RESTORATION OF LAND PRODUCTIVITY AND ENVIRONMENT THROUGH REFORESTATION OF *IMPERATA CYLINDRICA* GRASSLANDS

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ABSTRACT

Plantation forestry on the widespread *Imperata cylindrica* (L.) Beauv. secondary grasslands in Indonesia is technically feasible and financially profitable, provided that fast early growth and high yield per hectare are achieved. Fast early growth and canopy closure ensure rapid suppression of the grass, thereby reducing competition and fire susceptibility. Considerable differences in growth between species and among provenances indicate the need for careful species and provenance selection and species/site matching. Production of high-quality seedlings is a prerequisite for survival over the critical early phase when competition by grass is fierce. Total cultivation is better than strip cultivation, and a stand density of at least 1100 seedlings/ha is required. Plantation establishment costs have an insignificant effect on the financial profitability of the scheme, but a high yield per hectare has a highly significant effect. Plantation establishment has considerable environmental effects which make it profitable from a wider economical perspective. These include sequestration of atmospheric carbon and maintenance of biological diversity.

Keywords: afforestation; bio diversity; carbon sequestration; dipterocarp forests; forest economics; natural regeneration; plantation forestry; restoration ecology; weed control; *Acacia mangium*.

INTRODUCTION

An impressive example of vegetation change in the humid tropics, where physical conditions would normally lead to the development of moist forest, is the replacement of this forest by *Imperata cylindrica*-dominated grasslands in South-east Asia. This fire-climax vegetation type currently covers c. 9 million ha of large contiguous former forest areas of 10 000 ha or more in Indonesia alone (Garrity *et al.* 1995). Estimates for the total area covered by *Imperata* grasslands in Indonesia vary between 16 and 64.5 million ha (Dove 1983) and in the whole of tropical Asia from c. 70 to more than 200 million ha (Skerman & Riveros 1990; Garrity *et al.* 1995). The grass invades deforested areas after repeated loggings and subsequent shifting cultivation or natural fires (Eussen & Wirjahardja 1983). *Imperata* grasslands are characterised by low biological diversity and total biomass for maintenance of soil fertility and carbon stock, and are used mainly for low-productive swidden agriculture (Dove 1983; Eussen & Wirjahardja 1983; Garrity *et al.* 1995).

Despite some positive aspects noted in the agricultural and anthropological literature (Dove 1983), *Imperata* grasslands are generally considered under-utilised, degraded, and, due to their combustibility, a major threat to the nearby forest areas (ITFAP 1990). Consequently, the authorities have, since the colonial times, made efforts to reclaim the grasslands for more productive use. Regreening and reforestation programmes have largely failed to reach their targets because of the physical difficulties in planting, grass competition, and fire susceptibility (Ohta 1990; Kuusipalo in press). The current interest throughout tropical Asia in plantations of industrial trees has resulted in more concerted large-scale attempts at grassland conversion, with serious research and development of methods for plantation establishment and maintenance.

Reforestation and Natural Forest Management Project ATA-267, which is a part of the Indonesia-Finland forestry programme, has been studying reclamation of *Imperata* grasslands in Indonesia since 1981. The original target was to facilitate industrial plantations by developing sound seedling production and plantation establishment techniques. The scope of the project was enlarged later to include other aspects of forest rehabilitation. As a conclusion of our studies, we hereby suggest an environmentally sound and technically feasible reforestation system to be used for restoration of land productivity and the forest environment.

METHODS AND MATERIALS

The data were collected mainly from the Riam Kiwa pilot plantation and trial area located in South Kalimantan, Indonesia—3°30'S; 115°E; 100–200 m a.s.l. Mean annual rainfall is 2128 mm with a pronounced dry season from May to October. The soil belongs to the red-yellow podsolic type with low pH values and nutrient levels; the soils are deeply weathered and suffer from various degrees of degradation. *Imperata* vegetation has dominated the originally forested landscape since the 1930s (Potter 1995). Additional test and reference areas include industrial plantations in East and West Kalimantan.

