness with a combined total of 98 species observed. In addition, a total of 183 tree and shrub species were observed in the undergrowth (Appendix IX B); only 35 of these species were also observed in the 10 m x 20 m overstorey plots. This results in a total of 246 species observed in an area of 400 m^2 for the overstorey and 20 m^2 for the undergrowth. This suggests that species richness may be greater for a 1 ha plot in this study compared to other studies of undisturbed lowland rainforests, however, more replicates would be required to verify this.

The greater species richness of the UPF plots compared to the LOF plots is due to the type of logging (Malaysian Uniform System) that was used to harvest these sites. This logging system involves harvesting only of selected marketable species. Whitmore (1984) noted that of the estimated 2500 tree species in Malaysia only 402 are considered commercial and only 30 of these are exported in any substantial quantity. It was further estimated that in the Malaysian MDFs this results in the felling of about fourteen trees per ha. The difference in the mean number of tree species (> 30 dbh) between UPF and LOF plots in this study was fifteen trees per ha. The reduction in the number of species in LOF is illustrated by the genus *Shorea*, one of the most commonly logged trees in Sarawak MDFs. Appendix X shows that thirteen *Shorea* species were observed in the one hectare UPF plots, while only four were observed in the one hectare LOF plots.

The mean of eighteen overstorey species observed in the fallow forest plots in this study is similar to results reported for another 10 m x 20 m fallow plot in Sarawak (Chai, 1981) at seventeen species. However, *Ficus* and *Macaranga* were the only genera common to both studies. Another study of fallow forests in Sarawak (Ewel *et al.*, 1983) observed several genera and species that were observed in this study including *Macaranga, Ficus, Litsea* and *Endospermum*. Ewel *et al.* (1983) found a greater mean species richness of 43 species for three 10 m x 10 m plots. This was probably due to differences in soil type, age of fallow and severity of disturbance.

The fallow forest plots in this study had much lower species richness than that of the LOF plots due to the greater severity of disturbance. Uhl *et al.* (1982) observed that repeated weeding by shifting cultivators reduced the forest-tree density and increased the number of forbs and grasses. Repeated weedings were thought to exhaust the sprouting reserves of species that had survived clearing and burning. Another theory for the low species richness of fallow forests is that invasion of a site by pioneer tree species is on a first come first serve basis (Whitmore, 1978). The first seeds on site, or the first seeds to germinate will be the species that prevails or dominates; thus, the presence of a few aggressive pioneer species results in a low species richness. Pioneer species are generally short lived and begin to decline and disappear because many of them cannot regenerate under their own canopies. Several studies have shown that as the age of fallow forests increase, species richness also increases (Kochummen, 1966; Kochummen and Ng, 1977; Saldarriaga, 1987). This increase in species richness is due to the replacement of a few pioneer species with a broad range of slower growing shade tolerant species.

Appendix X also shows that only four of the species observed in the fallow plots were also observed in the LOF plots. This is not surprising since fallow forests in other studies in Sarawak and West Malaysia (Kochummen, 1966; Kochummen and Ng, 1977; Chai, 1981; Ewel et al., 1983) also had few species in common. This may be attributed to the large number of pioneer species in tropical areas. For example the genus *Macaranga* has approximately fifty species in Borneo alone (Whitmore, 1978). However, the differences in species between the LOF and fallow plots may also be related to the size of area cleared on the respective plot sites. In the LOF plots logging probably resulted in the creation of gaps at a rate of about fourteen gaps per ha (as suggested above). Clearing by shifting cultivators, however, results in opening up larger areas of one to four or more ha. In Java, Kramer (1926, 1933) observed that small gaps of 0.1 ha were soon occupied by surviving saplings of primary forest tree species, while larger gaps of 0.2 to 0.3 ha were rapidly occupied by a thick growth of pioneer species.

7.0 CONCLUSIONS

Logging resulted in a reduction of total aboveground biomass of undisturbed primary forest by just over 50 percent or 248 t/ha (Table 4). This resulted in removal of 40 to 57 percent (36 to 893 kg/ha) of immobilized nutrients, mostly in stemwood and bark (Figure 14). The effects on the top 30 cm of soil were increases in N, K, Mg and bulk density; decreases in C, Ca, Al and porosity; and little change in total P and H. The effect of clearing and burning had a more extreme effect than logging alone. Clearing and burning of logged over forest for shifting cultivation resulted in a complete removal of all living vegetation. The effects of clearing and burning on soil, within a month after burning, were increases in C, K, Ca and Mg; decreases in N and Al; and no change in total P. Increases were the result of additions from ash and/or unburned organic matter leaching into the soil. Decreases in N were attributed to volatilization and leaching of N from the soil profile. Decreases in Al were due to the increases in exchangeable bases and increased pH which may have resulted in Al becoming less soluble.

One and a half years after abandonment a cover of shrubs and secondary species was established with a biomass of five to ten t/ha. However, C and all nutrients, with the exception of K and Mg, decreased to their lowest levels in the chronosequence. These losses were thought to be the combined result of losses through leaching, erosion, nutrient removals through crop harvest, and uptake by rapidly growing successional vegetation.

Rehabilitation treatments involving fallow forest and plantations of *Acacia*, *Gmelina* and *Leucaena* resulted in a restoration of biomass ranging from 20 to 134 t/ha (Table 4). *Acacia* had the greatest biomass production of the rehabilitation treatments but also tended to have a greater drain on soil nutrients (Figures 4 and 15). Rapid nutrient uptake into the biomass, however, is a nutrient conserving mechanism which reduces nutrient leaching losses. The *Acacia* plantation showed the least improvement in soil bulk density and porosity (Appendix III). Although biomass production was high the *Acacia* were already showing signs of decline including heart rot and mortality due to pink disease. Early decline indicated that site recovery might not be complete before the trees reach rotation age. Since logging would not be in accord with the objective of rehabilitation it was suggested that the use of *Acacia* for rehabilitation purposes be reviewed, and that longer lived species be considered in its place.

Leucaena had the poorest biomass production and appeared to have a negative effect on site recovery and overall biomass production. The *Leucaena* plots had a large amount of undergrowth biomass production which appeared to impede the establishment of *Leucaena* as well as indigenous secondary species. *Leucaena* had lower amounts of C and N in the soil than the other rehabilitation treatments. This was probably due to the low biomass and litter production resulting in little organic matter being added to the soil. Due to low biomass production *Leucaena* contained only small amounts of nutrients, thus leaving large amounts of nutrients susceptible to leaching from the system and furthering site degradation. *Leucaena* was not recommended as a rehabilitation species for abandoned shifting cultivation sites because of its low biomass production, its intolerance to acidic soils, and its apparent inability to overcome competition from undergrowth vegetation.

Gmelina arborea had satisfactory biomass production and appeared to have a beneficial effect of increasing the nutrient contents in the topsoils over UPF levels, in particular P, K, Ca and Mg (Figure 15). However, large nutrient contents in the soil may leave nutrients susceptible to leaching out of the ecosystem. The plantation did not show signs of decline and, unlike *Acacia*, the *Gmelina* plantation may be sufficiently long lived to allow a more complete site recovery. However, *Gmelina* is known to be somewhat site specific; therefore, it may not be suitable for the rehabilitation of extremely degraded sites.

Fallow forest biomass production was similar to that of *Gmelina* but had the largest small-litter standing crop biomass in the chronosequence of plots (Table 4). Fallow forest also appeared to have a draining effect on soil nutrients similar to the *Acacia* plantation. This effect is beneficial in the long run because nutrients contained in the biomass are not susceptible to leaching out of the exploitable soil. Fallow forest generally had the greatest soil porosity and the lowest bulk density among the rehabilitation treatments. Fallow was found to provide a satisfactory protective forest cover for site rehabilitation.

8.0 RECOMMENDATIONS

1) *Leucaena leucocephala* should not be used as a rehabilitation treatment for abandoned shifting cultivation sites, in Sarawak. The *Leucaena* plots in this study had very poor growth mainly due to intolerance of acidic soils and soils having high Al content; *Leucaena* was also unable to overcome competition from undergrowth vegetation.

2) The use of *Acacia mangium* as a rehabilitation species should be reviewed. It appears to be too short lived to maintain productivity for the full duration of time required for site recovery. In addition, *Acacia* appears to be widely affected by pink disease while larger trees tend to be affected by heart rot at a relatively young age resulting in early decline of plantations.

3) *Gmelina arborea* growth rates in this study were satisfactory; however, other studies indicate it is somewhat site specific. Therefore, if *Gmelina* is to be used as a rehabilitation species, care should be taken in site selection. Sites with shallow soils or sites that have been severely degraded by shifting cultivation should not be planted with *Gmelina.*

4) *Gmelina arborea* showed definite increases in soil P, K, Ca and Mg over levels observed in undisturbed primary forest. These excess nutrients may be susceptible to leaching out of the soil profile and ecosystem. It is recommended that studies be carried out involving *Gmelina* interplanted with other species that may be able to take up and benefit from these excess nutrients. Selected species should preferably have a relatively long rotation age e.g. *Swietenia macrophylla* or *Shorea* species.

5) Alternative species should be considered for rehabilitation of abandoned shifting cultivation sites. These species should be longer lived than the presently selected species (*Acacia*) in order to extend the period for site and soil recovery e.g. *Shorea* spp., *Durio* spp. or *Swietenia macrophylla* may be suitable. Nitrogen-fixing species are recommended for severely degraded sites.

6) Fallow forest is a viable rehabilitation alternative that should not be discounted. In areas where a natural seed source of primary species is not available, fallow forest recovery may be assisted by enrichment or line planting with desirable primary tree species. The benefits of line planting include: establishment of desirable species; lower costs than plantation establishment; decreased nutrient losses through leaching and erosion; fewer

disease problems than monocultures; and planted trees may benefit from the litter of adjacent fallow trees.

However, on sites that have been severely degraded by shifting cultivation and are dominated by *Imperata cylindrica* or fern species it is advisable to establish plantations in order to promote regeneration of tree species. These plantations should include nitrogen-fixing species.

7) Burning of slash on abandoned shifting cultivation sites, prior to plantation establishment, should be avoided because it results in nutrient losses through leaching, erosion and volatilization and it promotes grass growth.

8) It is recommended that the Sarawak Forest Department examine the plantation and fallow plots again. At present the rehabilitation treatments are about fifteen years of age; it would be useful to estimate biomass at this stage and reassess the soil recovery status. This would give a more complete picture of site rehabilitation and forest condition along the chronosequence reported in this thesis, including changes in species composition on various plots and decline in the *Acacia* plantation.

9.0 GLOSSARY

Abandoned shifting cultivation site - a hill padi site that has been cropped for one to three years and then abandoned to fallow, usually as a result of declining crop yields.

Begunan series - Red-Yellow Podzolic soils in the Merit family that have a CEC of > 24 me per 100 g clay in the major part of the B horizon. They differ from the Merit series by having a red colour class.

Bekenu family - Red-Yellow Podzolic soils that have a fine loamy or fine silty particle-size class and are residual soils derived from sedimentary rocks.

Bekenu series - Red-Yellow Podzolic soils of the Bekenu family that have a yellow colour class; a fine loamy particle-size class; and are residual soils derived from sedimentary rocks.

Biomass - the weight of the living components of an ecosystem, usually expressed in dry-weight.

Bulk density - the mass of dry soil per unit bulk volume, including the air space. The bulk volume is determined before drying to a constant weight at 105° C.

Chronosequence - in the context of this study chronosequence refers to the sampling of a set of sites, taken at a single time, which represent several stages of forest development after disturbance. The assumption of this type of study is that the set of sites had relatively uniform soils and site conditions prior to disturbance.

CEC - cation exchange capacity - is a measure of the soil's ability to retain positively charged ions including Ca, Mg and K against leaching. The total amount of exchangeable cations that a soil can adsorb.

Diameter at breast height (dbh) - diameter of a tree stem taken at 1.3 m above ground level. In the case of buttressed trees dbh was taken 0.3 m above the buttress.

Diameter over bark (dob) - the diameter of a stem or branch which is measured to include bark thickness.

Dipterocarp - a member of the Dipterocarpaceae tree family.

Dry weight - the weight of biomass after drying at 105° C to a constant weight. In this study subsamples were oven-dried to determine a dry-weight conversion factor for each vegetation type which was then multiplied by the appropriate total fresh weight biomass to give the total dry weight of a vegetation category.

Fallow forest - a site which is regenerating naturally after abandonment by shifting cultivators. After several years of regeneration the term fallow forest is used.

Fresh weight - the weight of biomass while it is still fresh also green weight.

Immobilization - conversion of inorganic forms of nutrients to organic forms.

Jakar series - Merit family soils other than Begunan series having a red colour class.

Lallang - also called alang-alang; a species of grass that invades severely degraded shifting cultivation sites and impedes the establishment of tree species. Its botanical name is *Imperata cylindrica.*

LOF - Logged over forest. In this study it refers to forests logged using the Malaysian Uniform System

MDF - Mixed dipterocarp forest or mixed hill dipterocarp forest.

Malaysian Uniform System - involves a cutting cycle of 25 years where harvesting operations center on the selective removal of mature and over-mature trees of marketable species. The minimum tree size removed is 46 cm dbh.

Merit Family - Red-Yellow Podzolic soils that have a fine clayey particle-size class and are residual soils derived from sedimentary rock.

Merit Series - Red-Yellow Podzolic soils of the Merit family that have a CEC of >24 me/100 g clay in the major part of the B horizon, have a yellow colour class and are residual soils derived from sedimentary rock.

Mineralization - the conversion of an element from organic form to an inorganic form as a result of microbial decomposition.

Nitrogen fixing species - a species capable of converting elemental N to organic forms that are utilizable in biological processes.

Nyalau Family - Red-yellow Podzolic soils that have a coarse loamy or coarse silty particle-size class and are residual soils derived from sedimentary rock.

Nyalau Series - Red-yellow Podzolic soils of the Nyalau family that have a yellow colour class, a coarse loamy particle-size class, and are residual soils derived from sedimentary rock.

Parang - a bush knife used for clearing fallow forest and other vegetation.

Porosity - the percent volume of the bulk of soil not occupied by soil particles.

