

INTERCIENCIA

Revista de Ciencia y Tecnología de América

Interciencia

Asociación Interciencia

interciencia@ivic.ve

ISSN (Versión impresa): 0378-1844

VENEZUELA

2001

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EXPERIENCES FROM LATIN AMERICA

Interciencia, octubre, año/vol. 26, número 010

Asociación Interciencia

Caracas, Venezuela

pp. 498-503

Red de Revistas Científicas de América Latina y el Caribe, España y Portugal

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STRATEGIES FOR THE RECOVERY OF DEGRADED ECOSYSTEMS: EXPERIENCES FROM LATIN AMERICA

FLORENCIA MONTAGNINI

It is becoming widely accepted that the conservation of biodiversity has to take place in managed landscapes as well as in protected areas (Pimentel *et al.*, 1992; Brown and Lugo, 1994; Guindon, 1996; Lamb, 1998; Harvey and Haber, 1999). In many regions of tropical America, the landscape consists of a complex mosaic of forest patches, pastures and agricultural fields and is heavily influenced by human activity. Any efforts to conserve biodiversity within managed landscapes must be compatible with local livelihood needs and offer sustainable and economically attractive alternatives to local farmers. Strategies that provide various ecosystem services and fulfill local human needs, in addition to promoting the conservation of biodiversity, will have a higher chance of success (Cairns and Meganck, 1994; Lamb, 1998).

One strategy that can potentially facilitate the maintenance or recovery of biodiversity within agricultural landscapes is the establishment of native forest plantations on degraded agricultural lands. Tropical plantations can serve diverse economic, social, political and ecological functions. With considerably higher yields than managed native forests, tropical and subtropical plantations can make substantial contributions to world timber and pulp production (Wadsworth, 1983; Evans, 1992; 1999;

Sedjo, 1999). Tree plantations can also be a source of cash, savings and insurance for individual farmers. Plantations may help stabilize rural populations in regions where shifting agriculture is the predominant land use. In combination with subsistence and commercial crops (agroforestry) or cattle (agrosilvopastoral systems), plantations have been used as tools in rural development projects worldwide. Plantations are often seen as alternatives to deforestation as they can provide products that otherwise would be taken from natural forests (Fearnside, 1990; Mc Nabb *et al.*, 1994; Mc Nabb and Wadouski, 1999).

If plantation species are chosen with knowledge of their nutrient-use efficiencies and recycling capacities, they can be highly productive and also serve a function in ecosystem restoration projects. Particularly, tree plantations and tree-crop combinations represent productive land use alternatives for deforested lands with poor natural forest regeneration due to long distance to sources of propagules or intense site degradation. Among the latter, low soil fertility, soil compaction after abandonment from cattle grazing, and invasion by grasses and other aggressive vegetation can be serious obstacles to both forest regeneration and conventional agriculture (Lugo, 1988; Nepstad *et al.*, 1991). As the area in degraded lands spreads out, emphasis is increasing on the use of tree species which can grow in such conditions and

yield economic products (timber, fuelwood and other) as well as environmental benefits (soil conservation, watershed protection) (Evans, 1992; 1999).

The initial step in ecosystem rehabilitation projects is to identify the most important constraints to crop or tree productivity, as well as defining the specific land restoration objectives. Some soils can be recovered through the use of fertilizers, others need more drastic rehabilitation techniques, and there are situations of extreme degradation where soils cannot be recovered at all (Dedecek, 1992). The recovery of the soils' productive capacity is frequently very expensive, thus the techniques involved must produce financial returns to ensure their adoptability by the local farmers.

