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Effects of active pasture, teak (*Tectona grandis*) and mixed native plantations on soil chemistry in Costa Rica

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A B S T R A C T

In this study soil samples were taken from the O/A and B horizons of undisturbed forest, active pasture, and 8- to 12-year-old teak and mixed native plantations. Samples were analyzed for K, Ca, Mg, soil organic carbon, pH, exchangeable acidity, bulk density, and compared with a fertility equation. Bulk density was significantly lower in the undisturbed forest than other land uses, suggesting that after approximately 10 years of growth neither plantation lowered bulk density significantly from that of the active pasture. Teak plantations had significantly higher Mg and K (B horizon) and Ca (O/A horizon) concentrations than the undisturbed forest. This trend suggests that exchangeable base concentrations increase when land use changes from undisturbed forest to pasture, then pasture to plantation, with the most pronounced effect of this in teak plantations exhibiting more high fertility plots than other land uses. Soil organic carbon concentration was similar for all land uses except for a significantly lower concentration in teak plantations than in active pasture (O/A horizons). These results suggest that teak plantations may be advantageous for increasing soil fertility but, with respect to restoration of undisturbed forest conditions, present significant deviations in soil chemistry. Options for improved plantations soil management are discussed.

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1. Introduction

Large areas of forest throughout the tropics have been converted to pasture, but when pasture is no longer economically viable it is often abandoned (Fisher, 1995; Leopold et al., 2001). The ability of the ecosystem to recover is affected by the amount of time it has been in pasture and the intensity of use. To assure forest ecosystem rehabilitation on a site where natural succession is not an option, due to site or time constraints, managers may turn to plantations as rehabilitative tools (Lugo, 1992a,b; Parrotta, 1992). Other landowners may turn to plantations for timber production in order to generate income no longer possible through cattle production. Still others may wish to combine these two goals.

Conversion of undisturbed forest to pasture is often associated with land degradation (Cassel and Lal, 1992; Leopold et al., 2001; Krishnaswamy and Richter, 2002). The conversion from pasture to plantation has the potential to improve or diminish soil chemical (Montagnini, 2000) and physical properties (Fisher, 1995; Powers et al., 1997). It is important for landowners who consider establishing plantations on abandoned pasture to understand what soil property changes might occur based on the plantation species or mixture they select.

Trees that influence soil chemical and physical properties have been used in agricultural applications through agroforestry and forest fallow for some time (Nair, 1993). By studying the effects of fallow periods on productivity and plant nutrition of crops, Fisher (1990, 1995) outlined five ways that a tree can ameliorate soil conditions at a given site. These include N-fixation, surface soil nutrient enrichment through litterfall and root turnover, increase in soil organic matter (SOM) through additional litter and root inputs, changes in above- and belowground microclimate (moisture and temperature extremes, aeration, etc.), and through the increase in organism activity within the rhizosphere of perennial roots. Therefore, tree species selection for rehabilitation or plantations is an important consideration for maintaining or enhancing soil properties.

Plantations of native tropical species have been used in reforestation efforts throughout the tropics to catalyze restoration, reduce soil erosion, or serve as sinks for carbon dioxide (Cuevas et al., 1991). There is an abundance of literature that examines tropical plantations of mixed and pure species including their effect on regeneration (Parrotta, 1995; Carnevale and Montagnini, 2002; Cusack and Montagnini, 2004), their influence on soil

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chemical and physical properties (Parrotta, 1992; Fisher, 1995; Montagnini, 2000), and silvicultural systems (Finegan and Camacho, 1999; Guariguata, 1999; Petita and Montagnini, 2004). Furthermore, the Tropical Agriculture Research and Higher Education Center (CATIE) in Costa Rica studies the economic and ecological feasibility of plantations, silvicultural practices, and overall forest management for native tree species throughout Central America (Montagnini et al., 2002). Landowners throughout the tropics are well served by the findings of these studies, but the decision to establish a native or mixed plantation is not always an easy one.

Established plantations will modify microsite conditions regardless of the tree species origin. In some cases, exotic species may be advantageous due to their adaptability to damaged sites (Zobel et al., 1987; Lugo, 1992a,b) or for their ability to catalyze secondary growth (Parrotta, 1995; Feyera et al., 2002). Alternatively, native species may be preferred for establishing habitat for native animal species (Evans and Turnbull, 2004), to preserve genetic diversity, because of local seed availability, or because farmers are more familiar with them (Montagnini, 2001). Whether exotic or native, the key to successful plantation establishment is adequate matching of species to site and a commitment from the local people (Evans, 1999).

Of the exotic plantations established throughout the tropics over two million ha have been planted with teak (*Tectona grandis* Linn. f.) (Evans, 1999), a valuable exotic timber species that is used for shipbuilding, furniture, and carving (Kaosa-ard, 1981). In Costa Rica alone approximately 25,600 ha have been established in plantations (Schmincke, 2000). Pure teak plantations, however, have been scrutinized for having problems with soil deterioration and erosion (Champion, 1932; Pandey and Brown, 2000).

