Agroforestry Approaches or Rehabilitating Degraded Lands after Tropical Deforestation

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Abstract

There are three main types of degraded lands that result from slash and burn agriculture: degraded fallows, degraded pastures and *Imperata cylindrica* grasslands. Together they may cover as much as 250 million hectares, and have the advantage for recuperation of being close to road, market and urban infrastructure. Land degradation can be due to one or more causes: physical (e.g. soil compaction, erosion), chemical (e.g. increases in soil acidity, decline in available nutrients) and biological degradation (e.g. loss of microsymbionts, weed encroachment). The use of bulldozers to clear land accelerates degradation and generally requires more labour, energy and/or purchased inputs for reclamation. The current research knowledge base has focused upon alternatives to slash and burn that start with fertile, cleared forests rather than degraded systems. In the past, agroforestry approaches for reclaimimg the three types of degraded lands were employed but most of the experiences are not based on sound research. The establishment of *Acacia mangium* on *Imperata* grasslands is one success story.. In the case of degraded fallows and pastures, land regeneration strategies have been identified (e.g. economically and biologically improved fallows; silvopastoral systems) but the essential research is still to be done. Fundamental concepts of restoration ecology with emphasis on nutrient cycling, plant succession and weed dynamics should set the stage for understanding how to turn degraded areas into productive lands. Coupled with appropriate policies and other socio-economic considerations, such work will provide viable alternatives to land abandonment after tropical deforestation.

Introduction

Conversion of tropical rainforests is one of the world's major environmental concerns because of its negative effects on plant and animal bio-diversity, greenhouse gas emissions and on watershed stability. Deforestation rates in the humid tropics have increased from 7 to 16 million hectares per year during the decade of the 1980s and are expected to increase even more during the 1990s (Houghton, 1990; Dale *et al*., 1993). Slash and burn agriculture, often preceded by logging, is the principal cause of deforestation. However, policies to mitigate deforestation seldom consider the needs of farmers and migrants who are placing land use pressures upon these forest margins.

Alternatives to slash and burn agriculture that include appropriate technological and policy components are urgently needed (Sanchez, 1991). There are two main components of such a strategy: 1) sustaining the productivity of the land being cleared and 2) reclaiming degraded and abandoned lands that follow slash and burn agriculture. This paper focuses on the second strategic dimension. Research on alternatives to slash and burn has provided a series of options that can sustain the productivity of recently cleared land at 5 to 10 times the original levels (Sanchez *et al*., 1990; National Research Council, 1993).

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Very little detailed research has addressed land reclamation technologies. As a result of this paucity of information, this paper summarizes what is known and suggests research approaches rather than offers a concrete strategy for the regeneration of degraded and abandoned lands.

Degradation in this context is defined by Grainger (1990) as follows: "Tropical lands are regarded as degraded when modification or substantial removal of the composition or structure of their vegetative cover and/or consequent depletion of soil fertility by farming has prejudiced the stability of local and/or regional ecologies and economies".

Degradation can be physical, chemical or biological. Physical degradation involves soil compaction, sheet and gully erosion. Chemical degradation involves significant increases in soil acidity and decreases in available nutrients. Biological degradation involves weed encroachment, declining soil organic matter and losses of beneficial soil microorganisms and fauna. The loss of bio-diversity as a result of clearing of primary forest is a near universal and parallel form of ecosystem decline accompanying land degradation.

Extent of degraded lands

Of the original estimate of 1500 million hectares of humid tropical forests, about 600 million hectares are now deforested (FAO, 1990; Grainger, 1990, Oldeman *et al*., 1990). An approximation of the land use systems within these 600 million hectares of deforested lands is presented in Table 1. Degraded lands cover as much as 250 million hectares or 40% of the total. The principal types of degraded or abandoned lands are degraded forest fallows, *Imperata cylindrica* grasslands and degraded pastures. Not all degraded lands are totally abandoned as use is made for fruit gathering or light grazing. Three other major land use systems can be considered to be in the pre-degradation stage: previously logged forests, actively logged forests and active shifting cultivation. These three uses together amount to 260 million hectares. The remaining area includes more sustainable land uses (e.g. paddy rice, permanent cropping systems, improved pastures, agroforestry, perennial crops, plantation forestry), urban areas, and lands at marginal stages of degradation not included in the above categories.