The procedure required for successful establishment of forest plantation on *Imperata* grassland was determined and each separate phase was assessed in a series of experiments carried out in the trial area and tested in the reference areas. More than a hundred tree species were screened in three separate species elimination trials. The most promising species were selected for further testing and provenance selection (Hadi *et al.* 1990; Otsamo 1994). At the same time, major achievements in the development of seedling production techniques led to the launching of the nationwide Central Nurseries Establishment Project (Ådjers & Srivastava 1993). Site preparation, spacing, and fertiliser trials were completed subsequently (Otsamo *et al.* 1995). Finally, an economic analysis was carried out in order to see the actual costs of successful reforestation and the financial feasibility of industrial tree plantations (Lattunen *et al.* 1995). Environmental consequences, i.e., effect of plantation establishment on biological diversity and carbon sequestration, have been taken into account in economical considerations. Avian and mammal diversities were studied by Sulthoni (1990) and natural vegetation by Kuusipalo *et al.* (1995). Biomass estimations have been carried out in the area and by using the available reference material (FAO 1993). Carbon sequestration was estimated from biomass values using available information on carbon cycling in forest ecosystems (Woodwell 1983).

RESULTS

Establishment Procedure

Successful plantation establishment on *Imperata* grassland requires an intensive operation for c. 2 years. The most essential thing is to achieve fast early growth and rapid canopy closure of the trees so that *Imperata* grass is suppressed to the extent that it is no longer able to out compete the emerging trees. The plantation thus becomes less susceptible to its major threat—fire. Elements of a successful reforestation system in *Imperata* areas are (i) species and provenance selection, (ii) production of viable seedlings, (iii) site preparation and amelioration, (iv) adequate spacing, (v) a proper layout and management plan for the plantation, and (vi) an effective fire prevention and fire-fighting system.

A total of 106 tree species were tested in Riam Kiwa. Exotic species are the most suitable for planting directly on *Imperata* areas, and are fast-growing enough to suppress the grass quickly. Indigenous species have either failed or been far too slow-growing to suppress the grass efficiently enough to reduce the fire risk and resist the competition. *Acacia* species, notably *A. mangium* Willd. and *A. crassicarpa*, have shown the best performance. Yields of 10–60 m^3/ha/year have been recorded in preliminary testing of different provenances of *A. mangium* (Fig. 1). In recent trials (Table 1) the best provenances from Papua New Guinea grew more than three times better than those of Subanjeriji and Sanga-sanga origins, landraces which are commonly used for reforestation in Indonesia (*see* Tuomela *et al.* in press). *Gmelina arborea* has also proved promising, especially in suppression of grass, and is an optimal species to be used in firebreaks. Eucalypts and pines have performed below expectations, as have even the fastest-growing local pioneer tree species (Otsamo 1994).

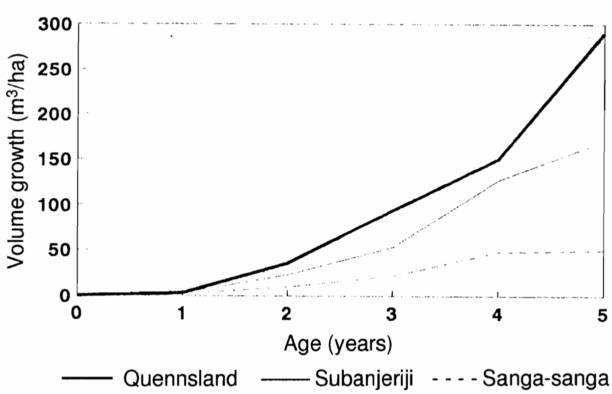

FIG. 1–Five-years' volume growth of three *Acacia mangium* provenances planted on *Imperata cylindrica* grasslands of Riam Kiwa, South Kalimantan, in 1986–91.

