The Americas Journal of Plant Science and Biotechnology ©2008 Global Science Books

Substitution of Brazilian Native Plants for Agricultural Systems

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ABSTRACT

The substitution of natural ecosystems by agriculture is mostly due to the persistent food insecurity of a growing population. It produces a series of negative outcomes such as an increase in the greenhouse effect, a decrease of biodiversity, soil quality and water availability, as well as decreases in the rates of addition and decomposition of soil organic matter. Native vegetation is increasingly being replaced by agricultural crops and cultivated pastures in Brazil, especially by large land owners that produce cattle for export to developed countries, or also by small farmers that farm for subsistence. Agricultural systems can sometimes positively influence the environment, although they are the main factor responsible for imbalances in natural systems, and for losses of biodiversity. In this article, we focus on the effects of agricultural systems over four of the main native Brazilian vegetation types: Amazonia, Atlantic Forest, Caatinga and Cerrado.

Keywords: Amazonia, Atlantic Forest, Caatinga, Cerrado, impacts

CONTENTS

INTRODUCTION

In order to fulfill the demand for food from an increasing population it has become frequent to find agricultural practices in preserved areas, especially due to the quality of their soils and the proximity to water sources. Brazil is known world-wide for its natural reserves and the environmental impacts on the Amazon. The problem is that agricultural practices usually do not adopt conservationists' management of natural resources such as soil, fauna and flora, creating the need for exploring new areas even for short-term agrarian production. Although this problem does not belong solely to developing countries, we will focus on showing how natural Brazilian ecosystems are differently affected when inadequately used.

Environmental protection, development and food production are closely linked. They are not exclusively compatible, but we cannot have one without the other. If humankind does not protect the environment, it will not be possible to produce food in the near future. If sustainable food production systems can not be developed, then the environment can also not be protected.

One of the critical questions that developing countries face is whether agricultural production can be intensified without harming the environment. Developing countries must produce more food in the future not only for internal use, but to accomplish the demand for over-populated countries. It has been estimated that demand for cereals, roots and tubers will increase by more than 50% by 2020 (Rosegrant *et al*. 2001), implying an enormous threat to the conservation of natural resources and to their service production (Hoynck *et al*. 2003). The actual dominant agricultural systems worldwide are a risk because of a combination of several interrelated factors, including the lack of fresh water, lack of drainage, and salinization of soil and groundwater resources (Shoups *et al*. 2005).

Water depletion and soil erosion have already emerged as serious problems for agriculture. Up to 50% of the world's arable land is substantially impacted by soil loss which directly affects rural livelihoods and indirectly aquatic resources, lake and river sediment dynamics (Pimentel 1993; Kelley and Nater 2000).

Conservation activities have been focused entirely on protected sites. However, the importance of farming activities on biodiversity is emerging (Feehan 2001). The diversity of cropping systems, crop species and farm management practices have received increasing attention in recent years as a way of spreading risk and supporting food security in resource-poor farming systems (Tengberg *et al*. 1998). The effects of agriculture on biodiversity are of considerable importance because farming is the human activity occupying the largest share of the total land area (Torrico *et al*. 2005).

Even the importance of adopting biodiversity conservation practices, they most of the times are perceived as a cost by those involved in the exploitation, both in terms of forgone benefits and actual cost of conservation (Groombridge and Jenkins 1996). Other important obstacles are limited

Received: 21 February, 2008. Accepted: 24 May, 2008.

Invited Review

knowledge regarding important functions of the environment and insecurity and risk regarding current and future environmental impacts.

AGRICULTURAL LAND USE AND DEFORESTATION RATES

Some agricultural systems contribute extremely to the degeneration of natural ecosystems, but others might even contribute positively in the recuperation of degraded ecosystems, such as is often the case with agroforestry, sylvopastoral and ecological systems (Schroth *et al.* 2004; Maia *et al.* 2007). Where landscapes have been denuded through inadequate land use or degraded agricultural areas have been abandoned, regeneration with agroforestry practices can promote biodiversity conservation (Schroth 2004). These systems help reduce pressure from additional land deforestation for agricultural purposes. They can also provide habitat and resources for partially forest-dependent native plants and animal species (Laurance 2004). In tropical land use mosaics, ecological processes and characteristics such as microclimate, water and nutrient fluxes, pest and disease dynamics, and the presence and dispersal of fauna and flora may be positively affected by agroforestry elements (Thurston *et al.* 1999; Schroth 2004).