Table 1 Preliminary estimates of the status of deforested lands which were originally tropical rain forests

Land type	Million hectares	%	Source*
Secondary forest fallows	203	32	1
Logged forests	136	22	1
Active shifting cultivation	120	19	2
Imperata grasslands (S.E. Asia)	40	8	3
Degraded pastures (Amazon)	10	2	4
Active pastures (Amazon)	10	2	4
Active logging	4	1	1
Others	104	17	5
Total deforested area	627	100	6

* 1. Grainger, 1990; 2. Calculation based on a population of 300 million shifting cultivators (Denevan, 1980) with 5 people per family, each cultivating 2 hectares; 3. Myers, 1989; Grainger, 1990; 4. Serrao and Toledo, 1990; Serrao and Homma, 1993; 5. Calculated by difference between total deforested area and other uses in the table. This includes permanent crop agriculture, other pasture areas, agroforestry, perennial crops, plantation forests and other land uses not specified above. 6. Mean estmate; values range from 579 to 675 million hectares. (FAO, 1990; Grainger 1990; Oldeman *et al*., 1990).

Main types of degraded lands

1 Degraded forest fallows

An estimated 203 million hectares of secondary forest fallows occur due to shifting cultivation (Table 1). This area consists of fallows of all ages, including some approaching the biomass and structure of primary forests. Older secondary forest fallows show few signs of physical, chemical or biological degradation as soil properties are improved during extended fallows (Andreisse, 1989; Fehlberg, 1989).

Shifting cultivation does not in itself lead to land degradation, rather it is the extension of cropping and shortening of fallow phases that impede the recovery of the soil as a resource base (Fehlberg, 1989). Andreisse (1989) identified the two important climatically regulated mitigators of soil degradation following shifting agriculture as the rates of biomass recovery and the leaching of plant nutrients. In this way, extended cropping leads to excessive loss of plant nutrients due to harvest removal and leaching, which in turn reduces the recovery rate of the shallow-rooted succeeding vegetation. Regeneration of forest fallows after abandonment also depends on factors such as frequency of burning, intensity of cultivation, weeding, size of clearing and availability of seed dispersing agents (Uhl and Clark, 1983; Szott and Palm, 1986).

Examples of degraded fallows as a result of intensified cropping are illustrated in the wetter miombo woodlands of Southern Africa where *Chitemene*, a form of slash and burn agriculture is practiced on highly weathered Ultisols of low inherent fertility (Chidumayo, 1987; Edje *et al*., 1988; Araki, 1993). The reduction of fallow periods from 50 to 10 years has resulted in a decline in ash production from 3.13 to 1.15 t/ha (Araki, 1993). This has led to a 40% reduction in yields of finger millet (*Eleusine coracana*). Reduced vigor of the recovering miombo has resulted in the incursion of derived grasslands dominated by *Hyparrhenia rufa*. Farmers without access to well-established miombo fallow have resorted to an alternative land use strategy, Fundakila (Edje et al., 1988) Under *Fundakila*, the grasses are cut at the soil surface, piled and buried under mounds of soil. The composted grasses provide sufficient plant nutrients to support healthy crop growth, but crop densities and per area yields are extremely low. *Fundakila* may be viewed as an indigenously developed land use technology of the last resort because degraded lands must be further degraded to enable humans to survive.

In many areas of the humid tropical Asia and Latin America where population pressures are high, fallow periods have been reduced from 25 to less than 10 years resulting in large areas of land in the process of degradation (Sanchez, 1991). Similar trends were reported by Mishra and Ramakrishnan (1984) as fallow intervals in N.E. India declined from 15 to 5 years. While it is not possible to assign a specific fallow interval that does not lead to land degradation, the overall pattern is clear, fallow periods must be maintained beyond some critical interval to enable sufficient land regeneration to occur.