Intensive site preparation is essential for suppression of the grass until the trees are big enough to survive competition. Subsequently, carefully designed fertiliser treatment will enhance the growth and canopy closure of the young trees (Fig. 2). Fires will not harm the trees much if the understorey grass and shrub vegetation (e.g., *Eupatorium pallescens*)

TABLE 1–Mean annual increment (MAI) of 19 provenances of *Acacia mangium* 41 months after planting on *Imperata* grassland in Riam Kiwa, South Kalimantan, Indonesia. Standard error of the average MAI is given in parentheses.

Seedlot*	Seed collection site*			MAI m³/ha
CSIRO 17866	PNG	06°51'S	141°29'E	35.7 (3.8)
FF 1996	PNG	08°31'S	142°41'E	39.3 (1.3)
CSIRO 16971	PNG	08°47'S	142°52'E	34.7 (0.5)
CSIRO 17872	PNG	08°49'S	142°54'E	33.7 (1.6)
FF 2011	PNG	08°01'S	142°58'E	35.7 (3.5)
CSIRO 16938	PNG	08°05'S	142°58'E	37.8 (2.8)
FF 2013	PNG	08°19'S	143°02'E	35.8 (2.1)
CSIRO 16997	PNG	08°37'S	141°58'E	29.6 (2.3)
FF 1981	PNG	08°40'S	142°00'E	33.5 (3.8)
CSIRO 16990	PNG	08°42'S	141°52'E	28.8 (1.4)
FF 1998	PNG	08°31'S	141°13'E	27.3 (2.7)
CSIRO 17701	QLD	12°45'S	143°17'E	28.2 (1.6)
CSIRO 17946	QLD	12°48'S	143°18'E	26.8 (2.8)
CSIRO a538	QLD	15°53'S	145°20'E	14.3 (2.2)
CSIRO d590	QLD	16°16'S	145°21'E	20.5 (0.6)
CSIRO 15367	QLD	16°31'S	145°24'E	16.6 (1.9)
CSIRO 15238	QLD	18°00'S	145°50'E	25.5 (2.6)
Own collection	IRIAN	00°46'S	133°34'E	35.3 (1.9)
INHUTANI II	SUB	03°45'S	103°55'E	12.9 (1.0)
Own collection	SAN	00°55'S	117°18'E	11.1 (1.0)

* Seedlots and seed collection sites:
- CSIRO = Commonwealth Scientific International Research Organisation, Australia
- FF = Future Forests, Seed Supplier, Australia
- INHUTANI II = A parastatal forestry company in Indonesia
- PNG = Papua New Guinea
- QLD = Queensland, Australia
- IRIAN = Irian Jaya, Indonesia
- SUB = Subanjeriji, South Sumatra, Indonesia
- SAN = Sanga-sanga, South Kalimantan, Indonesia

remains low. Total cultivation, i.e., mechanical ploughing and harrowing during the dry season before planting, proved to be the most effective method (Fig. 3). Combined with initial fertiliser application of 60 g NPK/seedling, intensive cultivation will ensure fast early growth and canopy closure of the trees. Adequate stocking is 1100 seedlings/ha at minimum. A good account of the production of viable seedlings has been presented by Ådjers & Srivastava (1993).

Sound planning and management of reforestation schemes are essential for the success of established plantations. Preventive measures against fire include the establishment of firebreaks (e.g., planted and especially carefully maintained lines of *G. arborea*) around and between the plantation blocks, sufficient weeding during the establishment phase of the plantations, and sound layout of plantation blocks so that there will be no gateways of grass or bushy thickets to allow access for fire inside the plantation area. Risk of fire has to be taken into account in planning of the regeneration cuttings and any other operations within the reforestation scheme. Finally, early detection of fires and quick mobilisation of fire-fighting units have to be ensured.