Primary forest tree species - refers to tree species found in the primary rain forest or the "mature phase" of the rain forest. These species generally tend to be long lived (250 to 450 years), are shade tolerant, have relatively slow growth rates, and have dense wood.

Perhumid climate - a climate which has no distinct dry season.

Red-Yellow Podzolic - soils that have a cambic or an argilic horizon, not overlain by an oxic horizon, within 150 cm of the surface.

Rehabilitation treatment - in the context of this paper it refers to one of the four treatments in this study including plantations of *Acacia mangium, Gmelina arborea, Leucaena leucocephala* or natural regeneration (fallow forest).

Secondary forest tree species - refers to tree species found on disturbed areas e.g. logged sites, small gaps caused by windfall, or large openings caused by shifting cultivation. Species tend to be short lived (20 to 40 years), light demanding, fast growing, and have low density wood.

Site recovery - refers to the recovery of an abandoned shifting cultivation site to a productive forest condition. Includes recovery of soil nutrients, biomass, litter layer, and the return of certain tree species.

Site rehabilitation - a term used by the Malaysian Forest Department referring to site recovery through some form of silvicultural treatment, usually plantations; also to restore the protective function of a forest.

Slash-and-burn agriculture - a term commonly used for shifting cultivation.

Small-litter standing crop - a term used to differentiate between "annual litterfall", which is measured at regular intervals in litter traps, and the "litter standing crop" which is found on the forest floor at any given point in time. The "small-litter", in this study, is defined as $\leq$ 3 cm dob.

UPF - Undisturbed primary forest.

Weathering - physical and chemical disintegration, decomposition and alteration of rocks and minerals at or near the earth's surface by atmospheric agents.

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APPENDICES

APPENDIX I

LOCATION OF BIOMASS PLOTS

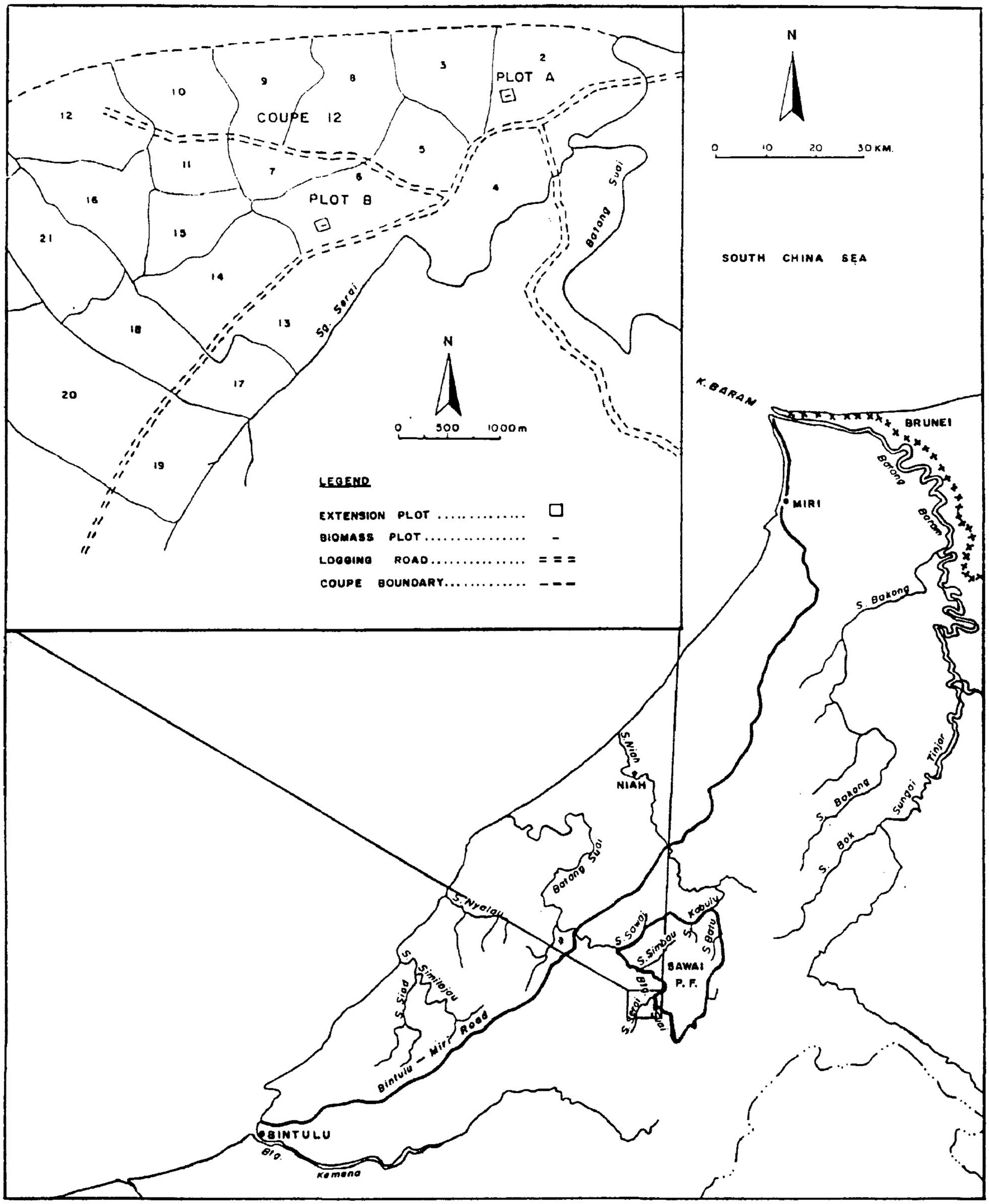

Figure A.1 Location of undisturbed primary forest biomass and extention plots.

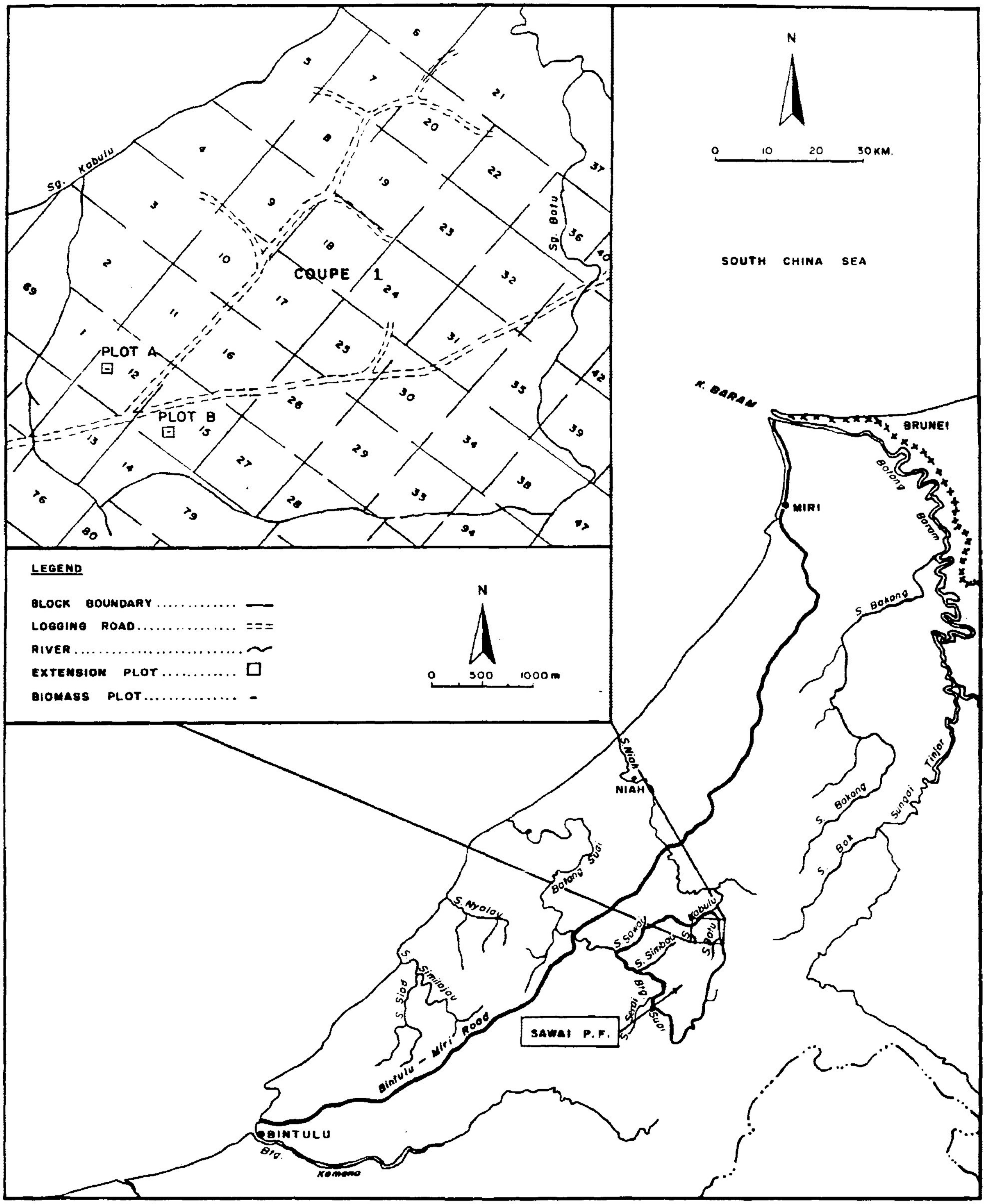

Figure A.2 Location of logged over forest biomass and extention plots.

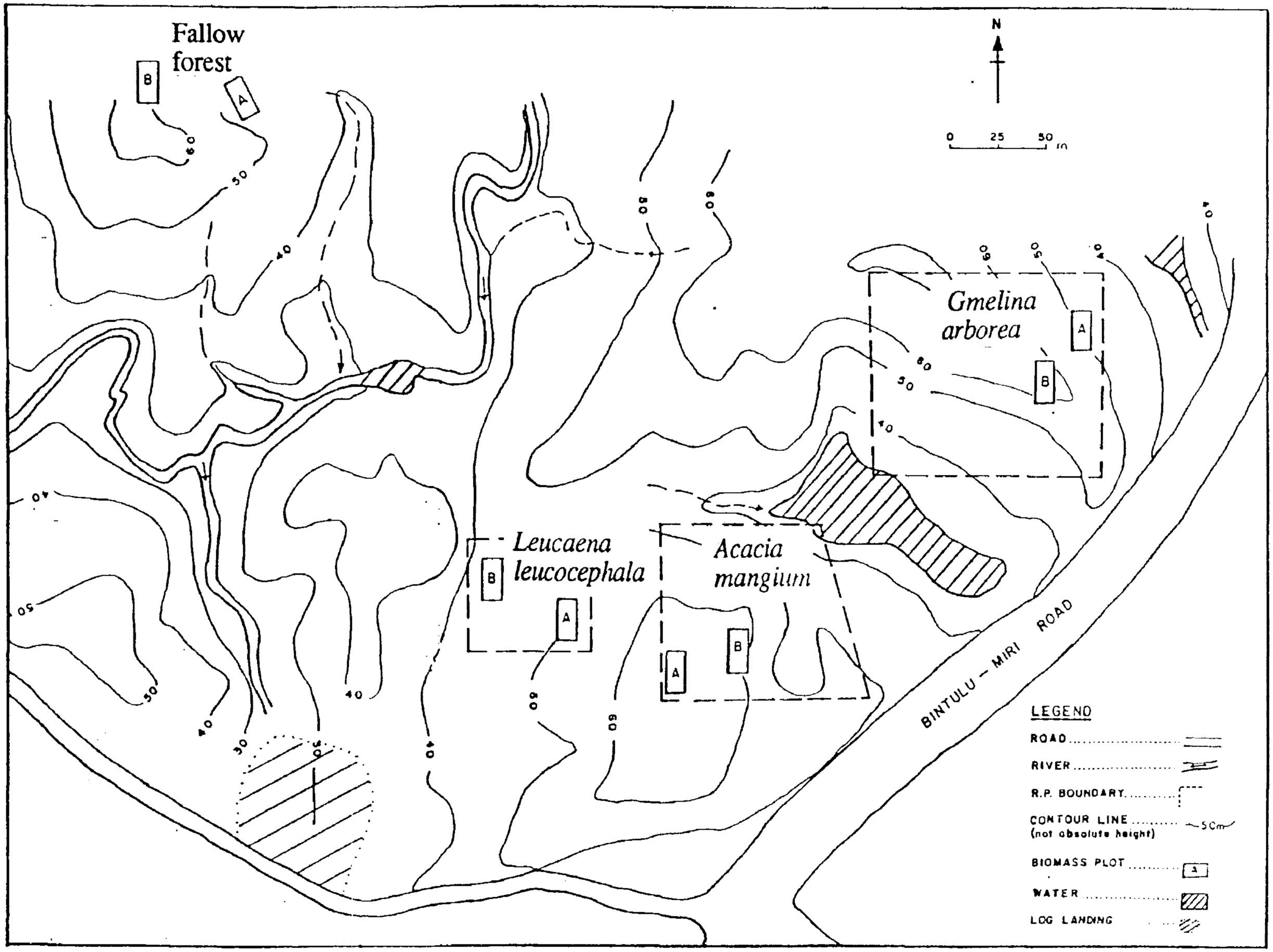

Figure A.3 Location of plantation and fallow forest biomass plots.

APPENDIX II SOIL PROFILE DESCRIPTIONS

Profile: Undisturbed Primary Forest (UPF) Plot A.