The choice of appropriate tree species for plantation forestry or agroforestry is influenced by knowledge on the species' performance and their economic and environmental benefits. Locally, tree species choice is determined by seed or seedling availability and information on silvicultural characteristics and management, including fast growth and the possibility of intercropping during early establishment. Most reforestation or tree planting programs and subsidies promote the use of well-known, often exotic species. About 85% of plantation forestry in the tropics is dominated by three genera: *Pinus*, *Eucalyptus* and *Tectona*, while

KEYWORDS / Mixed Plantations / Native Species / Soil Fertility / Succession / Windbreaks /

Recibido: 03/04/2001. Aceptado: 10/08/2001

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TABLE I
CHARACTERISTICS OF THE STUDY SITES USED FOR RESEARCH
ON REHABILITATION OF ABANDONED LANDS IN THE LATIN AMERICAN HUMID TROPICS

Location	Mean annual rainfall and temperature	Soil type	Previous land use	Experimental setting
La Selva Biological Station, Atlantic Lowlands of Costa Rica	4,000mm, 24°C	Fluventic Dystrupepts pH 4.3-4.6	1-3 yrs. agriculture, cattle	Pure plantation, 2mx2m, 2-6 yrs. old
Pau Brazil Ecological Station Porto Seguro, Bahia, Brazil	1,700mm, 23°C	Oxisols (Haplorthox) pH 4.5-5.0	Shifting agriculture	Pure plantation, 2mx2m, 14-15 yrs. old
Eldorado, Misiones, NE Argentina (private farms)	1,700-2,400mm 22°C	Acid, clayey Ultisols pH 4.5-5.0	50 yrs. of agriculture, pine plantations	Pure stands from natural regeneration, 10-20 yrs. old

there may be thousands of indigenous species suitable for similar purposes (Evans, 1992; 1999). Native trees can be more appropriate than exotics because (1) they are better adapted to local environmental conditions, (2) seeds and other propagules are locally available, and (3) farmers are familiar with them and their uses. Besides, the use of indigenous trees in productive systems helps preserve genetic diversity and is in better balance with the local flora and fauna.

Rehabilitating Abandoned Lands in the Latin American Humid Tropics

A research program to develop alternatives for the rehabilitation and use of abandoned lands took place from 1987 to 1998 in three humid forest regions of Latin America: the Atlantic lowlands of Costa Rica, the Atlantic rainforest of Bahia in NE Brazil, and the sub-tropical forest of Misiones, NE Argentina (Table I). In these regions, common situations of rapid deforestation, loss of biodiversity, resource misuse and land degradation persist. Similar methods were used in the three locations: soil chemistry and nutrient cycling parameters were measured in pure stands of selected indigenous species, using adjacent areas free of trees (abandoned agricultural field or pasture, secondary/primary forest) for comparison. The size of each project varied with the sites: in Costa Rica the studies were the most complete (soils, above- and below-ground tree biomass, litterfall and forest-floor litter biomass and tissue chemistry), while in Bahia and Misiones the trees were part of a forest reserve or were in private farms and thus destructive sampling was not possible.

The soils under the species, grassy areas free of trees and adjacent young secondary forest were sampled for soil fertility and nitrogen availability

measurements at the three research sites. Soils were sampled with a soil auger and composite samples were dried and sieved using a 2mm sieve, and then brought to the laboratory for chemical analyses. The soil pH, total nitrogen and carbon, and extractable P and cations were analyzed following standard procedures recommended by the Ministry of Agriculture in each country. In Costa Rica, soil organic matter was measured with the Walkley-Black technique, and total N was measured using a semi-micro-Kjeldahl technique (Montagnini and Sancho, 1990), while in Argentina and Brazil total C and N were measured using a C-N-H Analyzer (Montagnini *et al.*, 1994; Montagnini *et al.*, 1995a). At all three sites, the pH was measured in a 1:2.5 mixture of soil:deionized water, and P was measured in the extracts by colorimetry. More detail on soil sampling procedures and chemical methods can be found in Montagnini and Sancho (1990; 1994a; 1994b), and Montagnini *et al.* (1995a, b, c). Litterfall was measured bi-weekly with litter traps, and forest-floor litter accumulation was sampled every three months at La Selva, while at Bahia data from existing studies was used.