2 Degraded pastures

Large-scale cattle ranching has resulted in the clearance of about 20 million hectares of Amazon rainforest during the 1980s, primarily in Brazil and Colombia. Cattle raising is also the main cause of rainforest conversion in Mexico and Central America. Stimulated by government incentives, most of the clearings are very large and poorly managed (Hecht and Cockburn, 1989). The degradation process is attributed to the introduction of grass species, such as *Panicum maximum* and *Hyparrhenia rufa*, not adapted to high soil acidity, low fertility, poor grazing management, and invasion of better adapted weedy species. Phosphorus deficiency is a principal cause of low soil fertility leading to land degradation in pastures and weed encroachment is an immediate consequence (Serrao *et al*., 1979). The end result of pasture degradation varies from pure weeds to almost bare land (Serrao and Homma, 1993; Uhl *et al*., 1990). Serrao and Toledo (1990) consider that a pasture is degraded when weeds comprise more than 80% of the pasture biomass and the potential carrying capacity has decreased from 1 to less than 0.3 animal units per hectare. The time required to achieve this stage of pasture decline varies between 7 and 15 years.

3 *Imperata* grasslands

In Southeast Asia many of the abandoned shifting cultivation fields are rapidly colonized by *Imperata cylindrica*, a coarse rhizomatous grass also known as alang-alang in Indonesia, lalang in Malaysia and cogon in the Philippines. About 40 million hectares of *Imperata* grassland are present in Southeast Asia as a result of shifting cultivation (Sukmana, 1986 ; Myers, 1989 ; Grainger, 1990). *Imperata* grasslands also occur in large areas of eastern Madagascar due to incursion following shifting cultivation. These grasslands occur to a limited, non-dominant extent in West Africa and Australia but are conspicuously absent in Latin America. The grass thrives on acid soils low in nutrients, reproduces by seeds and rhizomes, responds vigorously to burning and competes aggressively with other invaders. Except for young growth shortly after a burning, *Imperata* has very low palatability to cattle. On the other hand, *Imperata* provides sufficient ground cover to prevent soil erosion.

4 Lands in the process of degradation

Approximately 41% of the area deforested by previously logged forests, active shifting cultivation and active logging will also become degraded unless corrective measures are taken (Table 1). Logging usually involves the harvest of a few marketable, high-value timber trees per hectare, but results in about a third of the hectare being severely disturbed. At present, approximately 2 million hectares of logged forests are under adequate forest management (Poore *et al*., 1990). Much of the rest is used by shifting cultivators, who frequently utilize forest margins along recently established logging access roads.

Land area in the cultivation phase of shifting cultivation is estimated to amount to 120 million hectares (Table 1). As a traditional practice under low population pressure, shifting cultivation is a sustainable, low-yielding cropping system that is not degrading. But at present most of the shifting cultivation is practiced under great population demands by migrants unfamiliar with the locally-developed indigenous knowledge (Warner, 1991). These farmers seldom maintain secondary forest fallows of sufficient duration to accumulate nutrients and suppress weeds. Many of the lands cleared for shifting cultivation by migrants will result in abandoned forest fallows or *Imperata* grasslands.

Not included in Table 1 are steep, deforested hillsides. These constitute an important extreme because of their susceptibility to severe soil erosion. There are other, less extensive forms of land degradation caused by urban development, reservoir construction, industry and mining (Hecht and Cockburn, 1989) that are not discussed within this paper.

Constraints on the reclamation of degraded lands

Degraded lands in the humid tropics are highly visible because many are located within areas with improved infrastructure (e.g. along roads, near towns or cities) because they were among the first lands to be cleared. Degraded pastures and degraded fallows border hundreds of kilometres around the two main penetration roads of the Brazilian Amazon, the Bēlem-Brasilia, and BR364 in the State of Rondonia. *Imperata* grasslands dominate many of the hilly areas of the Philippines and mainland Southeast Asia, near settlements in the Outer Islands of Indonesia and parts of the eastern coast of Madagascar.