This is often attributed to the lack of understory vegetation that leaves the soil exposed and vulnerable to erosion, which may be a result of low light due to a close spacing (Bell, 1973), allelopathic properties of teak leaves that reduce understory growth (Healey and Gara, 2003), or frequent fires that reduce leaf cover, regeneration (Laurie and Griffith, 1942; Bell, 1973) and organic carbon (Balagopalan and Alexander, 1985).

The purpose of this study was to explore the effects of two land managers' decisions to establish plantations on abandoned pastures. One established a native mixed plantation with the goal of ecological rehabilitation, while the other established a teak plantation with the goal of timber production. In this study we compared the chemical and physical soil properties of active pasture, undisturbed forest, and abandoned pasture that had been planted with either mixed native or teak plantations. The results highlight changes that occur during the first decade of plantation establishment and, therefore, do not represent the effects of a full rotation, but may assist landowners in making management decisions about species selection, establishment, and maintenance of tropical plantations established on abandoned pastures.

2. Methods

2.1. Study area

The study was conducted in the tropical wet forest life zone (Holdridge et al., 1971) in southwestern Costa Rica from July through September, 2004. Sites were located in and around Los Árboles, a 125 ha restoration project owned and managed by the Tropical Forestry Initiative (Leopold and Finkeldey, 1995). The area is located at 9°19′47″N and 83°51′45″W and receives an annual rainfall of approximately 2700 mm, falling primarily from May until November. Nearby temperatures fluctuate daily from a low of 18 °C to a high of 29 °C throughout the year (WWIS, 1994).

The sites used in this study were selected based on proximity to Los Árboles, similarity of soil texture, morphology, parent material (based on soil pit excavation), and past management (based on informal landowner interviews). They included active pastures, undisturbed forests, teak plantations, and mixed native plantations. Active pastures were used to represent the condition of the plantations before they were planted with tree species. The undisturbed forest was selected to provide a reference of comparison for a local undisturbed forested system.

The soils were classified as Ultisols with A horizon colors around 7.5YR4/3 and B horizon colors around 5YR4/6. All study sites had a soil texture of clay, except for one teak plantation which was sandy clay loam. Physiographic and stand characteristics of each of the study sites are listed in Table 1.

2.2. Study sites

The mixed native plantation sites were established by Tropical Forestry Initiative in 1993 (MN2) and 1995 (MN1) as a means of restoring the degraded pasture that had occupied the area for approximately 45 years. Both plantations were planted with native species at a spacing of 3 m × 3 m and cleared of competing vegetation for 4 years (Leopold et al., 2001). Afterward MN1 received minimal enrichment planting with *Terminalia amazonia*. MN2 was thinned of many *Vochysia ferruginea* that had naturally regenerated into the area and had been competing with the plantation species. Both plantations included nearly 30 species of native trees with the highest concentrations being *Terminalia amazonia*, *Vochysia hondurensis*, *Pithecellobium arboreum*, and *Vochysia ferruginea*. At the time of sampling the plantations were 9 and 11 years old.

Both undisturbed forest sites were located within Los Árboles. In the past the areas surrounding the undisturbed forest had been cut for timber extraction and to clear the land for agricultural crops or pasture. The undisturbed forest sites in this study had not been cleared, perhaps due to the steepness of the terrain (especially UF2), and only a few of the larger trees had been removed (E. Gamboa, pers. comm.). Each site contained over 40 species of native trees.

Table 1
Slope, area, elevation, basal area, tree density, and canopy cover for the eight study sites at Los Arboles and vicinity (n = 17–20).

Site	Slope (°)	Area (ha)	Elevation (m)		Average DBH (cm)	Basal area (m^2 ha^{-1})	Density (trees ha^{-1})	Canopy cover (%)
			Low	High				
UF1	24 (8)	4.89	171	337	82.9 (90.1)	37.7 (23.6)	574 (172)	96.9 (1.6)
UF2	34 (6)	4.00	406	498	93.4 (84.6)	40.3 (24.9)	522 (170)	98.1 (1.1)
AP1	25 (10)	2.09	121	176	–	–	–	–
AP2	20 (9)	2.44	321	351	–	–	–	–
MN1	29 (5)	2.25	114	171	30.2 (19.5)	13.4 (4.3)	574 (156)	93.3 (2.2)
MN2	22 (9)	1.89	410	445	42.0 (34.2)	17.6 (9.2)	393 (202)	92.3 (7.7)
TP1	22 (7)	2.12	95	170	20.8 (4.1)	17.6 (3.8)	497 (129)	92.6 (3.2)
TP2	15 (9)	1.33	251	262	22.4 (3.9)	16.1 (4.4)	400 (100)	92.2 (3.7)

UF = undisturbed forest, AP = active pasture, MN = mixed native plantation, TP = teak plantation. Standard deviation given in parentheses.