Impacts of Trees on Soil Fertility

At La Selva, in just 2.5 years soil conditions improved in the tree plantations compared to abandoned pasture. In the top 15 cm, soil nitrogen and organic matter were higher under the trees than in nearby pasture, with values close to those found in adjacent 20-year-old forests (Table II). The highest values for soil organic matter, total N, Ca and P were found under *Vochysia ferruginea*, a species common in mature and secondary forests in the region (Montagnini and Sancho, 1990). Subsequent measurements revealed similar trends in the soil parameters in the three following years.

Based on the standards determined by the Ministry of Agriculture of Costa Rica for soil fertility assessments (Bertsch, 1986), the cation (Ca, Mg and K) levels under most of the tree species were at or above the critical values for agriculture (Montagnini and Sancho, 1990). In contrast, the cation levels in the adjacent abandoned pasture soils were too low for the subsistence crops preferred in the region (rice, beans). The standards set by the Ministry of Agriculture do not include N or organic matter. However, an indication of the importance of the improvement of the soil organic matter levels is given by the close relation found between organic matter content and the sum of bases (Ca+Mg+K), showing that the organic matter was responsible for much of the cation retention capacity (Montagnini and Sancho, 1990). For example, based on this relationship, a 1-2% increase in soil organic matter (in the 4-6% range) would more than double the base content, reaching values in the range recommended for agriculture (Bertsch, 1986).

Low crop yields in the humid tropics are often a result in part of unfavorable physical properties such as soil compaction (Cassel and Lal, 1992). At La Selva site, soil organic matter also had positive influences on soil physical properties: the soil bulk density was lower (i.e., lower compaction) while soil moisture was higher under the trees than in abandoned pasture (Montagnini and Mendelsohn, 1996).

The results of standard soil fertility tests used in agriculture may not always reveal the soil's productive potential, because they do not include all chemical forms of nutrients available for plant uptake. For example, although they make up less than 10% of the total soil N pool, mineral N ($\text{NO}_3^- + \text{NH}_4^+$), are the forms of N available to plants. Nitrogen

TABLE II
THE PH, TOTAL CARBON (C), TOTAL NITROGEN (N), AND EXTRACTABLE PHOSPHORUS (P) IN THE TOPSOIL UNDER PURE STANDS OF INDIGENOUS TREE SPECIES AT LA SELVA, COSTA RICA; PORTO SEGURO, BAHIA, BRAZIL; AND MISIONES, ARGENTINA