Proximity to infrastructure is a significant asset to land reclamation potential. In many cases secure land tenure exists with fencing and clear delimitations of land boundaries. Urban facilities such as schools, electricity and telephone systems are more available than in remote forest margins. The positive infrastructural aspects are countered by the fundamental constrains (e.g. physical, chemical and biological) on the regeneration of degraded lands (Table 2). These constraints are compounded by socio-economic considerations such as inadequate tenure, credit, markets, prices and government policies. The importance of socio-economic conditions is discussed in other publications (Anderson 1990 ; Sanchez 1991 ; National Research Council, 1993) and is not covered in this paper due to the technological nature of this symposium. Nevertheless, the reader should be aware that the technical approaches offer only part of the solution and will have limited impact unless they are implemented within an appropriate socio-economic framework.

Table 2 Constraints and costs of reclamation of degraded lands based on methods of land clearing

Type	Type of clearing	Severity of constraints forreclamation				Level of investment		
		Gully erosion	Soil compaction, sheet erosion	Fertility depletion	Weed encroachment	Labour	Tillage energy	Cash inputs
Degraded forest fallow	Slash and burn	None	Slight	SEvere	Severe	High	Moderate	Moderate
	Bulldozer	Possible	Severe	Severe	Moderate	Moderate	High	High
Degraded pasture	Slash and burn	Slight	Moderate	Moderate	Severe	Moderate	Moderate	Moderate
	Bulldozer	Possible	Severe	Severe	Moderate	Low	High	High
Imperata grassland	Slash and burn	None	Slight	Severe	Severe	Moderate	Moderate	Moderate
	Bulldozer	Slight	Slight	Severe	Severe	Moderate	High	Moderate

1 Severity of constraints

Three types of degraded lands are presented in Table 2. The possibility for reclamation of each condition is determined by the severity of four major constraints: the physical soil constraints of gully erosion and soil compaction accompanied by sheet erosion; the chemical constraint of soil fertility depletion; and weed encroachment, a biological constraint. A qualitative indicator of the investment required for successful land reclamation is listed in terms of labour, energy expenditure as tillage, and capital expenditures for fertilizers and herbicides. This table assumes gentle slopes and highly weathered soils (e.g. Oxisols and Ultisols).

For degraded forest fallows there is usually no significant erosion or compaction, but the levels of fertility depletion and weed encroachment may be severe. The levels of investment in land reclamation are relatively high in terms of labour and low in terms of energy. The level of capital inputs required for reclamation depends on the intensity of weedy vegetation and the amounts of fertilizers required to correct soil infertility.

For degraded pastures weed encroachment is often the most severe constraint in those areas previously cleared by slash and burn. Compaction and fertility depletion represent only moderate constraints. However, if the forests were cleared using heavy machinery, degraded pastures may demonstrate significant gully erosion, severe soil compaction and fertility depletion.

Imperata grasslands pose little erosion hazard or soil compaction but by their very nature they show severe weed encroachment and to a lesser extent soil fertility constraints.

2 Long-term consequences of land clearing methods

The land-clearing methods are included in Table 2 because they often exacerbate the severity of biophysical constraints, primarily in terms of soil compaction and fertility depletion. The extent of weed encroachment is less sensitive to the clearing method. One of the most important aspects when degraded lands are being considered for reclamation is whether they were cleared mechanically (e.g. bulldozing) or manually, (e.g. machetes and chainsaws). The slash and burn method is to some extent beneficial because it converts the nutrients stored in the biomass into ash which in turn fertilizes the soil without excessive disturbance of the topsoil. In contrast, straight blade bulldozing displaces biomass into windrows that when burned produce poorly distributed ash, compacts the soil and removes a large amount of topsoil (Seibert *et al*., 1977; Smyth and Bastos, 1984). Land cleared by bulldozing is often abandoned earlier and subsequent forest fallow regeneration is reduced when compared to land cleared by slash and burn (Lal *et* *al*., 1986).

The soil compaction effect persists for several years and often extends to significant depths. For example Alegre *et al*. (1986) recorded severe soil compaction to a depth of 45cm in the subsoil of an Ultisol that was bulldozed seven years previously, cropped for two years and then abandoned to a grass fallow for five more years. Successful reclamation of this land with annual crops was possible only through chisel ploughing or subsoil tillage. At the same time, regular tillage was sufficient for lands originally cleared by slash and burn.