Great Group : Red-Yellow Podzolic
Family : Merit
Series : Begunan
Parent Material : Sandstone

Drainage : Well drained
Topography : Undulating
Slope : 11°
Position : Midslope

Horizon	Depth (cm)	Description *
O	0.5-0	Leaf litter
A1	0-4	Sandy clay loam; dark yellowish brown (10YR 4/4); loose when moist; weak fine crumb; abundant fine and medium roots; abundant fine and medium pores; clear and smooth horizon boundary to:
A2	4-28	Sandy clay loam; brownish yellow (10YR 6/8); very friable when moist; weak medium subangular blocky structure; few fine and large roots; many medium roots; many medium pores; diffuse and wavy horizon boundary to:
B1	28-44	Clay loam; reddish yellow (7.5YR 6/8); firm when moist; moderate medium angular blocky structure; few medium roots; many fine pores; diffuse and wavy horizon boundary to:
B21	44-55	Clay loam; yellowish red (5YR 5/8);firm when moist; moderate medium angular blocky structure; abundant moderately hard gravels; few medium roots; few fine pores; diffuse and wavy horizon boundary to:
B22	55-82	Clay loam; red (2.5YR 5/8); many fine prominent mottles, white (10YR 8/2); firm when moist; moderate medium angular blocky structure; few moderately hard grits; few fine roots; merging and wavy horizon boundary to:
B23	82-100	Clay loam; red (2.5YR 5/8); abundant fine and medium prominent mottles, white (10YR 8/2); firm when moist; moderate medium angular blocky structure; few moderately hard grits; few fine roots; few fine pores; merging and wavy horizon boundary.

* see last page of APPENDIX II

Profile: Undisturbed Primary Forest (UPF) Plot B.

Great Group	: Red-Yellow Podzolic	Drainage	: Well drained
Family	: Merit	Topography	: Hilly
Series	: Merit	Slope	: 2°
Parent Material	: Sandstone	Position	: Upper slope

Horizon	Depth (cm)	Description
O	0.5-0	Leaf litter and twigs
AB	0-5	Clay loam; brownish yellow (10YR 6/6); firm when moist; moderate medium crumb; many fine and medium roots; many fine and medium pores; diffuse and wavy horizon boundary to:
B21	5-47	Clay; brownish yellow (10YR 6/8); firm when moist; moderate fine angular blocky structure; few fine and medium roots; few fine and medium pores; patchy clay skins; diffuse and wavy horizon boundary to:
B22	47-76	Clay; brownish yellow (10YR 6/8); many fine faint mottles, yellow (10YR 7/6); firm when moist; moderate fine angular blocky structure; few fine roots; few fine pores; patchy clay skins; diffuse and wavy horizon boundary to:
B23	76-100	Clay; brownish yellow (10YR 6/8); many fine distinct mottles, red (2.5YR 4/8); firm when moist; moderate medium angular blocky structure; few moderately hard grits; no roots; few fine pores; patchy clay skins.

Profile: Undisturbed Primary Forest (UPF) Plot C.

Great Group	: Red-Yellow Podzolic	Drainage	: Moderately well drained
Family	: Bekenu	Topography	: Undulating hills
Series	: Bekenu	Slope	: 17°
Parent Material	: Shale	Position	: Midslope

Horizon	Depth (cm)	Description
O	1.0-0	Leaf litter and twigs
A1	0-4	Sandy loam; dark greyish brown (10YR 4/2); very friable when moist; nonsticky and nonplastic when wet; moderate medium crumb structure; abundant fine roots; abundant medium pores; discontinuous organic matter; diffuse wavy horizon boundaryto:
A2	4-13	Sandy loam; light yellowish brown (10YR 6/4); very friable when moist; nonsticky and nonplastic when wet; moderate medium crumb structure;

		many medium and few large roots; many medium pores; discontinuous organic matter; clear wavy horizon boundary to:
B11	13-30	Sandy loam; very pale brown (10YR 8/3); friable when moist; slightly sticky and slightly plastic when wet; moderate medium subangular blocky structure; few medium roots; many medium pores; clear wavy horizon boundary to:
B12	30-48	Sandy loam; reddish yellow (7.5YR 6/8); firm when moist; slightly sticky and slightly plastic when wet; moderate medium subangular blocky structure; few fine roots; many fine pores; merging smooth horizon boundary to:
B21	48-81	Sandy clay loam; red (2.5YR 5/8); firm when moist; plastic and sticky when wet; moderate medium subangular blocky structure; few large roots; few fine pores and cracks; discontinuous clay skins; merging smooth horizon boundary to:
B22	81-100	Clay loam; red (2.5YR 5/8); very firm when moist; very sticky and very plastic when wet; structureless, coarse and massive; no roots; few fine pores and cracks; discontinuous clay skins.

Profile: Logged Over Forest (LOF) Plot A.

Great Group	: Red-Yellow Podzolic	Drainage	: Moderately well drained
Family	: Merit	Topography	: Hilly
Series	: Begunan	Slope	: 12°
Parent Material	: Shale	Position	: Upper slope

Horizon	Depth (cm)	Description
O	2.5-0	Leaf litter and twigs.
A1	0-5	Sandy clay loam; dark yellowish brown (10YR 4/4); friable when moist; moderate medium crumb; many fine and medium roots; abundant fine and medium pores; clear and wavy horizon boundary to:
A2	5-25	Clay loam; brownish yellow (10YR 6/8); few faint mottles, very pale brown (10YR 7/4); friable when moist; weak fine subangular blocky structure; few fine roots; few fine pores; gradual and wavy horizon boundary to:
B1	25-40	Clay loam; reddish yellow (7.5YR 6/8); few fine distinct mottles, very pale brown (10YR 7/4); friable when moist; moderate medium subangular blocky structure; few medium roots; few fine pores; gradual and wavy horizon boundary to:
B2	40-83	Clay; yellowish red (5YR 5/8); many fine distinct mottles, yellow (10YR 7/6); firm when moist; moderate medium angular blocky structure; few

		moderately hard grits; many fine roots; few fine pores; patchy clay skins; diffuse and wavy horizon boundary to:
B3	83-100	Clay; yellowish red (5YR 5/8); abundant fine prominent mottles, pink (7.5YR 7/4); firm when moist; moderate medium angular blocky structure; abundant moderately hard grits; few medium roots; few fine pores.

Profile: Logged Over Forest (LOF) Plot B.

Great Group	: Red-Yellow Podzolic	Drainage	: Moderately well drained
Family	: Merit	Topography	: Undulating
Series	: Begunan	Slope	: 5°
Parent Material	: Shale	Position	: Upper midslope

Hori-zon	Depth (cm)	Description
O	2.5-0	Leaf litter and twigs.
A1	0-3	Sandy clay loam; yellowish brown (10YR 5/6); friable when moist; moderate coarse crumb; many fine and few medium roots; many fine and few medium pores; clear and wavy horizon boundary to:
A2	3-28	Clay loam; brownish yellow (10YR 6/8); few fine faint mottles, very pale brown (10YR 7/3); friable when moist; weak fine subangular blocky structure; few fine and many medium roots; few fine pores; gradual and wavy horizon boundary to:
B1	28-43	Clay loam; strong brown (7.5YR 5/8); few fine faint mottles, pink (7.5YR 7/4); firm when moist; moderate medium subangular blocky structure; few medium roots; few fine pores; gradual and wavy horizon boundary to:
B2	43-83	Clay; reddish yellow (5YR 6/8); few fine distinct mottles, pink (7.5YR 7/4); firm when moist; moderate medium subangular blocky structure; few moderately hard grits; few medium roots; few fine pores; patchy clay skins; diffuse and wavy horizon boundary to:
B3	83-100+	Clay; reddish yellow (5YR 6/8); abundant fine prominent mottles, pink (7.5YR 8/4); moderate medium angular blocky structure; few moderately hard grits; no roots; few fine pores; patchy clay skins.

Profile: Two days after clearing and burning (2DAB).

Great Group	: Red-Yellow Podzolic	Drainage	: Moderately well drained
Family	: Merit	Topography	: Low hills
Series	: Jakar	Slope	: 22°
Parent Material	: Shale	Position	: Midslope

Horizon	Depth (cm)	Description
O	-	Ashes.
A2	0-13	Sandy clay loam; yellowish brown (10YR 5/6); very friable when moist; slightly sticky and slightly plastic when wet; moderate medium subangular blocky structure; few large and many medium roots; abundant fine pores; few charcoal; merging wavy horizon boundary to:
B11	3-30	Clay loam; brownish yellow (10YR 6/8); friable when moist; slightly sticky and slightly plastic when wet; moderate medium subangular blocky structure; few moderately hard gravel; many medium roots; few fine pores; gradual wavy horizon boundary to:
B21	30-68	Clay loam; reddish yellow (7.5YR 6/8); firm when moist; sticky and plastic when wet; moderate coarse subangular blocky and columnar structure; few moderately hard grits; many fine roots; many fine pores; many cracks; discontinuous clay skins; diffuse smooth horizon boundary to:
B22	68-140	Clay; reddish yellow (7.5YR 6/8); abundant, coarse prominent mottles, light grey (10YR 7/1); very firm when moist; sticky and plastic when wet; medium massive, structureless; few moderately hard grits; few fine roots; few fine pores; discontinuous clay skins.

Profile: Two weeks after clearing and burning (2WAB).

Great Group	: Red-Yellow Podzolic	Drainage	: Well drained
Family	: Bekenu	Topography	: Low hills
Series	: Bekenu	Slope	: 19°
Parent Material	: Shale	Position	: Midslope

Horizon	Depth (cm)	Description
O	-	Ashes, Burnt roots and twigs
A2	0-20	Sandy clay loam; brownish yellow (10YR 6/8); very friable when moist; nonsticky and nonplastic when wet; moderate medium subangular blocky structure; many fine and abundant medium roots; abundant medium pores; gradual wavy horizon boundary to:

B1	20-46	Sandy clay; brownish yellow (10YR 6/8); friable when moist; slightly sticky and slightly plastic when wet; moderate medium subangular blocky structure; few moderately hard grits; many fine and few medium roots; abundant fine pores; diffuse irregular horizon boundary to:
B2	46-100	Sandy clay loam; brownish yellow (10YR 6/6); firm when moist; slightly sticky and slightly plastic when wet; structureless; abundant soft shale stones, red (2.5YR 5/8); few fine roots; few fine pores; many cracks; discontinuous clay skins.

Profile: One month after clearing and burning (1MAB) Plot A.

Great Group : Red-Yellow Podzolic
Family : Merit
Series : Jakar
Parent Material : Shale

Drainage : Well drained
Topography : Undulating hills
Slope : 20°
Position : Mid-slope

Horizon	Depth (cm)	Description
O	-	Bare to thin layer of ashes derived from the burn.
A2	0-18	Clay loam; brownish yellow (10YR 6/8); variegated colour, light yellowish brown (2.5Y 6/4); friable when moist; slightly sticky and slightly plastic when wet; moderate medium subangular blocky structure; many fine and medium roots; abundant medium pores; few charcoal; gradual and smooth horizon boundary to:
B1	18-40	Clay loam; brownish yellow (10YR 6/6); variegated colour, yellowish red (5YR 5/6); firm when moist; sticky and plastic when wet; weak coarse subangular blocky structure; many fine and few medium roots; abundant fine pores; clear wavy horizon boundary to:
B21	40-76	Clay; reddish yellow (5YR 6/8); variegated colour; brownish yellow (10YR 6/6); very firm when moist; very sticky and very plastic when wet; weak medium subangular blocky structure; few fine and many medium roots; few fine pores; patchy clay skins; merging wavy horizon boundary to:
B22	76-100	Clay; reddish yellow (5YR 6/8); firm when moist; very sticky and very plastic when wet; moderate medium subangular blocky structure;few fine roots; few fine pores; discontinuous clay skins; merging wavy horizon boundary to:
B3	100+	Clay; yellowish red (5YR 5/6); very firm when moist; very sticky and very plastic when wet; moderate medium subangular blocky structure; no roots; many moderately hard grits and gravel (of shale and iron concretions).

APPENDIX II (*continued*)

Profile: One month after clearing and burning (1MAB) Plot B.

Great Group	: Red-Yellow Podzolic	Drainage	:Well drained
Family	: Bekenu	Topography	: Undulating hills
Series	: Bekenu	Slope	: 20^o
Parent Material	: Sandy shale	Position	: Midslope

Hori-zon	Depth (cm)	Description
O	-	Bare to thin layer of ashes
A2	0-4	Sandy clay loam; yellowish brown (10YR 5/4); loose when moist; nonsticky and nonplastic when wet; moderate medium crumb structure; abundant fine and many medium roots; abundant medium pores; almost continuous coatings of organic matter; many charcoal; diffuse wavy horizon boundary to:
B1	4-24	Sandy clay loam; yellowish brown (10YR 5/8); very friable when moist; nonsticky and nonplastic when wet; granular moderate medium subangular blocky structure; abundant medium and many large roots; many medium pores; merging wavy horizon boundary to:
B21	24-54	Clay loam; brownish yellow (10YR 6/8); friable when moist; slightly sticky and slightly plastic when wet; moderate medium subangular blocky structure; few medium and many large roots; many medium pores; patchy clay skins; merging smooth horizon boundary to:
B22	54-92	Clay loam; yellowish brown (10YR 5/8); firm when moist; sticky and plastic when wet; moderate coarse subangular blocky structure; few fine and few medium roots; abundant fine pores; discontinuous clay skins; merging smooth horizon boundary to:
B3	92-115	Clay loam; reddish yellow (7.5YR 6/8); very firm when moist; sticky and plastic when wet; moderate coarse subangular blocky structure; no roots; few fine pores.

Profile: 1.5 Years after abandonment (1.5YAA) Plot A.

Great Group	: Red-Yellow Podzolic	Drainage	: Moderately well drained
Family	: Bekenu	Topography	: Hilly
Series	: Bekenu	Slope	: 15^{o}
Parent Material	: Sandstone	Position	: Midslope

Hori- zon	Depth (cm)	Description
O	1.5-0	Decomposed litter, mostly burned, rotten bark present.
A1	0-6	Very fine sandy loam; dark yellowish brown (10YR 4/4); very friable when moist; moderate medium crumb; many fine roots; many fine pores; patchy organic matter; abrupt and wavy horizon boundary to:
B1	6-40	Very fine sandy loam; brownish yellow (10YR 6/8); few fine faint mottles, very pale brown (10YR 7/4); friable when moist; weak medium subangular blocky structure; few fine and medium roots; few fine pores; patchy organic matter; gradual and wavy horizon boundary to:
B21	40-62	Sandy clay loam; strong brown (7.5YR 5/8); many fine distinct mottles, pinkish white (7.5YR 8/2); friable when moist; moderate medium angular and subangular blocky structure; few fine roots; few fine pores; patchy clay skins; gradual and wavy horizon boundary to:
B22	62-100	Sandy clay loam; reddish yellow (5YR 6/8); many fine prominent mottles, pink (7.5YR 7/4); friable when moist; moderate medium angular and subangular blocky structure; no roots; few fine pores; patchy clay skins.