Site/Tree species	pH	C (%)	N (%)	P (cmol.kg ⁻¹)
a- La Selva, Costa Rica¹				
<i>Stryphnodendron microstachyum</i>	5.4ab	3.42ab	0.29b	5.6a
<i>Vochysia ferruginea</i>	5.4ab	3.76a	0.32a	7.1a
<i>Vochysia guatemalensis</i>	5.3ab	3.13ab	0.29b	5.2a
<i>Hieronima alchorneoides</i>	5.1b	2.96c	0.22b	1.5b
Abandoned pasture	5.3ab	2.73c	0.22b	4.9a
Secondary forest	5.3ab	4.33a	0.33a	3.6b
b- Porto Seguro, Bahia, Brazil²				
N-fixing leguminous species:				
<i>Bowdichia virgilioides</i>	4.9	1.98def	0.16def	1.32def
<i>Centrolobium minus</i>	4.6	1.87efg	0.16def	1.19efg
<i>Centrolobium robustum</i>	4.5	1.65ij	0.13f	1.07fgh
<i>Inga affinis</i>	4.9	2.10cde	0.18cd	3.64a
<i>Parapiptadenia pterosperma</i>	4.9	2.38ab	0.20bc	0.78ij
<i>Pithecellobium elegans</i>	4.8	1.67hij	0.15ef	0.59kl
<i>Platymenia foliolosa</i>	4.7	2.08cde	0.18bcd	0.13m
Non-N fixing leguminous species:				
<i>Arapatiella psilophylla</i>	4.7	1.94def	0.18bcd	1.45de
<i>Caesalpinia echinata</i>	5.1	2.41a	0.17cde	1.54de
<i>Cassia spp.</i>	4.7	1.94def	0.16def	1.40def
<i>Copaifera luscens</i>	5.0	2.02cde	0.17cde	0.63jk
<i>Dimorphandra jorgei</i>	4.9	1.97def	0.19bc	0.97ghi
<i>Hymenaea aurea</i>	4.4	2.00def	0.16def	2.03c
<i>Macrobium latifolium</i>	4.7	1.90efg	0.16def	0.67jk
Of other families:				
<i>Bombax macrophyllum</i>	4.8	1.78ghi	0.13f	1.42de
<i>Buchenavia grandis</i>	4.6	2.06cde	0.14f	2.09c
<i>Eschweilera ovata</i>	5.3	1.82fgh	0.31a	0.58kl
<i>Lecythis pisonis</i>	5.3	1.99def	0.18bcd	0.23lm
<i>Licania hypoleuca</i>	5.0	1.63j	0.14f	1.61d
<i>Pradosia lactescens</i>	4.9	2.15bcd	0.18bcd	0.81ij
Primary forest	4.9	1.99def	0.15ef	0.96hi
Secondary forest	5.1	2.15abc	0.22b	2.46b
c- Misiones, Argentina³				
<i>Balfourodendron riedelianum</i>	5.8	2.6b	0.34ab	n.d.
<i>Bastardiopsis densiflora</i>	7.1	6.3a	0.65a	n.d.
<i>Cordia trichotoma</i>	6.4	4.0ab	0.46ab	n.d.
<i>Enterolobium contortisiliquum</i>	6.1	3.4ab	0.39ab	n.d.
<i>Ocotea puberula</i>	6.1	4.4ab	0.59a	6.09a
Grass control	5.8	2.2b	0.027b	n.d.

Sources: ¹ Montagnini and Mendelsohn (1996), ² Montagnini *et al.*, (1994), ³ Fernández *et al.*, (1995). For each site, differences among means are statistically significant when followed by different letters (p<0.05).

Means were calculated using Analysis of Variance (ANOVA) and Least Significant Differences (LSD) tests were used to detect differences among means. n.d.: not detected

fertilizers are heavily used in the La Selva region, especially for the most demanding commercial crops such as bananas, in which case capital is available

for fertilizer in a more extensive land use system. For example, in our studies, *Stryphnodendron microstachyum*, a N-fixing tree, did not have an important effect

on total N (Table II), but its litter decomposes faster than the other species, resulting in increased soil mineral nitrogen under its canopy (Montagnini and Sancho, 1994a). Evaluating the effects of trees on soil P availability is even more difficult, although experiments with test crops can determine soil impacts. For example, in other experimental research, maize seedlings, grown in plots mulched with *S. microstachyum* and *Hieronima alchorneoides* versus the other species' litter, showed the greatest initial growth and the highest N and P plant uptake (Montagnini *et al.*, 1993). In these and in other related research at La Selva, the maize seedlings grown without mulch or fertilizer on soils from abandoned shifting agriculture fields grew very poorly, reaffirming the need for soil improvement techniques for growing conventional crops in the impoverished abandoned lands.

In Bahia, positive effects on at least five soil parameters were found under 15 out of the 20 species of the plantations, in comparison with primary and secondary forest (Table II). Several species contributed to increased C and N, among others: *Inga affinis*, *Parapiptadenia pterosperma*, *Platymenia foliolosa* (leguminous, N-fixing species), *Caesalpinia echinata*, *Copaifera luscens* (leguminous, non-N-fixing), *Eschweilera ovata*, *Pradosia lactescens* (of other families). Others increased soil pH and/or some cations, such as *C. luscens*, *E. ovata*, *Lecythis pisonis* and *Licania hypoleuca* (Montagnini *et al.*, 1994; Montagnini *et al.*, 1995a).