A contrasting example is reported for an Oxisol in Sitiung, Indonesia that had the top 30cm of soil removed by bulldozer clearing. Although no compaction was evident in the well-structured subsoil, little crop growth was possible without major fertilizer inputs and mycorrhizal inoculation (Cassel *et al*., 1990 ; Wade *et al*., 1989). Both inputs were required in order to return this infertile subsoil nearly devoid of biological activity into production. It is likely that neither of these conditions would be evident in lands cleared by slash and burn.

Agroforestry approaches to reclamation of degraded lands

One of the main findings of a worldwide study on sustainable agriculture and the environment in the humid tropics is that our current approaches to restoring degraded lands are based on empirical evidence and limited research data (National Research Council, 1993). Among the many approaches to restore degraded lands, agroforestry is often considered to be the most suitable strategy (Uhl *et al*., 1990 ; Robison and McKean, 1992 ; Serrao and Homma, 1993). The main reasons given are that agroforestry most closely resembles the forest by retaining and recycling nutrients protecting the soil from erosion and providing sustained yields (Uhl *et al*., 1990).

Such reasons appear to be based more upon hope and conviction from a theoretical perspective than upon sound scientific evidence. The gap between theory and practice remains distressingly obvious. However, there are mounting indications that some agroforestry technologies represent viable alternatives to shifting agriculture and prevent subsequent land degradation (Szott *et al*., 1991 ; Anderson, 1990 ; Sanchez, 1987 ; National Research Council, 1993). However, such technologies have been successful on lands recently cleared of primary or mature secondary forests rather than on degraded lands. Following slash and burn, such lands have high levels of nutrients, small populations of weed species and favorable soil physical properties. The greater challenge is to establish agroforestry systems on degraded lands (Table 2).

There is strong evidence that most of these degraded lands can be restored to productivity with large energy and capital inputs. Soil compaction (Alegre *et al*., 1986), and nutrient availability (Cassel *et al*., 1990 ; Wade *et al*., 1989) are reversible constraints. *Imperata* grasslands can be eradicated by applications of glyphosate and other herbicides, but at a high cost (Sukumana, 1986). These options requiring high external inputs may be technically possible but of limited economic and social feasibility. On the other hand, it is unlikely that planting trees alone can correct poor soil fertility, compaction and weed encroachment sufficiently for adequate regeneration. The issue is not whether purchased inputs should be used but how their requirements are minimized within agroforestry systems. The following sections describe issues specific to the three main types of degraded lands with emphasis on their reversibility through agroforestry management.

1 Degraded fallows

The agroforestry systems more closely resembling shifting cultivation practices are those more likely to be adopted by farmers currently practicing slash and burn. Biologically enriched, or managed fallows require the establishment of fast-growing, nitrogen-fixing leguminous shrub or tree species into abandoned fields (Raintree, 1987). In order to facilitate this establishment, degraded fallows may be burned in order to provide the improved fallow with nutrients although the ash contribution from many degraded systems may be small. Furthermore, the burn will temporarily reduce competition by the invasive weeds established within the degraded fallows. While biologically managed fallows have been successful when planted in shifting cultivation fields that are not degraded (Szott *et al*., 1991), establishment in degraded sites is more difficult due to an insufficient supply of plant nutrients. However, several candidate tree species, including several nitrogen-fixing legumes have been identified that are capable of establishment on extremely acid and nutrient-depleted soils. These include *Inga edulis, Gliricidia sepium, Cassia reticulata, Acacia mangium, Peltophorum inerme*, and *Acioa barteri* (van Noordwijk 1989 ; Szott *et al*., 1991). Deep rooting species, such as *Peltophorum inerme* are particularly important because of their ability to obtain water from underlying subsoils (van Noordwijk, 1989). Although establishment and growth may be slower under degraded conditions, adapted tree species will eventually form a canopy, accumulate nutrients, and compete with weeds. Combining trees with vigorous, leguminous ground covers well suited to acid soils, such as *Mucuna cochichinenses, M. utilis, Centrosema macrocarpum, C. acutifolias* and *Calopogonium mucunoides* improves weed control.