Profile: 1.5 Years after abandonment (1.5YAA) Plot B.

Great Group	: Red-Yellow Podzolic	Drainage	: Moderately well drained
Family	: Nyalau	Topography	: Hilly
Series	: Nyalau	Slope	: 15^{o}
Parent Material	: Sandstone	Position	: Midslope

Hori- zon	Depth (cm)	Description
O	1.5-0	Decomposed litter, mostly burned, rotten bark and charcoal present.
A1	0-4	Very fine sandy loam; yellowish brown (10YR 5/4); friable when moist; moderate medium crumb; few medium and many fine roots; many fine and medium pores; clear and wavy horizon boundary to:
B1	4-36	Very fine sandy loam; yellowish brown (10YR 5/8); few fine faint mottles, light yellowish brown (10YR 6/4); friable when moist; moderate medium

		subangular blocky structure; few fine roots; many fine pores; patchy organic matter; gradual and wavy horizon boundary to:
B21	36-62	Very fine sandy loam; yellowish brown (10YR 5/8); firm when moist; moderate medium angular and subangular blocky structure; many soft grits and moderately hard gravel; few fine roots; few fine pores; gradual and wavy horizon boundary to:
B22	62-100	Very fine sandy loam; yellow brown (10YR 5/8); few fine faint mottles, very pale brown (10YR 7/4); firm when moist; moderate medium angular and subangular blocky structure; few soft grits and moderately hard gravel; no roots; few fine pores.

Profile: *Acacia mangium* plantation (Plot A)

Great Group	: Red-Yellow Podzolic	Drainage	: Well drained
Family	: Merit	Topography	: Hilly
Series	: Begunan	Slope	: 11°
Parent Material	: Shale	Position	: Midslope

Horizon	Depth (cm)	Description
O	2.5-0	Leaf and fern litter.
A1	0-4	Sandy clay loam; yellowish brown (10YR 5/6); firm when moist; moderate medium crumb; many fine and few medium roots; many fine pores; clear and wavy horizon boundary to:
B1	4-35	Sandy clay loam; brownish yellow (10 YR 6/8); firm when moist; moderate medium subangular blocky structure; many fine and few medium roots; many fine pores; diffuse and wavy horizon boundary to:
B21	35-85	Clay loam; reddish yellow (7.5YR 6/8); few fine distinct mottles, yellow (10YR 7/8); firm when moist; moderate medium subangular blocky structure; many fine and few medium roots; many fine pores; patchy clay skins; diffuse and wavy horizon boundary to:
B22	85-100	Clay; reddish yellow (5YR 6/8); few fine distinct mottles, yellow (10YR 7/8); firm when moist; moderate medium angular blocky structure; few moderately hard grits and gravels; few fine roots; few fine pores.

APPENDIX II (*continued*)

Profile: *Acacia mangium* plantation (Plot B).

Great Group	: Red-YellowPodzolic	Drainage	: Moderately well drained
Family	: Merit	Topography	: Hilly
Series	: Begunan	Slope	: 19°
Parent Material	: Shale	Position	: Midslope

Hori-zon	Depth (cm)	Description
O	2.5-0	Leaf litter.
A1	0-6	Sandy clay loam; yellowish brown (10YR 4/8); friable when moist; moderate medium crumb; abundant fine and few medium roots; abundant fine pores; clear and wavy horizon boundary to:
A2	6-22	Sandy clay loam; brownish yellow (10YR 6/8); friable when moist; moderate medium subangular blocky structure; few fine and medium roots; many fine pores; patchy organic matter; diffuse and wavy horizon boundary to:
B1	22-36	Clay loam; brownish yellow(10YR 6/8); few fine distinct mottles, very pale brown (10YR 7/4); firm when moist; moderate medium subangular blocky structure; few fine and medium roots; few fine and medium pores; diffuse and wavy horizon boundary to:
B21	36-63	Clay loam; reddish yellow (7.5YR 6/8); few fine distinct mottles, very pale brown (10YR 7/4); firm when moist; moderate medium angular blocky structure; few fine and medium roots; few fine pores; diffuse and wavy horizon boundary to:
B22	63-95	Clay; reddish yellow (5YR 6/8); many fine prominent mottles, very pale brown (10YR 7/4); firm when moist; moderate medium angular blocky structure; few fine and medium roots; few fine pores; discontinuous clay skins; abrupt and wavy horizon boundary to:
B3	95-100	Clay; reddish yellow (5YR 6/8); many fine prominent mottles, very pale brown (10YR 7/4); firm when moist; moderate medium angular blocky structure; no roots; few moderately hard grits and gravel.

Profile: *Gmelina arborea* plantation

Great Group : Red-Yellow Podzolic
Family : Merit
Series : Begunan
Parent Material : Sandstone
Drainage : Moderately well drained
Topography : Hilly
Slope : 21°
Position : Midslope

Hori-zon	Depth (cm)	Description
O	1.5-0	*Gmelina* leaf litter
A1	0-8	Sandy clay loam; brown (10YR 4/3); friable when moist; moderate medium crumb; few moderately hard grits; abundant fine and many medium roots; abundant fine and many medium pores; clear and wavy horizon boundary to:
B2	8 -58	Clay; brownish yellow (10YR 6/8); firm when moist; moderate medium subangular blocky structure; many soft gravels; few fine and medium roots; few fine pores; merging and wavy horizon boundary to:
B22	58-100	Clay; brownish yellow (10YR 6/8); few fine faint mottles, brownish yellow (10YR 6/8); firm when moist; moderate medium angular blocky structure; no roots; many soft gravels.

Profile: *Leucaena leucocephala* plantation (Plot A)

Great Group : Red-Yellow Podzolic
Family : Merit
Series : Begunan
Parent Material : Sandstone
Drainage : Moderately well drained
Topography : Hilly
Slope : 14°
Position : Midslope

Hori-zon	Depth (cm)	Description
O	3.0-0	Fern litter.
A1	0-6	Sandy clay loam; yellowish brown (10YR 5/6); friable when moist; moderate medium crumb; abundant fine and few medium roots; abundant fine and few medium pores; clear and wavy horizon boundary to:
B1	6-23	Sandy clay loam; very pale brown (10YR 7/4); abundant medium prominent mottles, red (2.5YR 4/8); firm when moist; moderate fine angular blocky structure; few fine roots; few few fine pores; clear and wavy horizon boundary to:
B21	23-50	Clay loam; reddish yellow (7.5YR 6/8); few fine faint mottles, yellow (10YR 7/8); firm when moist; moderate medium subangular blocky structure; few fine roots; few cracks; patchy clay skins; diffuse and wavy horizon boundary to:

B22	50-72	Clay; reddish yellow (7.5YR 6/8); many fine faint mottles, yellow (10YR 7/8); friable when moist; moderate medium subangular blocky structure; few moderately hard grits; few fine pores; patchy clay skins; diffuse and wavy horizon boundary to:
B3	72-100	Clay; reddish yellow (7.5YR 6/8); abundant fine faint mottles, yellow (10YR 7/8); firm when moist; moderate medium subangular blocky structure; no roots; many moderately hard grits and gravel.

Profile: *Leucaena leucocephala* plantation (Plot B)

Great Group	: Red-Yellow Podzolic	Drainage	: Moderately well drained
Family	: Bekenu	Topography	: Hilly
Series	: Bekenu	Slope	: 14°
Parent Material	: Sandstone	Position	: Lower midslope

Horizon	Depth (cm)	Description
O	1.5-0	Fern litter.
A1	0-7	Sandy clay loam; very dark greyish brown (10YR 3/2); friable when moist; moderate medium crumb; abundant fine and few medium roots; abundant fine and few medium pores; many charcoal; abrupt and wavy horizon boundary to:
B1	7-26	Sandy clay loam; brownish yellow (10YR 6/8); few fine distinct mottles, reddish yellow (7.5YR 6/8); friable when moist; weak medium subangular blocky structure; many fine roots; many fine pores; patchy organic matter; diffuse and wavy horizon boundary to:
B2	26-47	Sandy clay loam; brownish yellow (10YR 6/8); few fine faint mottles, reddish yellow (7.5YR 6/8); firm when moist; weak medium subangular blocky structure; few moderately hard grits; few fine roots; gradual and wavy horizon boundary to:
B3	47-100	Sandy clay loam; brownish yellow (10YR 6/8); few fine distinct mottles, very pale brown (10YR 8/4); firm when moist; moderate medium subangular blocky structure; no roots; abundant moderately hard and very fine sandstone, dark yellowish brown (10YR 3/6).

APPENDIX II (*continued*)

Profile: Fallow forest (Plot A)

Great Group : Red-Yellow Podzolic
Family : Merit
Series : Begunan
Parent Material : Sandstone

Drainage : Moderately well drained
Topography : Hilly
Slope : 24°
Position : Midslope

Hori-zon	Depth (cm)	Description
O	2.5-0	*Macaranga* spp. leaf litter.
A1	0-7	Sandy clay loam; dark yellowish brown (10YR 4/4); friable when moist; moderate medium crumb; abundant fine and few medium roots; many fine and few medium pores; clear and wavy horizon boundary to:
A2	7-30	Sandy clay loam; brownish yellow (10YR 6/8); friable when moist; moderate medium subangular blocky structure; many fine and few medium roots; many fine pores; diffuse and wavy horizon boundary to:
B1	30-51	Clay loam; reddish yellow (7.5YR 6/8); firm when moist; moderate medium subangular blocky structure; few medium roots; few fine pores; patchy clay skins; diffuse and wavy horizon boundary to:
B21	51-81	Clay loam; reddish yellow (7.5YR 6/8); few fine faint mottles, yellow (10YR 7/8); firm when moist; moderate medium angular blocky structure; few fine roots; few fine pores; patchy clay skins; diffuse and wavy horizon boundary to:
B22	81-100	Clay; reddish yellow (7.5YR 6/8); many fine faint mottles, yellow (10YR 7/8); firm when moist; moderate medium angular blocky structure; no roots.

Profile: Fallow forest (Plot B)

Great Group : Red-Yellow Podzolic
Family : Merit
Series : Begunan
Parent Material : Sandstone

Drainage : Moderately well drained
Topography : Hilly
Slope : 15°
Position : Upper midslope

Hori-zon	Depth (cm)	Description
O	3.0-0	*Macaranga* spp. leaf litter.
A1	0-8	Sandy clay loam; yellowish brown (10YR 5/6); friable when moist; moderate medium crumb; abundant fine and few medium roots; abundant fine and few medium pores; clear and wavy horizon boundary to:

APPENDIX II (*continued*)

A2	8-23	Clay loam; brownish yellow (10YR 6/8); friable when moist; moderate medium subangular blocky structure; few fine roots; few fine pores; diffuse and wavy horizon boundary to:
B1	23-42	Clay loam; brownish yellow (10YR 6/8); firm when moist; moderate medium subangular blocky structure; few fine and many large roots; few fine pores; diffuse and wavy horizon boundaryto:
B21	42-94	Clay; reddish yellow (7.5YR 6/8); firm when moist; moderate medium subangular blocky structure; few moderately hard grits; few medium roots; few fine pores; patchy clay skins; diffuse and wavy horizon boundary to:
B22	94-100	Clay; reddish yellow (7.5YR 6/8); many fine distinct mottles, yellow (10YR 7/6); firm when moist; moderate medium angular blocky structure; no roots; many soft grits and moderately hard gravels; patchy clay skins.

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* Key To Soil Descriptions

Mottles

Few : 2% of exposed surface
Many : 2% to 20% of exposed surface
Abundant : > 20% of exposed surface

Stones or Concretions

Abundance:

Few : < 10% of exposed area
Many : 10 to 30% of exposed area
Abundant : > 30% of exposed area

Size:

Grit : 2 to 3 mm
Gravel : 3 to 10 mm
Stony : 10 to 250 mm
Boulders : > 250 mm

Roots

Abundance:

Few : 4 to 20 per 30 cm^2 of profile face
Many : 20 to 100 per 30 cm^2 of profile face
Abundant : > 100 per 30 cm^2 of profile face

Size:

Fine : < 1 mm
Medium : 1 to 12.5 mm
Large : > 12.5 mm

Pores

Abundance :

Few : 1 to 3 /sq inch (2-6 per 5 cm^2)
Many : 4 to 14 /sq. inch (8-28 per 5 cm^2)
Abundant : > 14 /sq.inch (>28 per 5 cm^2)

Size:

Fine: < 1 mm diameter
Medium: 1 to 5 mm diameter
Abundant: > 5 mm diameter

APPENDIX III SOIL PHYSICAL ANALYSIS

		Size Class and Particle Diameter									Bulk density	Porosity
Hori- zon	Depth	Total (% of < 2mm)			Sand (% of < 2mm)							
	(cm)	Sand	Silt	Clay	VC	C	M	F	VF	Text.	(g/cm^3)	(%)
Undisturbed Primary Forest (UPF).												
Plot A												
A1	0-4	46.55	26.76	26.69	0.31	0.44	0.25	4.95	40.60	SCL	1.14	60.96
A2	4-28	46.73	26.69	26.59	0.11	0.38	0.16	2.37	43.71	SCL	1.28	47.97
B1	28-44	42.68	26.15	31.16	0.59	0.65	0.32	1.89	39.23	CL	1.62	42.96
B21, B22&B23	44-100	31.27	28.59	40.14	1.70	2.23	1.01	1.70	24.63	CL	1.50	45.65
Plot B												
AB	0-5	27.47	31.80	40.74	0.30	0.89	1.49	3.51	21.28	CL	0.96	62.50
B21	5-47	15.03	31.37	53.60	0.11	0.44	0.66	1.48	12.34	C	1.34	54.11
B22	47-76	12.51	28.47	59.02	0.26	0.90	1.06	1.48	8.81	C	1.30	46.50
B23	76-100	13.06	27.24	59.72	0.82	1.52	1.47	1.69	7.56	C	1.30	51.31
Plot C												
A1	0-4	58.23	23.01	18.76	0.00	0.10	0.65	2.15	55.33	SL	n.d.*	n.d.
A2	4-13	57.78	24.33	17.89	0.10	0.10	0.20	0.76	56.62	SL	1.25	43.44
B11	13-30	56.14	27.86	16.00	0.00	0.10	0.10	0.56	55.38	SL	1.52	35.53
B12	30-48	53.17	37.03	9.80	0.10	0.15	0.10	0.51	52.31	SL	1.66	31.97
B21	48-81	47.03	21.76	31.21	0.20	0.20	0.10	0.35	46.18	SL	1.54	35.19
B22	81-100	41.06	21.83	37.11	0.10	0.15	0.10	0.25	40.46	SL	1.40	41.51
Logged Over Forest (LOF).												
Plot A												
A1	0-5	46.86	23.08	30.05	0.34	0.45	0.74	21.98	23.35	SCL	1.22	58.64
A2	5-25	41.64	24.52	33.84	0.17	0.33	0.72	23.68	16.74	CL	1.41	47.39
B1	25-40	37.03	24.59	38.39	0.38	0.43	0.65	16.67	18.90	CL	1.48	42.64
B2&3	40-100	24.35	22.51	53.14	2.11	3.09	1.78	7.41	9.96	C	1.36	52.61
Plot B												
A1	0-3	46.56	24.84	28.59	0.44	0.50	0.72	22.06	22.84	SCL	1.31	56.19
A2	3-28	42.15	26.00	31.86	0.11	0.32	0.70	19.33	21.69	CL	1.55	40.61
B1	28-43	34.69	26.77	38.54	0.32	0.32	0.65	15.11	18.29	CL	1.47	51.00
B2&3	43-100	26.34	24.30	49.36	3.29	3.94	2.16	6.96	9.99	C	1.48	54.18

Appendix III (*continued*)

		Size Class and Particle Diameter									Bulk density	Porosity
Hori-zon	Depth	Total (% of < 2mm)			Sand (% of < 2mm)							
	(cm)	Sand	Silt	Clay	VC	C	M	F	VF	Text.	(g/cm^3)	(%)
Two Days After Clearing and Burning (2DAB)												
A2	0-13	47.71	25.26	27.04	0.31	0.31	0.26	0.52	46.31	SCL	0.92	59.74
B1	13-30	44.85	25.86	29.29	0.61	0.40	0.20	0.40	43.24	CL	1.53	37.17
B21	30-68	37.96	25.09	36.95	0.31	0.51	0.41	0.66	36.07	CL	1.49	35.26
B22	68-140	28.97	28.04	43.00	0.31	0.83	0.67	1.14	26.02	C	1.55	34.49
Two Weeks After Clearing and Burning (2WAB).												
A2	0-20	45.08	18.14	33.53	0.26	0.37	0.31	2.31	45.08	SCL	1.10	52.00
B1	20-46	41.76	17.50	35.44	0.72	1.13	0.82	2.63	41.76	SC	1.33	44.92
B2	46-100	36.71	19.49	32.13	1.40	3.53	3.01	3.73	36.71	SCL	1.35	41.43
One Month After Clearing and Burning (1MAB)												
Plot A												
A2	0-18	40.37	29.05	30.58	0.31	0.31	0.68	15.40	23.67	CL	1.30	45.75
B1	18-40	32.00	28.85	39.15	0.10	0.16	0.47	11.95	19.32	CL	1.45	39.38
B21	40-76	26.00	26.76	47.23	0.10	0.26	0.42	9.46	15.76	C	1.47	39.88
B22	76-100	22.27	28.06	49.67	0.32	0.32	0.42	7.67	13.54	C	1.33	44.12
B3	100 +	21.98	26.11	51.90	2.20	2.69	1.61	6.40	9.08	C	1.30	43.81
Plot B												
A2	0-4	48.22	24.71	27.07	0.05	0.27	0.64	10.58	36.68	SCL	n.d.	n.d.
B1	4-24	47.62	23.09	29.29	0.05	0.21	0.26	9.72	37.38	SCL	1.31	44.10
B21	24-54	42.43	23.78	33.79	0.05	0.15	0.31	8.94	32.98	CL	1.45	38.60
B22	54-92	40.95	23.96	35.09	0.10	0.16	0.26	8.30	32.13	CL	1.40	43.25
B3	92-115	37.51	23.13	39.36	0.10	0.21	0.26	7.61	29.33	CL	1.42	38.97
1.5 Years After Abandonment (1.5YAA).												
Plot A												
A1	0- 6	68.15	14.11	17.74	0.00	0.11	0.81	34.29	32.94	VFSL	1.30	49.01
B1	6-40	63.21	29.01	7.78	0.05	0.10	0.62	29.72	32.72	VFSL	1.52	42.19
B21	40-62	59.10	15.73	25.17	0.05	0.21	0.57	27.00	31.28	SCL	1.58	38.61
B22	62-100+	54.28	17.08	28.64	0.15	0.15	0.56	24.22	29.19	SCL	1.53	43.00

Appendix III (*continued*)

		Size Class and Particle Diameter									Bulk density	Porosity
Horizon	Depth	Total (% of < 2mm)			Sand (% of < 2mm)							
	(cm)	Sand	Silt	Clay	VC	C	M	F	VF	Text.	(g/cm^3)	(%)
1.5 Years After Abandonment (1.5YAA).												
Plot B												
A1	0- 4	67.16	15.06	17.78	0.16	0.16	0.86	28.97	37.01	VFSL	1.39	46.27
B1	4-36	64.98	15.33	19.70	0.16	0.21	0.73	26.18	37.71	VFSL	1.53	42.44
B21	36-62	60.93	29.73	9.34	2.13	1.61	1.15	23.08	32.96	VFSL	1.65	38.58
B22	62-100+	56.36	30.95	12.69	0.62	0.73	0.78	20.81	33.42	VFSL	1.56	41.07
Acacia mangium												
Plot A												
A1	0- 4	53.69	22.31	24.00	0.05	0.21	0.53	20.65	32.25	SCL	1.34	49.05
B1	4-35	48.56	22.26	29.19	0.05	0.16	0.47	18.02	29.86	SCL	1.39	49.45
B21	35-85	41.61	21.66	36.72	0.10	0.15	0.46	15.54	25.36	CL	1.46	45.52
B22	85-100	37.07	22.63	40.29	0.52	0.72	0.62	13.18	22.03	C	1.44	54.43
Plot B												
A1	0- 6	60.40	18.17	21.43	0.11	0.16	0.64	18.67	40.82	SCL	1.46	46.52
A2	6-22	54.54	20.49	24.96	0.05	0.10	0.46	15.66	38.27	SCL	1.51	47.75
B1	22-36	44.40	22.06	33.55	0.05	0.16	0.36	12.01	31.82	CL	1.49	42.47
B21	36-63	42.20	21.70	36.11	0.11	0.16	0.36	11.39	30.18	CL	1.51	46.07
B22 & B3	63-100	37.58	21.57	40.85	0.11	0.21	0.36	9.40	27.50	C	1.48	51.32
Gmelina arborea												
A1	0-8	50.41	22.58	27.00	0.53	0.96	1.44	17.00	30.48	SCL	1.32	53.19
B21	8-58	34.03	19.25	46.72	2.64	2.32	1.59	8.35	19.13	C	1.46	44.49
B22	58-100	31.38	20.51	48.12	2.92	3.96	2.61	5.11	16.78	C	1.40	54.55
Leucaena leucocephala												
Plot A												
A1	0-6	57.61	19.20	23.20	0.16	0.36	0.52	16.74	39.83	SCL	1.32	50.56
B1	6-23	51.68	19.17	29.15	0.10	0.21	0.36	13.89	37.12	SCL	1.53	47.24
B21	23-50	43.86	19.20	36.94	0.31	0.26	0.42	11.51	31.36	CL	1.53	43.96
B22 & B3	50-100	42.49	17.45	40.06	1.69	1.52	0.84	10.06	28.38	C	1.41	47.78

Appendix III (*continued*)

		Size Class and Particle Diameter									Bulk density	Porosity
Hori-zon	Depth	Total (% of < 2mm)			Sand (% of < 2mm)							
	(cm)	Sand	Silt	Clay	VC	C	M	F	VF	Text.	(g/cm^3)	(%)
Leucaena leucocephala												
Plot B												
A1	0-7	60.98	18.22	20.80	0.05	0.16	0.48	11.01	49.28	SCL	1.20	48.94
B1	7-26	59.52	15.93	24.55	0.00	0.10	0.35	8.94	50.13	SCL	1.45	49.48
B2	26-47	52.61	16.78	30.61	0.15	0.15	0.30	7.02	44.99	SCL	1.45	48.58
B3	47-100	49.71	17.66	32.63	1.66	1.96	1.11	4.88	40.10	SCL	1.46	45.72
Fallow Forest												
Plot A												
A1	0-7	48.07	23.33	28.59	0.05	0.16	1.34	20.55	25.97	SCL	1.23	56.69
A2	7-30	47.12	22.30	30.57	0.05	0.10	1.14	19.37	26.46	SCL	1.39	48.33
B1	30-51	44.27	22.17	33.56	0.05	0.10	1.02	18.00	25.10	CL	1.47	44.74
B21 &B22	51-100	42.27	20.84	36.88	0.05	0.11	0.94	17.69	23.48	CL	1.49	38.17
Plot B												
A1	0-8	46.58	22.92	30.50	0.11	0.21	0.70	17.18	28.38	SCL	1.30	52.55
A2	8-23	39.64	22.94	37.42	0.00	0.21	0.52	13.84	25.07	CL	1.37	48.50
B1	23-42	40.37	22.42	37.21	0.05	0.21	0.51	13.37	26.23	CL	1.42	45.80
B21 &B22	42-100	36.35	22.24	41.41	0.11	0.21	0.47	12.73	22.83	C	1.39	42.56

* not determined

APPENDIX IV SOIL CHEMICAL ANALYSIS

Hor-izon	Depth (cm)	LOI	pH H_2O (1:2.5)	pH KCl (1:2.5)	OC (%)	N (%)	C/N	TP (ppm)	Ca (me/100 g)	Mg (me/100 g)	K (me/100 g)	Na (me/100 g)	CEC (me/100 g)	Base Sat. (%)	Al (me/100 g)	H (me/100 g)
Undisturbed Primary Forest (UPF)																
Plot A																
A1	0-4	16.35	3.5	2.9	5.20	0.34	15.29	200	0.50	0.36	0.27	0.11	39.26	3.16	5.49	1.64
A2	4-28	4.14	4.0	3.4	0.84	0.08	10.50	100	0.37	0.06	0.10	0.09	26.11	2.37	5.50	0.29
B1	28-44	3.66	4.3	3.4	0.52	0.05	10.40	100	0.06	0.02	0.06	0.12	22.42	1.16	5.71	0.30
B21 -B23	44-100	4.72	4.5	3.6	0.52	0.06	8.67	200	0.43	0.05	0.15	0.12	24.12	3.11	6.97	0.11
Plot B																
AB	0-5	14.86	4.3	3.5	3.22	0.34	9.47	200	2.21	0.71	0.40	0.27	14.97	23.98	5.87	0.67
B21	5-47	10.77	4.3	3.5	0.57	0.17	3.35	200	0.35	0.19	0.10	0.12	14.45	5.26	10.71	0.70
B22	47-76	11.51	4.3	3.6	0.47	0.14	3.36	200	0.01	0.14	0.12	0.35	14.21	4.36	11.06	0.44
B23	76-100	12.02	4.2	3.6	0.35	0.18	1.94	200	0.80	0.21	0.07	0.09	15.27	7.66	11.08	0.51
Plot C																
A1	0-4	10.62	3.5	3.3	3.69	0.23	16.04	108	0.38	0.63	0.24	0.04	9.72	13.27	3.81	1.01
A2	4-13	4.79	3.6	3.5	1.27	0.11	11.55	105	0.22	0.15	0.09	0.03	9.84	4.98	4.22	0.43
B11	13-30	3.00	3.8	3.7	0.49	0.05	9.80	100	0.24	0.07	0.05	0.03	9.86	3.96	4.06	0.58
B12	30-48	2.84	3.8	3.8	0.24	0.04	6.00	110	0.07	0.02	0.03	0.01	9.87	1.32	4.19	0.54
B21	48-81	3.44	3.8	3.8	0.19	0.04	4.75	126	0.17	0.03	0.04	0.03	9.84	2.74	4.43	0.48
B22	81-100	3.90	3.9	3.6	0.17	0.05	3.40	177	0.20	0.04	0.08	0.04	9.80	3.67	5.28	0.57

APPENDIX IV (*continued*)