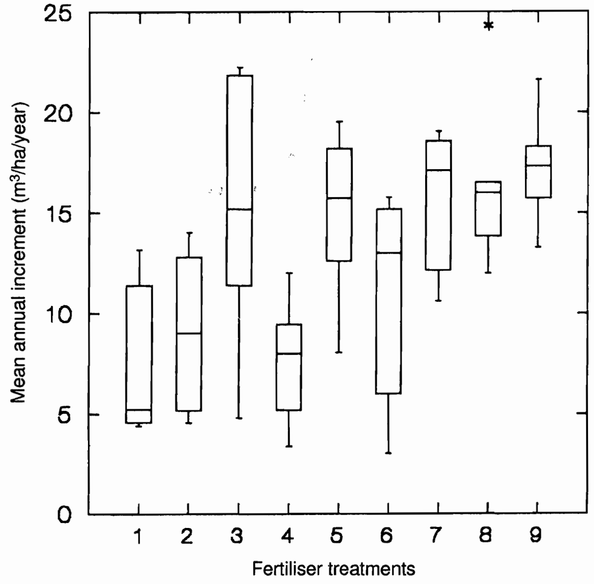

FIG. 2–Response in volume growth of *Acacia mangium* to different fertiliser treatments 2 years after planting on three different *Imperata* grassland sites in Riam Kiwa. Vertical bars divided in two by a horizontal line depict the pooled median and upper and lower quartiles of the volume growth in each treatment. Minimum and maximum values are marked by vertical lines. Treatments include the following nutrients (kg/ha):

1 = 0 *2* = 50 N *3* = 50 P *4* = 50 K
5 = 50 N + 50 P *6* = 50 N + 50 K *7* = 50 P + 50 K
8 = 50 N + 50 P + 50 K *9* = 50 N + 50 P + 50 K + 107 Ca + 74 Mg + 5 Cu + 5 Zn + 5 B

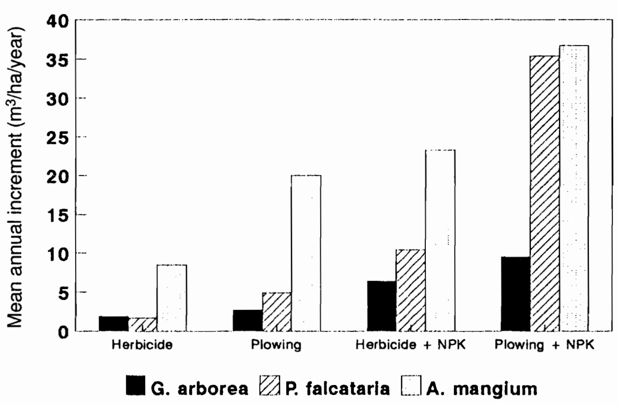

FIG. 3–Effect of different land-preparation methods and initial fertiliser treatment (60 g NPK/ seedling) on the mean annual increment of three exotic plantation tree species at the age of 3 years in the *Imperata* grasslands of Riam Kiwa.

Financial Setting

A forest plantation, either industrial or a small-holder-based system, is a financial undertaking which is expected to yield a profit. The single most-important factor affecting the financial return is the existence and adequacy of market price for the product, i.e., timber. In Indonesia, plantation-grown wood is presently used mainly for pulp and paper production. We estimated a reasonable stumpage price of US$20/m^3 for the financial analysis. The costs of silvicultural operations may vary somewhat but figures presented here (Table 2) are considered typical for an industrial tree plantation on grassland (Lattunen *et al.* 1995).

TABLE 2–Assumptions for financial analysis (*see also* Lattunen *et al.* 1995).

General assumptions

- Private or parastatal commercial forest plantation established on *Imperata* grassland in South Kalimantan
- *Acacia mangium*, pulp wood, stumpage price US$20/m^3
- Total net area 100 000 ha
- Inflation: costs & revenue 8%
- Salvage value 50%

Specific assumptions

- Rotation 8 years
- Yield (utilisable wood) 25 m^3/ha
- Annual planting and harvesting 12 500 ha
- Plantation road construction:
  - access road US$10,500/km; 50 km
  - main road US$7,500/km; 10 m/ha
  - secondary road US$5,000/km; 20 m/ha
- Production, transport, and planting of seedlings US$140/ha
- Soil preparation US$213/ha
- Weeding US$105/ha
- Fertiliser US$100/ha
- Harvesting and extraction US$10/m^3
- Taxes and royalties US$1.5/m^3