In Misiones, NE Argentina, the greatest differences in soil C and N levels under tree species and grass were found under *Bastardiopsis densiflora*, where they were twice those in areas beyond the canopy influence (Table II) (Fernández *et al.*, 1997). The pH was higher under *B. densiflora* and *Cordia trichotoma*, while the sum of bases (Ca+Mg+K) was highest under *Cordia trichotoma*, *B. densiflora* and *Enterolobium contortisiliquum*.

Tree Productivity in Plantations Used for Land Rehabilitation

As stated earlier in this article, land rehabilitation programs must use species and designs that not only help in soil recovery but also are productive. If a land rehabilitation system is productive it may represent an economic incentive for the local farmers. At La Selva, the values of whole tree biomass for the 4-year-old plantations (Table III) were greater than those reported for 4-year-old *Albizia lebbek* (Parrotta, 1989),

TABLE III
MEANS, ABOVEGROUND BIOMASS AND ANNUAL INCREMENTS
FOR THE FOUR NATIVE SPECIES IN 4-YEAR-OLD PLANTATIONS
AT LA SELVA, COSTA RICA^{1,2}.

Tree species	Aboveground live biomass, kg/ha				Mean annual Increment, t ha ⁻¹ yr ⁻¹	
	Stem	Branches	Leaves	Total	Total	Stems
<i>Stryphnodendron microstachyum</i>	35,250a	15,250a	4,325a	54,825a	13.7a	8.8a
<i>Vochysia ferruginea</i>	24,750b	14,250a	5,925a	44,925	11.2b	6.2b
<i>Vochysia guatemalensis</i>	41,750a	6,500b	7,250a	55,500	13.9a	10.4a
<i>Hieronima alchorneoides</i>	26,250a	12,250a	5,350a	43,850	12.0b	6.5b

¹ Source: Montagnini and Sancho (1994b).

²Differences between sites for a given parameter are statistically significant ($P < 0.05$) when means are followed by different letters. Means were calculated using Analysis of Variance (ANOVA) and Least Significant Differences (LSD) tests were used to detect differences among means.

and for 5.5-year-old *Leucaena leucocephala* (Wang *et al.*, 1991), both growing in dense plantations for biomass production in Puerto Rico. Values of total tree above-ground net primary productivity (calculated by dividing whole-tree biomass by tree age) lie within the ranges reported elsewhere for monospecific plantations in the humid tropics. The value for *Vochysia guatemalensis* is close to that reported for *Gmelina arborea* (12.8 tons per ha/yr) in the Brazilian Amazon (Russell, 1987); and to *Gmelina arborea* (12.7 tons/ha) and *Albizia falcataria* in the Philippines (11.3) (Kawajara *et al.*, 1981, in Young, 1989). The increments shown here are however lower than those reported for some of the fastest growing trees in the humid tropics such as *Acacia mangium* (15.5 to 18.0 tons/ha in Malaysia), *L. leucocephala* (20-30 and even up to 80 tons/ha in Hawaii) and other tropical sites (Young, 1989). Biomass of the same species planted in other experiments at La Selva was consistent with the results presented here (Montagnini and Sancho, 1994b; Montagnini and Porras, 1998; Shepherd and Montagnini, 1999).

Natural Regeneration in Mixed and Pure Plantations of Native Species

In addition to providing a variety of economic and environmental services (such as timber production, carbon accumulation, soil protection, and land reclamation), plantations may help local biodiversity by facilitating forest tree regeneration and by providing habitats for forest animals (Parrotta, 1992; Lamb, 1998). Although in humid tropical regions it is often assumed that recovery

of the degraded landscape through natural regeneration processes will take place within a time frame acceptable to the foreseen human use, forest regeneration is often significantly delayed by physical or biological barriers (Lugo, 1988; Nepstad *et al.*, 1991). The establishment of plantations may overcome some of these barriers by attracting seed dispersal agents into the landscape and by ameliorating local microclimatic conditions within the area, and thereby accelerating the recovery of these lands.