Horizon	Depth (cm)	LOI	pH H_2O (1:2.5)	pH KCl	OC (%)	N (%)	C/N	TP (ppm)	Ca	Mg (me/100 g)	K	Na	CEC	Base Sat. (%)	Al (me/100 g)	H
Logged Over Forest (LOF)																
Plot A																
A1	0-5	11.11	3.7	3.4	2.94	0.27	10.89	230	0.84	0.75	0.26	0.13	16.59	11.93	4.19	0.78
A2	5-25	5.21	3.8	3.6	0.79	0.12	6.58	123	0.20	0.21	0.24	0.16	11.21	7.23	5.81	0.53
B1	25-40	5.41	3.9	3.6	0.59	0.09	6.56	122	0.17	0.13	0.17	0.13	14.10	4.26	6.15	0.52
B2 &B3	40-100	7.60	4.0	3.7	0.84	0.09	9.33	162	0.15	0.07	0.08	0.12	16.26	2.58	7.31	0.60
Plot B																
A1	0-3	9.31	3.9	3.5	2.49	0.24	10.38	180	0.48	0.40	0.15	0.15	13.59	8.68	4.93	0.69
A2	3-28	4.77	3.9	3.6	0.70	0.12	5.83	104	0.17	0.31	0.06	0.14	12.72	5.35	5.33	0.46
B1	28-43	5.09	4.0	3.7	0.42	0.08	5.25	111	0.15	0.11	0.06	0.11	13.69	3.14	6.23	0.57
B2 &B3	43-100	7.33	4.3	3.8	0.31	0.08	3.88	141	0.15	0.09	0.08	0.14	15.15	3.04	7.43	0.62
Two Days After Clearing and Burning (2DAB)																
Ashes		20.44	9.8	9.8	0.50	0.06	8.33	1233	45.30	39.39	70.50	0.38	9.63	-	-	-
A2	0-13	5.92	3.8	3.6	1.38	0.12	11.50	143	0.45	0.20	0.14	0.02	9.79	8.27	4.40	0.44
B1	13-30	4.43	4.1	3.7	0.52	0.06	8.67	145	0.22	0.09	0.07	0.02	9.81	4.08	5.06	0.41
B21	30-68	4.48	4.2	3.7	0.30	0.06	5.00	168	0.25	0.06	0.06	0.02	9.79	3.98	6.41	0.46
B22	68-140	5.42	4.4	3.7	0.20	0.07	2.86	199	0.29	0.08	0.09	0.03	9.78	5.01	6.75	0.77
Two Weeks After Clearing and Burning (2WAB)																
A2	0-20	8.56	4.1	3.9	1.79	0.17	10.53	141	0.63	0.36	0.29	0.05	9.62	13.83	5.10	0.50
B1	20-46	5.68	4.2	3.8	0.44	0.07	6.29	130	0.26	0.11	0.08	0.03	9.63	4.98	7.68	0.38
B2	46-100	6.58	4.1	3.9	0.30	0.09	3.33	121	0.17	0.07	0.08	0.04	9.61	3.75	8.21	0.50

APPENDIX IV (*continued*)

Horizon	Depth (cm)	LOI	pH H_2O (1:2.5)	pH KCl (1:2.5)	OC (%)	N (%)	C/N	TP (ppm)	Ca (me/100 g)	Mg (me/100 g)	K (me/100 g)	Na (me/100 g)	CEC	Base Sat. (%)	Al (me/100 g)	H (me/100 g)
One Month After Clearing and Burning (1MAB)																
Plot A																
A2	0-18	7.13	4.3	4.7	1.65	0.18	9.17	157	1.61	0.64	0.58	0.02	9.70	29.38	3.41	0.60
B1	18-40	5.23	4.0	3.6	0.39	0.08	4.87	111	0.20	0.11	0.09	0.03	9.70	4.43	6.32	0.41
B21	40-76	5.92	4.4	3.5	0.37	0.07	5.29	123	0.15	0.08	0.08	0.01	9.65	3.32	6.85	0.74
B22	76-100	6.32	4.4	3.6	0.36	0.07	5.14	122	0.22	0.08	0.10	0.04	9.63	4.57	7.22	0.56
B3	100+	7.30	4.6	3.6	0.37	0.08	4.63	127	0.24	0.07	0.10	0.03	9.59	4.59	6.61	0.80
Plot B																
A2	0-4	8.00	6.2	6.4	3.19	0.26	12.27	250	1.46	0.65	0.48	0.03	9.68	27.07	3.01	0.15
B1	4-24	5.25	4.0	3.6	0.67	0.08	8.37	112	0.38	0.10	0.11	0.01	9.75	6.15	5.75	0.57
B21	24-54	5.04	3.9	3.6	0.38	0.06	6.33	109	0.18	0.05	0.05	0.02	9.74	3.08	6.30	0.52
B22	54-92	4.85	4.1	3.5	0.28	0.06	4.67	103	0.16	0.05	0.04	0.02	9.71	2.78	6.72	0.51
B3	92-115	5.27	4.4	3.6	0.24	0.05	4.80	100	0.21	0.05	0.05	0.02	9.70	3.40	6.86	0.51
1.5 Years After Abandonment (1.5YAA)																
Plot A																
A1	0-6	6.55	4.4	3.5	1.92	0.12	16.00	101	1.05	0.37	0.18	0.07	9.78	17.08	3.71	0.13
B1	6-40	3.12	4.5	3.6	0.39	0.05	7.80	67	0.10	0.08	0.09	0.01	9.82	2.85	4.16	0.42
B21	40-62	3.32	4.6	3.6	0.23	0.04	5.75	70	0.10	0.05	0.09	0.04	9.80	2.86	4.91	0.10
B22	62-100	3.64	4.8	3.7	0.11	0.03	3.67	75	0.07	0.03	0.08	0.04	9.79	2.25	4.99	0.22
Plot B																
A1	0-4	7.05	4.3	3.6	1.85	0.16	11.56	145	0.91	0.65	0.20	0.07	9.78	18.71	4.06	0.21
B1	4-36	3.57	4.4	3.7	0.56	0.05	11.20	88	0.07	0.08	0.14	0.01	9.81	3.06	4.26	0.38
B21	36-62	3.91	4.6	3.8	0.27	0.04	6.75	84	0.06	0.04	0.07	0.03	9.80	2.04	4.16	0.06
B22	62-100	4.06	4.6	3.9	0.27	0.03	9.00	85	0.05	0.03	0.06	0.01	9.78	1.53	4.35	0.07

APPENDIX IV (*continued*)

Hor-izon	Depth (cm)	LOI	pH H_2O (1:2.5)	pH KCl	OC (%)	N (%)	C/N	TP (ppm)	Ca	Mg (me/100 g)	K	Na	CEC	Base Sat. (%)	Al (me/100 g)	H
Acacia mangium																
Plot A																
A1	0-4	8.45	3.8	3.5	2.26	0.23	9.83	147	0.56	0.73	0.28	0.14	17.23	9.92	4.23	0.64
B1	4-35	4.76	3.7	3.5	0.70	0.09	7.78	102	0.14	0.10	0.08	0.12	11.40	3.86	5.85	0.46
B21	35-85	4.98	3.9	3.6	0.28	0.05	5.60	102	0.13	0.06	0.06	0.12	11.49	3.22	6.48	0.29
B22	85-100	5.85	3.8	3.6	0.44	0.05	8.80	116	0.14	0.06	0.06	0.14	12.18	3.28	6.72	0.37
Plot B																
A1	0-6	7.52	3.8	3.5	1.86	0.19	9.79	130	1.03	0.52	0.23	0.17	12.58	15.50	3.62	0.55
A2	6-22	4.64	3.8	3.5	0.88	0.09	9.78	94	0.30	0.16	0.10	0.14	12.18	5.75	5.63	0.59
B1	22-36	4.91	3.8	3.5	0.47	0.08	5.88	92	0.16	0.09	0.06	0.12	10.23	4.20	7.55	0.70
B21	36-63	4.73	3.8	3.5	0.31	0.06	5.17	89	0.14	0.06	0.06	0.13	11.10	3.51	7.40	0.55
B22	63-100	5.52	3.8	3.6	0.26	0.06	4.33	100	0.15	0.07	0.08	0.17	11.14	4.22	7.51	0.37
Gmelina arborea																
A1	0-8	10.04	4.4	3.8	2.41	0.20	12.05	175	3.34	1.72	0.30	0.14	16.00	34.38	1.40	0.41
B21	8-58	7.72	3.8	3.5	0.52	0.10	5.20	143	0.47	0.32	0.21	0.14	16.71	6.82	9.47	0.78
B22	58-100	7.51	3.7	3.5	0.14	0.08	1.75	148	0.23	0.10	0.15	0.14	17.26	3.59	10.75	0.58
Leucaena leucocephala																
Plot A																
A1	0-6	6.55	4.1	3.8	1.48	0.14	10.57	134	1.15	0.51	0.29	0.11	10.91	18.88	2.71	0.32
B1	6-23	4.23	3.7	3.5	0.31	0.06	5.17	93	0.23	0.07	0.09	0.11	8.55	5.85	4.88	0.46
B21	23-50	5.58	3.8	3.5	0.48	0.06	8.00	110	0.21	0.08	0.19	0.13	11.63	5.25	6.35	0.52
B22 &B3	50-100	6.42	3.8	3.6	0.26	0.06	4.33	118	0.23	0.07	0.10	0.16	12.05	4.65	6.64	0.47

APPENDIX IV (*continued*)

Hor-izon	Depth	LOI	pH H_2O	pH KCl	OC	N	C/N	TP	Ca	Mg	K	Na	CEC	Base Sat.	Al	H
	(cm)		(1:2.5)		(%)	(%)		(ppm)		(me/100 g)				(%)	(me/100 g)	
Leucaena leucocephala																
Plot B																
A1	0-7	9.79	4.6	4.1	2.51	0.24	10.46	154	1.50	1.11	0.23	0.14	15.92	18.72	0.21	0.33
B1	7-26	4.26	4.0	3.7	0.57	0.08	7.13	83	0.60	0.25	0.08	0.11	9.38	11.09	3.56	0.33
B2	26-47	4.70	3.8	3.6	0.36	0.06	6.00	93	0.39	0.20	0.17	0.13	10.01	8.89	4.57	0.39
B3	47-100	5.69	4.0	3.7	0.23	0.06	3.83	98	0.23	0.11	0.15	0.14	9.98	6.31	4.77	0.36
Fallow forest																
Plot A																
A1	0-7	8.86	3.9	3.6	2.15	0.21	10.24	148	0.86	0.92	0.23	0.18	14.44	15.17	4.31	0.70
A2	7-30	4.95	3.8	3.5	0.64	0.09	7.11	91	0.15	0.17	0.08	0.14	9.62	5.61	6.02	0.22
B1	30-51	4.69	3.8	3.6	0.22	0.06	3.67	87	0.21	0.10	0.07	0.16	9.60	5.63	6.42	0.37
B21 &22	51-100	4.98	3.9	3.6	0.30	0.06	5.00	94	0.14	0.08	0.06	0.16	12.04	3.65	6.47	0.42
Plot B																
A1	0-8	9.68	3.7	3.4	2.47	0.23	10.74	163	0.86	0.43	0.18	0.15	15.25	10.62	7.03	0.62
A2	8-23	5.94	3.7	3.5	0.65	0.09	7.22	112	0.18	0.10	0.07	0.15	14.43	3.47	7.41	0.53
B1	23-42	5.59	3.7	3.5	0.47	0.07	6.71	113	0.14	0.08	0.08	0.11	13.70	2.99	7.63	0.43
B21 &23	42-100	5.98	3.7	3.5	0.31	0.07	4.43	108	0.25	0.09	0.06	0.13	14.59	3.63	8.11	0.48

APPENDIX V MEAN BIOMASS OF SMALL-LITTER STANDING CROP

Litter type	Primary forest		Logged forest		*Acacia mangium*		*Gmelina arborea*		*Leucaena leucocephala*		Fallow forest	
	t/ha	%	t/ha	%	t/ha	%	t/ha	%	t/ha	%	t/ha	%
Fruit & flowers	0.16	2.3	0.00	0.0	0.79	12.2	0.00	0.0	0.01	0.3	0.00	0.0
Foliage	2.99	43.1	3.47	58.9	1.82	28.1	1.82	46.3	0.54	15.2	3.62	48.7
Branches < 3 cm dob	1.87	26.9	1.76	29.9	1.48	22.9	1.55	39.4	0.62	17.4	2.46	33.1
Grass	0.00	0.0	0.00	0.0	0.06	0.9	0.20	5.1	1.28	36.0	0.18	2.4
Ferns	0.00	0.0	0.00	0.0	1.72	26.6	0.36	9.2	0.62	17.4	0.47	6.3
Vines	0.00	0.0	0.08	1.4	0.00	0.0	0.00	0.0	0.06	1.7	0.00	0.0
Pandans	0.00	0.0	0.02	0.3	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
Palms	0.15	2.1	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
Trash	1.77	25.5	0.56	9.5	0.60	9.3	0.00	0.0	0.43	12.0	0.70	9.4
Total	6.94		5.89		6.50		3.93		3.56		7.43	

APPENDIX VI MEAN BIOMASS PRODUCTION OF THE UNDERGROWTH

Vegetation type	Primary forest		Logged forest		*Acacia mangium*		*Gmelina arborea*		*Leucaena leucocephala*		Fallow forest	
	t/ha	%	t/ha	%	t/ha	%	t/ha	%	t/ha	%	t/ha	%
Grass	0.00	0.0	0.00	0.0	0.71	20.8	0.59	16.5	3.70	45.3	<0.01	<0.1
<u>Ferns</u>:												
Foliage	0.00	0.0	0.00	0.0	1.46	42.8	1.87	52.4	3.06	37.6	0.00	0.0
Stem	0.00	0.0	0.00	0.0	1.10	32.3	0.40	11.2	0.00	0.0	0.00	0.0
Non-woody plants	0.01	0.3	0.10	2.8	0.00	0.0	0.00	0.0	0.44	5.4	0.00	0.0
<u>Woody plants</u>:												
Foliage	0.44	13.8	0.46	12.6	0.04	1.2	0.21	5.9	0.22	2.7	0.46	20.3
Stem	2.11	65.9	2.34	64.3	0.10	2.9	0.50	14.0	0.40	4.9	1.77	79.7
<u>Woody vines</u>:												
Foliage	0.02	0.6	0.06	1.6	0.00	0.0	0.00	0.0	0.08	1.0	0.00	0.0
Stem	0.12	3.8	0.58	15.9	0.00	0.0	0.00	0.0	0.24	2.9	0.00	0.0
<u>Rattans</u>:												
Foliage	0.10	3.1	0.08	2.2	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
Stem	0.40	12.5	0.02	0.5	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
Total	3.20		3.64		3.41		3.57		8.14		2.23	