Apart from the market price of the wood, the factor which affects the financial result most directly is the yield per hectare. The Internal Rate of Return (IRR) rises rapidly with the yield level (Fig. 4): at a mean annual increment of 10 m^3/ha the IRR equals zero, while at 25 m^3/ha it is c.17%, which is close to the bank lending rate in Indonesia. The implication is that if a reforestation scheme is to be implemented completely with commercial financing, the mean annual increment must equal or exceed 25 m^3/ha. As discussed above, yield levels exceeding this critical level can be achieved provided that all phases of the reforestation process are completed in a professional manner.

Results of further sensitivity analyses of the effects of different cost items on the financial output of the plantation scheme are summarised in Table 3. The analyses revealed that an increase of 20% in the total investment costs caused c.1% decrease in the IRR. Thus, it is profitable to increase the investment costs by 20% if the subsequent yield increase exceeds 2.5 m^3/ha/year. The IRR appeared to be only weakly sensitive to any single item included

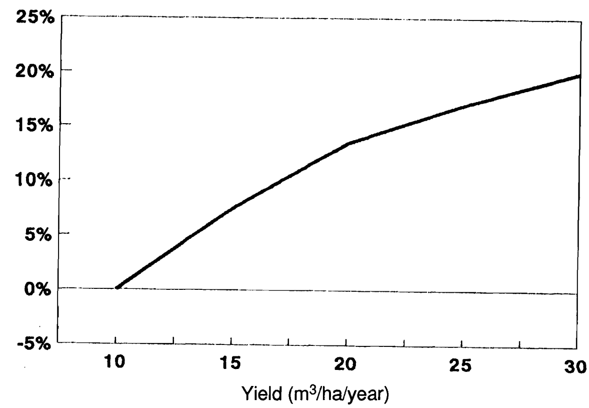

FIG. 4—Internal rate of return at different yield levels in a forest plantation on *Imperata* grassland. *See also* Tables 2 and 3.

TABLE 3—Summary of the analyses carried out on the sensitivity of the Internal Rate of Return of a grassland reforestation scheme to changes in various cost parameters.

Cost item	Sensitivity
Investments	Weak
Fixed costs	Weak
Seedling price	Weak
Land preparation cost	Moderate
Rotation period (6–12 years)	Moderate
Harvesting cost	Strong
Transport cost	Strong
Mean annual increment (m^3/ha)	Very strong
Roundwood price	Very strong

in the establishment costs of the plantation. For example, free seedlings (zero price) would raise the IRR less than 1% from the assumed price. If viable seedlings of good provenance raise the yield by only 1 m^3/ha, we can well afford to pay double the price for them. Similarly, a saving of 20% in land preparation and fertiliser costs would increase the IRR less than 1%. On the other hand, IRR is extremely sensitive to harvesting and transport costs, particularly those of long-distance transport, which alone can take more than one-third of revenue, if the mill-gate price instead of stumpage price is used.

Environmental Repercussions

From the national and global point of view, reforestation serves multiple purposes, including environmental and social ones. Our inventories show that plantation establishment creates an environment which facilitates spontaneous increase in biological diversity. In 5 years the number of naturally regenerating indigenous tree species increased by more than 100%, depending on the plantation species combination used (Fig. 5). Grass and herb vegetation suffers from severe shading beneath the canopy of *A. mangium* or *G. arborea* plantations, leaving more space for shade-tolerant perennial woody plants. Within a well-lit