Mixed plantations could promote the regeneration of a greater diversity of species in their understory than pure species plantations by creating a greater variability of habitat conditions that may favor seed dispersers and germination and growth of tree species (Guariguata *et al.*, 1995; Montagnini *et al.*, 1999). Mixed plantations may have considerably higher conservation value than single-species plantations. We have studied natural regeneration in young mixed and pure plantations with twelve indigenous species at La Selva Biological Station in the humid lowlands of Costa Rica in order to determine the potential role of plantations in recovering local biodiversity. The results so far suggest that plantations can accelerate natural successional processes in degraded pastures (Guariguata *et al.*, 1995; Montagnini *et al.*, 1999; Carnevale and Montagnini, 2001).

The plantations consisted of 12 native species: Plantation 1: *Jacaranda copaia*, *Vochysia guatemalensis*, *Calophyllum brasiliense* and *Stryphnodendron microstachyum*; Plantation 2: *Terminalia amazonia*, *Dipteryx panamensis*, *Virola koschnyi* and *Albizia guacha-*

pele; Plantation 3, *Hieronima alchorneoides*, *Vochysia ferruginea*, *Terminalia amazonia* and *Balizia elegans*. Plantation plots were in randomized blocks, with four replicates of six treatments: pure plantation plots of each species, mixed-species plots (with all four species), and plots that were not planted and left for natural forest regeneration as control.

In Plantation 1, at 7 years of age, forest tree invasion was higher under *V. guatemalensis*, while shrubs were more abundant under *J. copaia* and under mixed-species treatments (Table IV). In Plantation 2, at 7 years, *V. koschnyi* and *T. amazonia* had the highest number of woody species (Table IV). In Plantation 3, at 7 years the highest abundance of tree individuals was found in the mixed plantation, followed by *H. alchorneoides* and *V. ferruginea* (Table IV).

Overall, in the mixed-species plantations, abundance of woody regeneration was high relative to that of

TABLE IV
AVERAGE NUMBER OF
INDIVIDUALS OF REGENERATING
TREE SEEDLINGS IN THE
UNDERSTORY OF PLANTATIONS
AND IN NATURAL REGENERATION
CONTROLS, AT 7 YEARS OF AGE, AT
LA SELVA BIOLOGICAL STATION,
COSTA RICA

Treatment	Number of individuals per hectare
Plantation 1:	
<i>Vochysia guatemalensis</i>	15,842
<i>Calophyllum brasiliense</i>	13,789
<i>Jacaranda copaia</i>	10,017
Mixed plantation	15,368
Natural regeneration	5,017
Plantation 2:	
<i>Virola koschnyi</i>	11,875
<i>Dipteryx panamensis</i>	5,625
<i>Terminalia amazonia</i>	27,500
<i>Albizia guachapele</i>	0
Mixed plantation	10,625
Natural regeneration	4,375
Plantation 3:	
<i>Vochysia ferruginea</i>	5,703
<i>Hieronima alchorneoides</i>	7,891
<i>Balizia elegans</i>	4,219
<i>Genipa americana</i>	1,484
Mixed plantation	10,156
Natural regeneration	703

pure plantations. Natural regeneration was higher in understories with low or intermediate light availability. Most of the seeds entering the open pastures were wind-dispersed, while most seeds entering the plantations were bird or bat-dispersed. This suggests that the plantations are facilitating tree regeneration by attracting seed-dispersing birds and bats into the area. The different species of the plantations created different conditions of shade and litter accumulation, determining the abundance of the recruited and the surviving individuals (Carnevale and Montagnini, 2001). Competition for grasses is a major factor influencing woody invasion under these plantations. High accumulation of litter on the plantation floor may contribute to diminish grass growth and thus encourage woody invasion under the species' canopies.