APPENDIX VII MEAN OVERSTOREY BIOMASS PRODUCTION BY VEGETATIVE COMPONENT

Vegetation type	Primary forest		Logged forest		*Acacia mangium*		*Gmelina arborea*		*Leucaena leucocephala*		Fallow forest	
	t/ha	%	t/ha	%	t/ha	%	t/ha	%	t/ha	%	t/ha	%
Fruit & flowers	0.1	<0.1	0.01	<0.1	0.6	0.5	0.0	0.0	0.0	0.0	<0.1	<0.1
Foliage	8.5	1.8	5.8	2.6	4.7	3.8	2.5	3.0	0.5	5.9	4.2	4.8
Twigs <1 cm dob	18.1	3.9	8.5	3.9	2.9	2.4	2.0	2.3	0.9	10.7	1.8	2.1
Branches 1-3 cm dob	26.4	5.7	14.1	6.4	5.7	4.6	5.4	6.4	1.4	16.7	5.4	6.2
Branches >3 cm dob	40.4	8.7	10.8	4.9	6.3	5.4	5.1	6.0	0.3	3.6	7.9	9.0
Dead trees & branches	4.6	1.0	1.2	0.5	5.2	4.2	4.3	5.1	0.7	8.3	3.8	4.3
<u>Stems</u>:	353.0	75.8	162.3	74.3	97.4	79.0	65.7	77.3	4.6	54.8	63.5	72.7
Wood	318.6	68.4	142.8	65.4	84.3	68.3	58.2	68.5	4.0	47.6	54.7	62.6
Bark	34.3	7.4	19.5	8.9	13.2	10.7	7.5	8.8	0.6	7.2	8.8	10.1
Epiphytes	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Palms	1.5	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.9
<u>Lianas</u>:												
Wood	11.8	2.5	12.0	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bark	1.0	0.2	1.7	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Leaves	0.2	0.1	2.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	465.7		218.5		123.2		85.0		8.4		87.4	

APPENDIX VIII NUTRIENT CONTENT OF ABOVEGROUND BIOMASS

APPENDIX VIII A NITROGEN DISTRIBUTION IN ABOVEGROUND BIOMASS

Vegetation type	Primary forest	Logged forest	*Acacia mangium*	*Gmelina arborea*	*Leucaena leucocephala*	Fallow forest
	(kg/ha)					
Litter	63.7	57.8	88.0	47.0	34.3	82.1
Undergrowth	16.5	21.5	31.9	32.6	99.3	14.9
Overstorey:						
Fruit & flowers	2.0	0.1	14.7	0.0	0.8	0.3
Foliage	100.8	77.9	148.1	48.5	15.8	75.1
Twigs ≤ 1 cm dob	78.9	39.7	24.9	12.3	8.2	8.9
Branches > 1 cm dob	178.4	109.6	111.5	36.0	8.1	36.4
Dead branches	18.4	4.3	39.5	9.4	5.6	9.8
Stems:						
Wood	551.3	269.4	207.1	82.1	10.9	114.4
Bark	197.8	106.2	165.4	47.9	8.1	41.4
Lianas:						
Stem	54.4	57.8	0.0	0.0	0.0	0.0
Foliage	2.8	29.3	0.0	0.0	0.0	0.0
Palms	6.2	0.0	0.0	0.0	0.0	3.4
Total Overstorey	1191.0	694.3	711.2	236.2	57.5	289.7
Total	1271.2	773.6	831.1	315.8	191.1	386.7

APPENDIX VIII B PHOSPHORUS DISTRIBUTION IN ABOVEGROUND BIOMASS

Vegetation type	Primary forest	Logged forest	*Acacia mangium*	*Gmelina arborea*	*Leucaena leucocephala*	Fallow forest
	(kg/ha)					
Litter	2.2	2.1	1.3	1.5	1.0	2.2
Undergrowth	0.6	1.1	1.9	1.8	5.5	0.5
Overstorey:						
Fruit & flowers	0.1	< 0.1	0.7	0.0	0.0	< 0.1
Foliage	4.1	4.2	5.5	2.8	0.7	3.3
Twigs ≤ 1 cm dob	4.6	2.3	1.3	0.9	0.4	0.4
Branches > 1 cm dob	13.0	5.3	9.6	3.5	0.5	1.3
Dead branches	0.5	0.1	1.0	0.4	0.1	0.3
Stems:						
Wood	32.4	14.0	11.0	6.3	0.6	7.3
Bark	6.9	4.5	3.0	3.0	0.3	1.6
Lianas:						
Stem	10.3	5.4	0.0	0.0	0.0	0.0
Foliage	0.1	1.1	0.0	0.0	0.0	0.0
Palms	0.6	0.0	0.0	0.0	0.0	0.3
Total Overstorey	72.6	36.9	32.1	16.9	2.6	14.5
Total	75.4	40.1	35.3	20.2	9.1	17.2

APPENDIX VIII C POTASSIUM DISTRIBUTION IN ABOVEGROUND BIOMASS

Vegetation type	Primary forest	Logged forest	*Acacia mangium*	*Gmelina arborea*	*Leucaena leucocephala*	Fallow forest
	(kg/ha)					
Litter	16.8	8.7	19.6	5.0	20.7	23.1
Undergrowth	18.1	21.6	68.8	63.6	175.0	18.7
Overstorey:						
Fruit & flowers	1.4	0.1	8.7	0.0	0.2	0.4
Foliage	87.7	73.3	67.4	33.7	6.7	58.6
Twigs ≤ 1 cm dob	105.3	54.9	21.6	20.0	5.9	14.1
Branches > 1 cm dob	191.9	51.6	50.3	71.5	6.1	46.0
Dead branches	7.4	3.3	11.5	6.7	1.1	12.4
Stems:						
Wood	518.9	311.5	128.4	192.6	4.2	174.5
Bark	137.5	114.8	77.6	69.6	4.8	68.8
Lianas:						
Stem	60.7	64.5	0.0	0.0	0.0	0.0
Foliage	1.8	18.7	0.0	0.0	0.0	0.0
Palms	13.9	0.0	0.0	0.0	0.0	7.0
Total Overstorey	1126.5	692.7	365.5	394.1	29.0	381.8
Total	1161.4	723.0	453.9	462.7	224.7	423.6

APPENDIX VIII D CALCIUM DISTRIBUTION IN ABOVEGROUND BIOMASS

Vegetation type	Primary forest	Logged forest	*Acacia mangium*	*Gmelina arborea*	*Leucaena leucocephala*	Fallow forest
			(kg/ha)			
Litter	35.7	48.4	53.8	57.0	30.0	77.2
Undergrowth	14.9	18.1	8.9	17.5	39.6	13.9
Overstorey:						
Fruit & flowers	0.2	< 0.1	1.6	0.0	0.1	0.1
Foliage	72.7	59.9	33.2	22.4	4.6	35.0
Twigs ≤ 1 cm dob	87.0	51.0	25.8	8.0	3.7	6.7
Branches > 1 cm dob	304.4	108.0	75.6	23.0	5.4	31.2
Dead branches	39.4	6.3	50.5	7.2	5.6	9.0
Stems:						
Wood	664.7	199.5	80.1	68.6	6.4	45.0
Bark	363.1	203.3	192.8	85.2	9.0	120.0
Lianas:						
Stem	39.2	41.6	0.0	0.0	0.0	0.0
Foliage	1.0	10.6	0.0	0.0	0.0	0.0
Palms	1.5	0.0	0.0	0.0	0.0	0.8
Total Overstorey	1573.2	680.2	459.6	214.4	34.8	247.8
Total	1623.8	746.7	522.3	288.9	104.4	338.9

APPENDIX VIII E MAGNESIUM DISTRIBUTION IN ABOVEGROUND BIOMASS

Vegetation type	Primary forest	Logged forest	*Acacia mangium*	*Gmelina arborea*	*Leucaena leucocephala*	Fallow forest
	(kg/ha)					
Litter	25.8	15.8	9.5	18.1	8.4	21.1
Undergrowth	7.4	6.4	5.8	8.7	18.4	3.4
Overstorey:						
Fruit & flowers	0.2	< 0.1	0.9	0.0	0.1	0.1
Foliage	31.7	18.5	8.0	12.7	2.0	13.0
Twigs ≤ 1 cm dob	34.0	17.4	2.9	3.4	0.9	2.3
Branches > 1 cm dob	49.3	23.1	7.7	8.3	1.1	14.1
Dead branches	6.1	1.9	5.0	1.9	0.8	3.9
Stems:						
Wood	146.0	92.8	11.0	17.7	1.6	62.1
Bark	91.4	50.4	5.6	25.5	1.1	28.8
Lianas:						
Stem	8.8	9.4	0.0	0.0	0.0	0.0
Foliage	0.3	3.4	0.0	0.0	0.0	0.0
Palms	1.1	0.0	0.0	0.0	0.0	0.6
Total Overstorey	368.9	216.9	41.1	69.5	7.6	124.9
Total	402.1	239.1	56.4	96.3	34.4	149.4

APPENDIX IX UNDERGROWTH SPECIES LIST

APPENDIX IX A SPECIES LIST OF NON-WOODY AND WOODY VEGETATION

Species	Plot*				
	UPF **	*Acacia*	*Gmelina*	*Leucaena*	Fallow
Grasses					
Carex breviscapa		b	b		
Centotheca lappacea		b	ab		
Centotheca sappaeca		a			
Centotheca latifolia				ab	b
Imperata cylindrica				ab	
Paspalum conjugatum				ab	b
Scleria purpurascens		ab	b	ab	
Ferns					
Blechnum orientale		ab		ab	
Lygodium cernuum		b	b		
Lygodium civicinnatum		b			
Lygodium scandens		b	b		
Nephrolepis falcata		a	a	ab	
Nephrolepis sp.		b			
Selaginella alopecinoides		a	a		
Selaginella lobbii		b	b		
Sphaenostephanos heterocarpus		b			
Non-woody Plants					
Alocasia sp.	a				
Amomum sp.	a				
Costus paradoxus		ab		b	a
Cyrtandra sp.		b			
Globba sp.	a				
Hallieracantha caudata	b				
Hedyotis sp.		b			
Hypestes sp.		a	b		a
Mikania sp.		b	b	ab	a
Musa paradoxica		b			
Neoclemensia sp.			a		
Scindapsus beccarii	a				
Zingiber sp.	a				
Climbers < 3 cm dob					
Agelaea sp.	a				
Bauhinia sp.	a				
Calamus sp.	a				
Daemonorops sp.		b	b		a
Embelia effusa		b	b		ab

APPENDIX IX A (*continued*)

Species	Plot				
	UPF	*Acacia*	*Gmelina*	*Leucaena*	Fallow
Freycinetia sp.	b				
Gnetum neglectum	a				
Gnetum sp.					b
Merremia peltata				a	
Passiflora foelida				b	
Pothos borneensis	a				
Rourea sp.	a				
Smilax sp.					b
Stenochlaena palustris				ab	
Tetracera scandens	b				
Uncaria sp.					b
Uvaria cauliflora	b				
Trees and shrubs < 3 cm dob***					
Adinandra sp.					a
Actinodaphne myriantha		b			
Alstonia angustifolia					a
Anisophyllea disticha					ab
Barringtonia sp.					b
Brownlowia grandistipulata		b	b		
Callicarpa involucrata					b
Combretum nigrescens		b			
Dillenia suffruticosa		b		b	b
Eugenia sp.					b
Ficus beccarii		b			
Ficus brunneo-aurata					b
Ficus fulna		b			
Ficus stolonifera					ab
Ficus sp.		ab			
Fordia filipes		ab	a	ab	b
Gironniera nervosa					a
Glochidion glomerulatum				a	
Glochidion lutescens		b			
Goniothalamus malayanus		b			
Ixora sp.					b
Leea aculeata		ab			a
Licuala bintulensis					a
Lithocarpus sp.					b
Litsea sp.		b	b		
Macaranga calcicola		b			
Macaranga costulata					b
Macaranga lowii			b		
Macaranga hosei		b		ab	
Macaranga sp.		a	a		
Melanochyla elmeri					a

APPENDIX IX A (*continued*)

Species	Plot				
	UPF	*Acacia*	*Gmelina*	*Leucaena*	Fallow
Melastoma malabathricum		b		a	
Nephelium lappaceum					b
Pentace curtisii					a
Pternandra multiflora		b			
Randia sp.		b			
Tarenna sp.		b			
Timonius sp.		b			
Urophyllum sp.		b			
Vitex pubescens				b	

* a - presence of species in plot a:
b - presence of species in plot b.

** UPF - Undisturbed Primary Forest.

*** UPF - species are listed separately in APPENDIX IX B; a species list for the Logged Over Forest plots was not recorded.