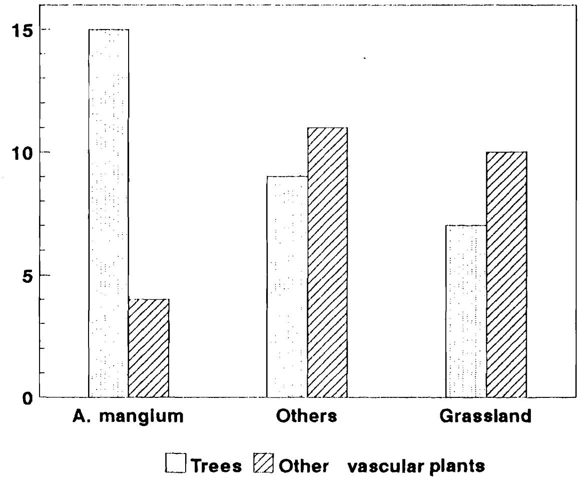

FIG. 5—Number of naturally regenerated species of trees and other vascular plants (vertical axis) in 5-year-old *Acacia mangium* and other exotic tree plantations and on unplanted *Imperata* area in the grasslands of Riam Kiwa, South Kalimantan. *See also* Kuusipalo *et al.* (1995).

understorey of other common plantation trees such as *Paraserianthes falcataria* herbs and grasses tend to prevail, thereby increasing the combustible fuel load on the ground. *Imperata* grassland is an extremely species-poor environment. Another inventory showed that after 4 years the number of bird species grew by c.60%, and mammalian wildlife increased both in the number of species and the abundance of individuals (Sulthoni 1990).

Land-use pattern affects the global climate change through its effects on atmospheric carbon balance. In a typical virgin dipterocarp forest, the organic carbon stock is estimated at 400 tons carbon/ha (Fig. 6). Degradation of the virgin dipterocarp forest into *Imperata* grassland diminishes the carbon stock drastically: *Imperata* grasslands typically have above-ground organic carbon stock of c.5–15 tons/ha and in the rhizosphere about a half of that (Soerjani 1970). Due to annual fires typical of *Imperata* grasslands, the amount of carbon stored in soil humus also decreases depending on the age of the grassland and frequency of fires (Fig. 6).

Reclamation of *Imperata* grasslands for other uses increases the organic carbon stock at various levels. Establishment of a plantation of, for example, *A. mangium* will raise the organic carbon stock to c.200 tons C/ha (Fig. 6). Full restocking with dipterocarps by assisted natural regeneration would finally bring the level up to the original 400 tons C/ha. Elimination of annual fires would be another advantage.

DISCUSSION

To establish a plantation of fast-growing exotic tree species, e.g., *A. mangium*, for wood production and the suppression of the combustible grass, the average cost is US$600–1000/ha.The establishment method includes careful site assessment and subsequent species and provenance selection, mechanical soil cultivation and amelioration, production of high-quality seedlings, adequate spacing and professional stand management, and the establishment

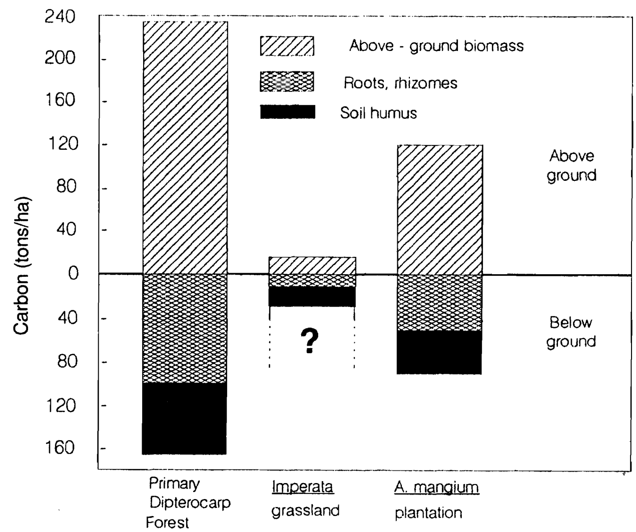

FIG. 6–Estimated carbon stock and its spectrum (tons of carbon per hectare) in a primary dipterocarp forest, an average *Imperata* grassland, and an *Acacia mangium* plantation in Riam Kiwa, South Kalimantan.

of an efficient fire protection system. Our reforestation process ensures fast early growth of the tree stand, total suppression of grass, and subsequent decrease in the risk of fire within 1–2 years after plantation establishment. In Indonesia, reforestation schemes usually show survival rates as low as 50% and growth rates c.15 m^3/ha/year (Kuusipalo in press). The survival rate in our plantations exceeds 90% and yields higher than 40 m^3/ha/year can be achieved.