Other Tree-Based Strategies for Recovery of Biodiversity in Deforested Landscapes

In other regions with larger agricultural fields and farther from sources of propagules, windbreaks and remnant trees in pastures and agricultural fields may be important reservoirs of native tree species (Harvey and Haber, 1999; Harvey, 2000). For example, the effects of planted windbreaks on seed deposition patterns were examined in dairy farms in Monteverde by Harvey (2000). The windbreaks were planted strips of trees about 5m wide and 9m tall and were 7-8 years old at the time of the study. Trees and rows within the windbreaks were spaced at 1.5m. The most common species were *Cupressus lusitana*, *Croton niveus*, *Casuarina equisetifolia* (all exotic species) and *Montanoa guatemalensis* (native). None of these species produce fruits that attract frugivorous birds, and their seeds are wind dispersed except for *Croton* which is gravity dispersed. Windbreaks were found to receive significantly greater densities and species richness of seeds of tree and shrub species than pastures: windbreaks received an average of 39 times as many tree seeds, and 67 times as many shrub seeds as pastures. In addition, windbreaks received an average of 2 times as many tree species, and more than 2 times as many shrub species as pastures. The differences in the seed rain entering windbreaks vs. pastures appeared to be due almost entirely to the enhanced activity of birds in windbreaks: bird-dispersed seeds occurred in greater densities (about 100 times greater), and number of bird-dispersed species was three times greater in windbreaks than in pastures. The high

densities of bird-dispersed seeds within windbreaks suggests that windbreaks increase forest seed recruitment by serving as habitat and/or movement corridors for seed-dispersing birds (Harvey, 2000).

Windbreaks may serve as sources of woody colonists if the agricultural lands are later abandoned. Positioning of windbreaks within the landscape may affect seed deposition patterns by influencing the movements of seed-dispersing birds. Tree recruitment may be higher in windbreaks that are connected to forests. Windbreaks could be made more attractive to birds by including native, fruit-producing trees, by increasing their species and structural complexity, and by positioning them between forest patches to facilitate bird movement (Harvey, 2000).

Remnant trees in pastures or agricultural fields may play an important role in conserving biodiversity within agricultural systems because they provide habitat and resources that are otherwise absent from agricultural landscapes (Harvey and Haber, 1999). For example, in a survey of 237 ha of pastures in Monteverde, Costa Rica, Harvey and Haber (1999) found over 5000 trees of almost 200 species, with a mean density of 25 trees/ha. Primary forest trees accounted for over half of the species and over one-third of the individuals. More than 90% of the species were known to provide food for forest birds or other animals. In addition, many of the species were important as sources of timber, firewood or fence posts for farmers. Reasons for leaving trees in the pastures included using them for shade for cattle, timber, fruits for birds, and fence posts. Results of surveys among farmers suggested that farmers in the region would be receptive to programs promoting the conservation of forest trees in pastures, if these programs would fit the particular requirements of shade management for cattle and if they allowed farmers to use a small proportion of their trees for timber, fuelwood or fence posts. The conservation of pasture trees must be part of larger conservation initiatives that includes the conservation of large forest tracts, key habitats, forest fragments, migration routes, and corridors (Harvey and Haber, 1999).

Conclusions and Recommendations

A number of economically valuable native tree plantation species were found to have positive impacts on soils in three regions of the Latin American humid tropics. Tree productivity and biomass were high for these spe-

cies, relative to plantations of better-known exotic species, therefore they would be preferred by farmers for reforestation. Studies of natural regeneration entering the understory of established plantations showed that certain species were more effective in attracting seed dispersers and favoring seedling recruitment. Mixed plantations gave good results in accelerating natural succession. Among the factors favoring woody invasion of plantation understories, high production of leaf litter was most important in helping to suppress herbaceous vegetation and thus favoring competition by tree seedlings.

In addition to conventional plantations, planting trees in windbreaks, and planting or leaving trees in agricultural landscapes may contribute to conserving and restoring biodiversity by offering habitats for birds and other animals, and by enhancing seed dispersal into agricultural landscapes.

Examination of the role of strategies for recovery of biodiversity necessitates integrative approaches that consider factors influencing tree regeneration, other potential effects on the ecosystem, and economic, social and environmental constraints of the proposed systems.

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