APPENDIX IX B TREE AND SHRUB SPECIES IN THE UPF UNDERGROWTH PLOTS

Acranthera sp.
Actinodaphne sp.
Aglaia brachybotrys
Aglaia havilandii
Aglaia shawiana
Aglaia sp.
Allantospermum borneense
Alphonsea kinabaluensis
Anacolosa frutescens
Anisophyllea disticha
Anisophyllea ferruginea
Anisophyllea sp.
Anisoptera sp.
Antidesma hosei
Antidesma leucopodum
Antidesma montanum
Antidesma neurocarpum
Antidesma tomentosum
Antidesma sp.
Aporusa frutescens
Aporusa grandistipula
Aporusa lucida
Aporusa lunata
Aporusa miqueliana
Artocarpus odoratissimus
Artocarpus sp.
Baccaurea angulata
Baccaurea bracteata
Baccaurea lanceolata
Baccaurea parviflora
Barringtonia pendula
Beilschmiedia sp.
Brownlowia glabrata
Calophyllum biflorum
Calophyllum gracilipes
Calophyllum pulcherrimum
Calophyllum sp.
Casearia grewiaefolia
Casearia sp.
Cephalomappa malloticarpa
Chionanthus palustris
Chisocheton ambilis
Cinnamomum iners
Cleistanthus sp.
Cleistanthus sumatranus
Dacryodes rugosa
Dacryodes sp.
Dehaasia sp.
Dimocarpus longan
Diospyros hermaphroditica
Diospyros jaheri
Diospyros laevigata
Diospyros mindanaensis
Diospyros pendula
Diospyros sumatrana
Diospyros toposioides
Diospyros sp.
Diplospora beccariana
Durio grandiflorus
Durio kutejensis
Durio oblongus
Elaeocarpus sp.
Endiandra clavigera
Endiandra sp.
Escallonia sp.
Eugenia capuli
Eugenia chrysantha
Eugenia corymbifera
Eugenia fastigiata
Eugenia palembanica
Ficus sp.
Fordia sp.
Friesodielsia glauca
Friesodielsia linderifolia
Friesodielsia sp.
Gaertnera vaginans
Garcinia benthamiana
Garcinia gaudichaudii
Garcinia maingayi
Garcinia trianii
Garcinia sp.
Gironniera subaequalis
Gluta rugulosa
Gomphandra cumingiana
Goniothalamus ridleyi
Goniothalamus tapis
Goniothalamus velutinus
Grewia elmeri
Grewia sp.
Guioa pubescens
Harpullia sp.
Hydnocarpus borneensis
Hydnocarpus sp.
Ixora sp.
Knema cinerea
Knema furfuracea
Knema tridactyla
Koompassia malaccensis

Lepisanthes fruticosa
Lepisanthes ramiflora
Lepisanthes sp.
Leuconotis anceps
Lijndenia sp.
Lindera subumbelliflora
Lindera sp.
Lithocarpus conocarpus
Lithocarpus elegans
Lithocarpus encleisacarpus
Lithocarpus sp.
Litsea caulocarpa
Litsea ferruginea
Litsea lanceolata
Litsea sp.
Lophopetalum glabrum
Melanorrhoea sp.
Meliosma sumatrana
Memecylon sp.
Mesua sp.
Mezzettia umbellata
Mitrephora rufescen
Myrioneuron cyaneum
Neckia serrata
Neoscortechinia kingii
Neoscortechinia sp.
Nephelium sp.
Ophiorrhiza sp.
Palaquium sericeum
Palaquium sp.
Parartocarpus forbesii
Parashorea parvifolia
Pavetta axillaris
Payena acuminata
Pleiocarpidia coffeides
Porterandia anisophylla
Polyalthia cauliflora
Polyalthia hookeriana
Polyalthia hypogaea
Polyalthia microtus
Polyalthia rumphii
Polyalthia sp.
Popowia sp.
Praravinia borneensis
Psychotria laxiflora
Pternandra azurea
Pternandra crassicalyx
Pternandra sp.
Rinorea bengalensis
Ryparosa sp.
Sandoricum sp.
Santiria sp.
Saprosma arborea
Shorea acuminatissima
Shorea beccariana
Shorea macrobalanos
Shorea parvifolia
Shorea parvistipulata
Sindora sp.
Sloanea javanica
Spatholobus sp.
Stephania reticulata
Sterculia bicolor
Sterculia coccinea
Strombosia rotundifolia
Symplocos rubiginosa
Talauma gracilior
Talauma sp.
Tarrena fragrans
Tetracera macrophylla
Urophyllum arboreum
Urophyllum congestiflorum
Urophyllum hirsutum
Urophyllum sp.
Vatica umbonata
Vitex pubescens
Xanthophyllum ceraceifolium
Xanthophyllum griffithii
Xanthophyllum havilandii
Xanthophyllum velutinum
Xanthophyllum sp.
Xylopia malayana
Xylopia sp.

APPENDIX X OVERSTOREY SPECIES LIST

	Plot*		
	UPF	LOF	Fallow
Trees > 3 cm dob			
Actinodaphne myriantha	bB		
Actinodaphne sp.	b		
Adenanthera pavonina		A	
Afzelia borneensis		B	
Aglaia cordata	b		
Aglaia cuspidella		b	
Aglaia denticulata		b	
Aglaia glabriflora		a	
Aglaia shawiana	a		
Alangium javanicum	B		
Allantospermum borneense	bB		
Alstonia angustifolia		A	ab
Alstonia angustiloba	b		
Anacolosa frutescens		a	
Anisophyllea beccariana		a	
Anisophyllea corneri	A		
Anthocephalus cadamba		a	
Antidesma leucopodum	a		
Aporusa elmeri		a	
Aporusa grandispula	b		
Aporusa granularis		b	
Aporusa miqueliana	a		
Aporusa nitida		a	
Ardisia beccariana	b		
Ardisia sp.			b
Artocarpus anisophyllus	B	aA	
Artocarpus dadah	B		
Artocarpus elasticus	B		
Artocarpus heterophyllus	b		
Artocarpus kemando		bA	
Artocarpus odoratissimus	aAB	bA	
Artocapus tamaran		A	
Atuna excelsa	A		
Baccaurea bracteata	b	a	
Baccaurea oxycarpa	a		
Baccaurea sp.	B		
Barringtonia lanceolata	a		
Barringtonia sarcostachys	bA	AB	
Barringtonia sp.	a		
Beilschmiedia gynotrochioides		B	
Beilschmiedia jacobsii	A	b	
Beilschmiedia palembanica	B		
Beilschmiedia pulverulenta		a	
Bhesa paniculata	AB	b	
Blumeodendron elateriospermum	B	A	

APPENDIX X (*continued*)

		Plot	
	UPF	LOF	Fallow
Blumeodendron kurzii		aAB	
Brownlowia sarawakensis		AB	
Calophyllum biflorum	AB		
Callicarpa involucrata			a
Canarium apertum		A	
Canarium caudatum	B		
Canarium denticulatum	b		
Canarium littorale	bB	aA	
Canthium didymum			ab
Cephalomappa beccariana		a	
Cephalomappa malloticarpa	A		
Chionanthus oliganthus		a	
Chisocheton beccarianus	b		
Chisocheton divergens		b	
Chisocheton macranthus		a	
Cinnamomum javanicum		b	
Croton argyratus		ab	
Cryptocarya crassinervia	b		
Cryptocarya rugulosa		B	
Cyathocalyx biovulatus	b		
Dacryodes crassipes	A	A	
Dacryodes incurvata		AB	
Dacryodes rostrata	ab	ab	
Dacryodes rugosa	a	bB	
Dehaasia brachybotrys		b	
Dehaasia elmeri		A	
Dehaasia firma		B	
Dialium kunstleri	a		
Dialium laurinum		A	
Dillenia excelsa	aB	AB	
Dillenia reticulata			ab
Dillenia sp.	b		
Dimocarpus longan		ab	
Diospyros borneensis	B		
Diospyros cauliflora	b		
Diospyros elliptifolia		ab	
Diospyros ferruginescens	b		
Diospyros frutescens		b	
Diospyros graciliflora	B		
Diospyros latisepala	a		
Diospyros mindanaensis	A	a	
Diospyros pendula		b	
Diospyros polyathioides	a		
Diospyros sarawakana		a	
Diospyros sp.			b
Diplospora beccariana	ab		

APPENDIX X (*continued*)

	Plot		
	UPF	LOF	Fallow
Drypetes caesia	B		
Drypetes crassipes	aA		
Drypetes longifolia		a	
Durio carinatus	B		
Dyera costulata		B	
Dysoxylem cauliflorum	b	a	
Dysoxylem grande		b	
Dysoxylem havilandii		bA	
Elaeocarpus clementis	a		
Elateriospermum tapos	B	bAB	
Endiandra clavigera	A		
Endiandra sp.	a		
Endospermum diadenum			b
Enicosanthum coriaceum	b		
Eugenia acuminatissima	a		
Eugenia anisosepala	a		
Eugenia brachyrrachis	a		
Eugenia chlorantha	A		
Eugenia christmannii		b	
Eugenia chrysantha	ab		
Eugenia corymbifera	A		
Eugenia curtisii	A		
Eugenia elliptilimba	A		
Eugenia griffithii		B	
Eugenia havilandii	B	AB	
Eugenia heteroclada	B	A	
Eugenia ochneocarpa	B	aA	
Eugenia palawanensis	A		
Eugenia palembanica	B	AB	
Eugenia sp.	a		
Ficus brunneo-aurata			ab
Ficus stolonifera		a	ab
Fordia filipes		ab	
Fordia gibbsiae		a	
Ganua becarii	A		
Ganua coriacea	A		
Ganua sp.	A		
Garcinia bancana	A		
Garcinia benthamiana	a		
Garcinia gaudichaudii		B	
Garcinia maingayi	AB	B	
Garcinia sp.	A		
Gironniera hirta	A		
Gironniera nervosa	a		b
Gomphandra minus	bB		
Gomphia serrata	A		

	Plot		
	UPF	LOF	Fallow
Gonystylus borneensis	a		
Gonystylus brunnescens		A	
Grewia fibrocarpa		ab	
Gymnacranthera forbesii		B	
Harpullia sp.	a		
Heritiera abiflora	B		
Heritiera simplicifolia	A		
Horsfieldia fragillima	A		
Horsfieldia punctatifolia		b	
Horsfieldia sp.	A		
Hydnocarpus anomala		A	
Hydnocarpus borneensis	ab	a	
Hydnocarpus calophylla	b	aAB	
Hydnocarpus pinguis	a		
Hydnocarpus polypetala		ab	
Hydnocarpus subfalcata		B	
Ilex cissoidea			b
Isonandra lanceolata		B	
Ixora sp.	b		
Kingstonia nervosa		B	
Knema cinerea	b		
Knema curtisii	b		
Knema elmeri		b	
Knema furfuracea	B		
Knema glauca	B		
Knema pallens		B	
Knema woodii		AB	
Koompassia excelsa	B		
Koompassia malaccensis	AB		
Koordersiodendron pinnatum		A	
Leea aculeata		a	
Lepisanthes fruticosa	a		
Lijndenia laurina	a		
Lithocarpus annamensis	a		
Lithocarpus conocarpus		aB	
Lithocarpus echinifer		A	
Lithocarpus elegans	B		
Lithocarpus encleisacarpus	A		
Lithocarpus meijeri		B	
Lithocarpus nieuwenhuisii	a		
Litsea caulocarpa	a	A	
Litsea crassifolia		A	
Litsea machilifolia	A		
Litsea sp.	b		b
Lophopetalum affine	B		
Macaranaga costulata			a

	Plot		
	UPF	LOF	Fallow
Macaranaga gigantea			ab
Macaranaga hosei		a	ab
Macaranaga hullettii			a
Macaranga hypoleuca		ab	
Madhuca sandakanensis	A		
Madhuca sp.		a	
Magnolia sp.	B		
Melanochyla elmeri			b
Melanorrhoea wallichii	B		
Meliosma sarawakensis	a		
Meliosma sumatrana		b	
Mesua borneensis	b		
Mesua connata	a		
Mezzettia leptopoda	A		
Microtropis bivalvis		b	
Mischocarpus pentapetalus	B		
Myristica iners	B		
Myristica villosa		aA	
Nauclea maingayi		B	
Neoscortechinia kingii	b	a	
Nephelium lappaceum		a	
Nephelium subferrugineum	a		
Ochanostachys amentacea	B	aA	
Palaquium decurrens	B		
Pandanus odoratissimus		b	
Parashorea macrophylla		B	
Parashorea parvifolia	b	B	
Parastemon spicatum	A		
Parastemon urophyllum	A		
Parkia spinosa	B		
Pentace corneri	A		
Pentace curtisii	B		a
Pentace laxiflora		A	
Phoebe macrophylla			ab
Phoebe sterculioides	a		
Pimelodendron griffithianum		b	
Pithecellobium jiringa	A		
Pleiocarpidia coffeoides	b		
Pleiocarpidia enneandra	b		a
Polyalthia cauliflora		ab	
Polyalthia flagellaris		b	
Polyalthia hypogaea	a		
Polyalthia hypoleuca	b	AB	
Polyalthia lateriflora		a	
Polyalthia microtus	a		
Polyalthia rumphii	a		

	Plot		
	UPF	LOF	Fallow
Polyalthia sp.		ab	
Pomentia pinnata		B	
Pouteria malaccensis		A	
Prunus arborea		a	
Pternandra azurea	b		
Ptychopyxis grandis	b	a	
Ptychopyxis kingii	A		
Ricinocarpodendron polystachyum	B	b	
Ryparosa glauca	b		
Ryparosa javanica			b
Santiria apiculata		B	
Santiria laevigata	A	ab	
Santiria megaphylla	A	B	
Saurauia glabra			ab
Scolopia spinosa	a		
Scordocarpus borneensis		A	
Shorea argentifolia		aB	
Shorea beccariana	B		
Shorea ferruginea	B		
Shorea glaucescens	B		
Shorea lamellata		a	
Shorea leprosula	b	bA	
Shorea leptoclados	bAB		
Shorea macrobalanos	bB		
Shorea mecistopteryx	abAB		
Shorea ochracea	A		
Shorea parvifolia	bA	bA	
Shorea pauciflora		A	b
Shorea quadrinervis	A		
Shorea rubra	bB		
Shorea sagittata	bAB		
Shorea scaberrima	B		
Shorea scabrida	B		
Shorea sp.			a
Sindora beccariana	a		
Sindora leiocarpa	B		
Spatholobus macropterus		a	
Spatholobus oblongifolius		a	
Spatholobus persicinus		a	
Sympetalandra borneensis		B	
Talauma gigantifolia			b
Talauma gitingensis	a		
Talauma sclerophylla	b		
Terminalia foetidissima		bA	
Terminalia subspathulata	B		
Tetramerista glabra	A		
Timonius esherianus			a

	Plot		
	UPF	LOF	Fallow
Uncaria cordata		a	
Uncaria glabrata		b	
Urophyllum arboreum	b		
Vatica acrocarpa		a	
Vatica oblongifolia	bB		
Vitex pubescens	B		
Vitex quinata	B		
Xanthophyllum affine		a	
Xanthophyllum amoenum	A		
Xanthophyllum beccarianum	b		
Xanthophyllum ceraceifolium	a		
Xanthophyllum ferrugineum	a		
Xanthophyllum pedicellatum	a		
Xanthophyllum purpureum		A	
Xanthophyllum rufum		B	
Xanthophyllum sp.			b
Xanthophyllum velutinum	a		
Xanthophyllum vitellinum		ab	
Xerospermum muricatum		b	
Xerospermum norohianum	B		
Xylopia ferruginea	A		
Xylopia fusca	aA		
Xylopia malayana	a		
Overstorey Lianas > 3 cm dob			
Rourea mimosoides	a		
Rourea minor	b		
Rourea ovale	a		

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* a - presence of species in 10 m x 20 m Plot a (trees ≥ 3 cm dbh);
b - presence of species in 10 m x 20 m Plot b (trees ≥ 3 cm dbh);
A - presence of species in 1 ha Extension Plot A (trees ≥ 30 cm dbh);
B - presence of species in 1 ha Extension Plot B (trees ≥ 30 cm dbh).