Economic fallows resemble biologically improved fallows but also include tree species that provide economic products within a few years (Raintree, 1987). Examples of these include use of fruit (Alcorn, 1990) and timber trees (Peck and Bishop, 1992) ; low input cropping interplanted with peach palm (Sanchez and Benites, 1987 ; Szott *et al*., 1991) and intensively managed multispecies agroforestry systems adopted by Japanese settlers in Eastern Brazil (Subler and Uhl, 1990). Including trees that produce fruits or other non-wood products actually facilitates the establishment of a more stable agricultural system because the farmers are less likely to clear areas that are providing sources of income. The challenge is to identify economically valuable trees capable of establishment within these degraded systems while requiring little or no fertilization.

Additional studies on fallow establishment within degraded systems similar to those described by Szott *et al*. (1991) that measure biomass increase, nutrient accumulation, root development and weed dynamics are necessary because the fallow interval during land recuperation is of paramount importance to resource-limited farmers. Studies comparing establishment rates and economic returns of different combinations of tree species in conjunction with basal applications of fertilizers, particularly phosphorus, are also needed.

Alley cropping is often cited as an alternative to shifting cultivation. Alley cropping is successful on more fertile sites (Kang *et al*., 1984) but the results have been somewhat disappointing on low pH, nutrient poor Ultisols (Szott *et al*., 1991). Therefore, alley cropping appears less likely to succeed in nutrient-depleted lands.

Nonetheless, appropriate technologies for the regeneration of degraded secondary forest fallows must be developed soon. Degraded fallow lands may be returned to productive use through tillage and fertilization (Alegre *et al*., 1986), but these high external input solutions are unlikely to be adopted by smallholder farmers who are faced with this ever-growing problem.

2 Degraded pastures

Extensive studies in the Eastern Amazon of Brazil have developed the fundamental and practical basis for reclaiming degraded pastures (Serrao *et al*., 1979 ; Uhl *et al*., 1990 ; Serrao and Toledo, 1990 ; Nepstad *et al*., 1991). These degraded pastures may be recuperated by slashing and burning the vegetation, ploughing, fertilizing, cropping one or two cycles of maize in order to cover the costs of additional inputs, and then replanting the pastures with more acid-tolerant pasture species. In the Brazilian Amazon, 10% of the degraded pastures (approximately 700,000 hectares) have been recovered in this fashion (Serrao and Toledo, 1990).

Another option is the re-establishment of secondary forest fallows. The techniques are based on overcoming limitations to tree establishment and growth including low densities of tree propagules, seedling predation, seasonal drought and competition with existing vegetation. Nepstad *et al*. (1991) assert that agroforestry systems facilitate regeneration when stress-tolerant trees are established that attract seed-carrying animals. Much work needs to be done in identifying those tree species that are suited to specific stress conditions and are disseminated through natural processes. Although some trees are grown in pastures, silvopastoral technologies need to be more fully developed. This constitutes a high priority research area (Serrao and Homma, 1993).

Serrao and Toledo (1990) identified four important plant selection criteria in order to convert degraded pastures to productive silvopastoral systems, specifically: 1) grass and legume forages that are tolerant to shading; 2) tree crops that are tolerant to acid, infertile soils; 3) tree crops that are associated with nitrogen-fixing symbionts; and 4) forages, annual crops and trees that are compatible among themselves and with grazing animals. In addition, the authors suggest that live fences of nitrogen-fixing trees be established. Live fences provide browse or prunings during periods of stress and reduce the deforestation associated with the cutting of trees that would otherwise be used as fence posts. Not all trees in pastures need be capable of symbiotic nitrogen fixation as other non-fixing trees may provide valuable products such as fruit and timber. Recuperated pastures that are highly productive through intensive management can better afford additional purchases of fertilizers and animal health products that, in turn, result in the incentive and resources to ensure that the pasture does not undergo degradation in the future. This is a vast and exciting research agenda.