Only a relatively small number of tree species, mostly exotics, performed well in *Imperata* grasslands. An important factor affecting performance might be the mycorrhizal associations required by different tree species. *Imperata cylindrica* grass forms endomycorrhizas with a number of opportunistic VAM fungi which are also capable of infecting roots of *Acacia* spp. and several other broadleaved tree species. Pines and eucalypts, as well as indigenous dipterocarp species tested in our species trials, depend on ectomycorrhizal associations which might not be readily available in the conditions typical of degraded and seasonally dry *Imperata* grasslands (Bowen 1980; Smiths 1983). However, the specific mycorrhizal requirements of dipterocarps still require further testing.

Total cultivation proved to be the most successful plantation establishment technique in *Imperata* grasslands. Strip cultivation, which still is in wide use in reforestation schemes in Indonesia and elsewhere, is cheaper but fails to guarantee the suppression of the grass (Otsamo *et al.* 1995). Total cultivation improves texture of the often compacted soil and destroys the shoots and most rhizomes of *Imperata cylindrica* for a period sufficiently long for the trees to achieve closed canopy and root systems. Ideally, it should be necessary to use herbicides only on steep slopes where mechanical cultivation is impossible (Otsamo *et al.* 1995). Initial application of NPK fertiliser considerably encourages the early growth of the seedlings. The most important nutrient deficiency in *Imperata* areas is the general shortage of phosphorus (Ohta 1990). In some locations there are indications of other nutrient and trace element deficiencies and imbalances which might require a long-term amelioration of the soil with slowly soluble fertilisers such as rock apatite and biotite.

The financial situation of reforestation schemes is determined by their profitability against that of alternative land-uses such as rubber tree and oil palm cultivation. Establishment costs of agricultural cash crops are, however, much higher. Plantation trees can be harvested at the age of 6–15 years. With a stumpage price of US\$20/m^3, a mean annual increment of 25 m^3/ha is sufficient incentive for the entrepreneur. Investment in proper plantation establishment yields a good profit through increase in the yield level. Harvesting and transport costs affect the profitability considerably but, if the plantation is an integral part of a pulp mill project, even these costs are negligible because it is the price of the end product, pulp, which determines the financial profitability.

Apart from saleable commodities, reforestation brings other assets and effects such as carbon sequestration, biodiversity conservation, and social benefits (e.g., employment). Environmental cost or benefit of carbon is estimated at US\$10–30/ton of emitted or sequestered carbon (Pohjonen 1992). Using the low value of US\$10/ton, reclamation of *Imperata* grassland to timber plantation of, e.g., *A. mangium* would yield an environmental benefit of c.US\$1500/ha over a period of 7 to 10 years. Further reclamation of tree plantation into a fully stocked dipterocarp forest would sequester atmospheric carbon worth approx. US\$3500/ha, though this would take c.50 years.

Direct planting of local rainforest trees on the grass has proved impractical (e.g., Otsamo 1994). Instead, successful environmental restoration can be carried out by using fast-growing plantation tree species as a sacrificial fallow crop to suppress the grass and minimise the fire risk. The naturally emergent stand of indigenous trees can be left to recover the original species richness (Kuusipalo *et al.* 1995). It is also possible to plant dipterocarps and other indigenous trees within the shelter of the exotic trees (Otsamo 1994). Forests adjacent to cleared areas such as *Imperata* grasslands experience edge effects which are detrimental to original biodiversity. Forest fragmentation through the spreading of secondary grasslands and bushlands increases the edge effect and thus also the area of ecologically degraded land (FAO 1993). Forest fragmentation isolates species populations from each other and in the consequent absence of gene flow, many local populations may become extinct (Lugo 1988). Plantations create more suitable environments for forest species to maintain their populations and, consequently, the biological diversity of the whole area. Plantations may also be used as foster ecosystems to gradually restore the original forest vegetation (Parrotta 1993).

Brown & Lugo (1994) listed four benefits of forest rehabilitation: (i) conversion of unproductive lands to self-perpetuating ecosystems, (ii) prevention of further damage to downstream ecosystems, (iii) reversion of the worldwide negative trend to land degradation, and (iv) relief of the pressure on undisturbed lands and thereby reduction in further deforestation. They considered rehabilitation a last-ditch effort to reverse a negative situation caused by poor management of natural resources, and listed drawbacks such as high cost of rehabilitation and unpredictability of the results due to an apparent lack of ways and means to direct the rehabilitation process to a specific final state.

Forest degradation can be seen as a continuum from disturbance which creates so little damage to the forest ecosystem that the forest regenerates naturally without human intervention, through various levels of damage, to a point of irreversibility beyond which regeneration of the original ecosystem is no longer possible without human intervention (Fig. 7). Reversibility of tropical moist forests decreases along with the degree of degradation, with a steeper decline at the point where changed fuel loads and soil moisture regimes, together with shifting cultivation, induce fires which degrade the forest beyond the possibility of natural recovery. At the same time, the cost of forest rehabilitation increases, reaching its highest level at the point at which fire-climax secondary vegetation such as *Imperata* grassland takes over.

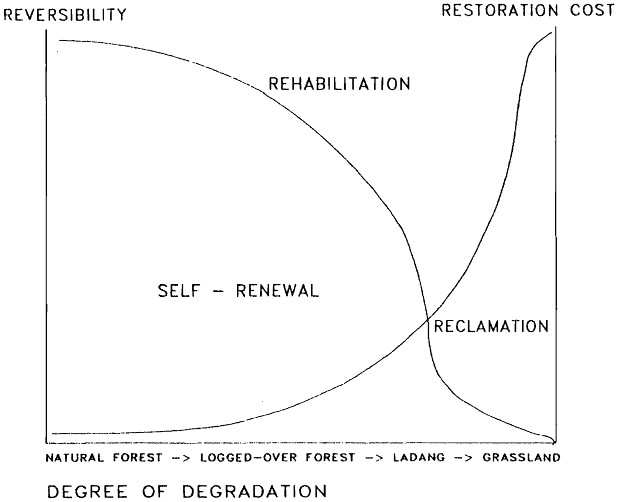

FIG. 7–Schematic presentation of the ecological reversibility and associated restoration cost in various degrees of forest degradation. "Ladang" is an Indonesian term refering to a forest area subjected to shifting cultivation.

The most economical way of natural forest management is apparently to do as little damage as possible and to rehabilitate the forest immediately after the first harvest. Rehabilitation of millions of hectares of *Imperata* grasslands back to natural forest might appear too expensive to be done on solely environmental grounds. It would be more realistic to use grassland and bushland for industrial wood production, not only that of the exotics for pulp mills but also dipterocarps and other valuable timber trees in shorter rotations for the timber and plywood industry. Furthermore, plantations can be used as a sacrificial fallow crop to create new agricultural land on grasslands rather than to clear forest for farm crops. These kinds of more intensive uses of grasslands would remove the pressure from undisturbed forests.

The prevailing practice of destroying undisturbed natural forest by heavy logging and conversion to agricultural land, while at the same time neglecting rehabilitation of degraded areas such as *Imperata* grasslands, is, in the long run, detrimental to the existing forest resources. The current trend to introduce a multi-purpose approach into natural forest management, i.e., "eco-forestry", is justified but requires deep changes in forest and land-use policy, as well as in public awareness and rural development. Moreover, such multi-purpose forestry needs to become fully adopted within a relatively short time before irreversible fragmentation and consequent ecological degradation occurs over large areas of the remaining South-east Asian undisturbed forests. A strictly separated use of land resources would provide an alternative. A proportion of remaining natural forests could be set aside for conservation and protection provided that other areas were used more intensively for industrial wood production. This would require the development of sound plantation techniques with reasonably short rotations, not only for exotic trees but also for the more valuable indigenous timber species such as dipterocarps.

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