3 *Imperata* grasslands

The characteristics of, and the difficulties associated with *Imperata cylindrica* grasslands are relatively well documented. The grass is a strong competitor in acid, infertile soils (Saxena and Ramakrishnan, 1983) but is susceptible to shading (Aken'Ova and Atta Krah, 1986), and becomes less competitive when pH and nutrient levels increase (Chou and Lee, 1988). The grass is very unpalatable to cattle, except for the young growth following burning. It is allelopathic to some crops and trees (Bhumibhamon *et al*, 1980; Rajan *et al*., 1988) which increases its competitiveness. *Imperata* is very difficult to eradicate by manual weeding because it readily reproduces by rhizomes and airborne seeds (Seibert and Kuncoro, 1987). Tillage alone does not eliminate *Imperata*. Herbicides such as glyphosate are sometimes only partly effective (Tjitrosemito and Suwinarno, 1988). However, low-volume applications of glyphosate may offer greater promise (Townson, 1989). Cropping of land cleared of *Imperata* may require nitrogen fertilization due to the high potential of *Imperata* residues to immobilize nitrogen (Utomo *et al*., 1989). Herbicidal applications combined with tillage, fertilization and liming may eradicate *Imperata* but at a very high cost. No wonder *Imperata cylindrica* is considered to be one of the 10 worst weeds of the world!

Agroforestry alternatives for the regeneration of *Imperata* grasslands focus upon competition for light. *Acacia mangium* has been successful in eliminating *Imperata* in as little as four to five years in Sabah, Malaysia (Miller and Hepburn, 1991). *A. mangium* seedlings are developed in nursery pots containing fertile, biologically-rich soils. The seedlings are transplanted in the field and weeded several times. Establishment is further promoted through fertilization with phosphorus (Udarbe and Hepburn, 1987). After two years, this management results in the establishment of a woodland savanna consisting of 4 meter tall *A. mangium* and an understorey of *Imperata*. By the fourth year *Imperata* had disappeared and a litter layer of *A. mangium* was evident on the soil surface.

The main constraints on this spectacular success are the susceptibility of *A. mangium* to the fires that frequently occur in *Imperata* grasslands. Furthermore, *A. mangium* does not coppice well. Additional research is required on improved provenances of *A. mangium*, silvicultural practices, fertilization, the effect of the tree on the soil properties and weed dynamics. Australian scientists suggest that after *Imperata* is suppressed and *A. mangium* is harvested, agroforestry systems that provide farmers with food, fruit, fodder and firewood should be established. De la Cruz (1986) suggested that *Imperata* grasslands be eliminated through accelerated plant succession that employs site preparation, fertilization, nurse trees and inoculation with beneficial microorganisms.

Need for a worldwide research initiative

Among the agroforestry strategies outlined for the recuperation of the three types of degraded systems there is one key issue: finding and establishing trees that are tolerant to acid, infertile soils and are able to compete with the established, weedy vegetation. Some promising species have been identified but need to be further tested under a range of degraded conditions. Many improved nursery techniques should be extended to the establishment of the trees. Such techniques include the inoculation with beneficial rhizobia and mycorrhiza (Nuhamara *et al*., 1986; CIAT, 1988; von Carlowitz *et al*., 1991; Hutton, 1990), the development of disease-free, nutrient-rich seedling growth media (Serrano, 1986) and the use of inexpensive, disposable plant containers. Approaches to the survival of these transplanted seedlings in terms of fire avoidance, weeding and fertilization are more difficult research issues.

Several agroforestry approaches to reclaiming the three types of degraded lands are described in this paper. A few have been tried and are successful as illustrated by the establishment of *A. mangium* on *Imperata* grasslands. In the case of the degraded forest fallows and degraded pastures, concepts are being formulated but the essential research is yet to be conducted. In addition to the selection of appropriate trees, ground covers and crops, additional research should focus on nutrient cycling and weed dynamics. Fundamental concepts of restoration ecology (Werner, 1990; Uhl *et al*., 1990) may serve as the basis for designing systems and developing a predictive understanding on how to return degraded areas to productive use.

A major, worldwide approach is needed to provide alternatives to shifting agriculture and to recuperate already degraded lands. Such a program has been submitted to donor agencies by a consortium of national and international research centers. Newly developed agroforestry technologies are by themselves meaningless unless they are coupled with policies designed to overcome more formidable socio-economic constraints. The design of such technologies should be developed with and directed to those most affected by the loss of the land to degradation and who therefore benefit most from returning those lands to productive use.

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