The deforested area in the three most important Brazilian biomes (by area) – Atlantic Forest, Amazonia and Cerrado (savanna-like) add in total to 2.7 million km^2 or roughly 31.7% of the national territory. More recently, since August 2003 to August 2004, 26,130 km^2 of forests were lost, an area that accounts to the 18.6% of the land deforested on all the earth in that year, as estimated by the Ministry of the Environment of Brazil (Ministério do Meio Ambiente, in Portuguese, MMA 2005).

Atlantic Forest

The original extension of the Brazilian Atlantic forest before the European conquest, covered all the eastern side of the country, more than 1,200,000 km² or 15% of Brazil's territory. Now only 95,000 km² of this natural habitat survives, just 8% of its initial extent (Mittermeier *et al.* 2000; Myers *et al.* 2000). It is still a large biodiversity reservoir in Brazil, second only to the Amazonian forest, but deforestation and intensive farming methods of coffee, cocoa, sugarcane and cassava plantations make this tropical forest one of Earth's most seriously threatened ecosystems. In the states of São Paulo and Minas Gerais, regions where agriculture has strongly developed in recent years, the forest is largely fragmented, represented only by small blocks located on the abrupt slopes which plunge down towards the Atlantic (Flechet 2007). Most fragments are smaller than 50 ha and only a few are larger than 1,000 ha (Ranta *et al.* 1998). According to the same authors, even with only about 8% of the original forest cover remaining, the Atlantic Forest harbors over 20,000 plant species, of which 8,000 are endemic, along with 850 bird species with an endemism rate higher than 22%.

The extraction of Brazil wood, *Caesalpinia echinata*, an arboreal species characteristic of the Atlantic forest which occurs from Rio Grande do Norte to São Paulo has also been an important cause for the current status of ecological losses in this area. Today its economical importance is reduced but still significant, due to the quality of the wood used in urban landscaping and the manufacture of violin bows (Cardoso *et al.* 1998).

Cattle or livestock grazing is one of the most widespread uses of land in Brazil. In the state of Rio de Janeiro, at least 90% of the tropical rain forests were cut down for charcoal production, additionally, the forests were substituted by coffee plantations and, later, as a result of soil overuse and decline of the coffee plantations, pastures and cattle were implemented (DEAN 1996). In the municipality of Teresópolis (RJ), the agrobiodiversity of farming systems was evaluated, and results showed cattle raising as the dominant system with 74% of the total agricultural surface of the basin. Horticultural systems are the second most important (24%), of which leafy vegetable systems are the most important with 14%. The sylvopastoral system occupies only 2% and the ecological and organic cultivations less than 0.4% (**Fig. 1**) (Torrico 2006). Following a pattern similar to the one described for the forests in Rio de Janeiro, the neighboring States of Minas Gerais and São Paulo, were also deforested, mainly for agricultural purposes (Bastos *et al.* 2005).

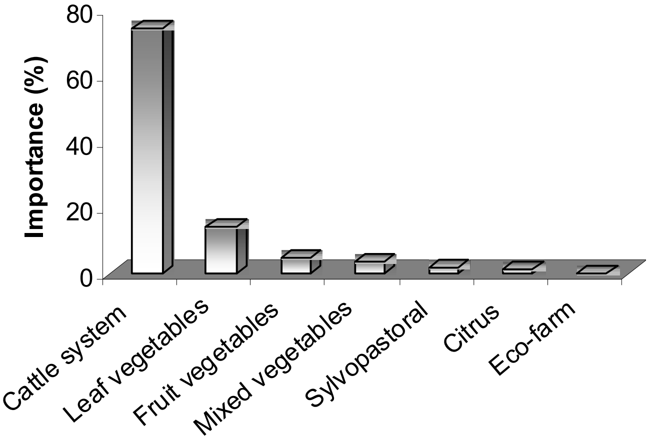

Fig. 1 Relative importance of farming systems. (Adapted from Torrico 2006)

The gradual transformation of forest into pasture and agricultural land has had profound ecological impacts in the region, changing the species composition of communities, disrupting ecosystem functions (including nutrient cycling and succession), altering habitat structure, aiding the spread of exotic species, isolating and fragmenting natural habitats, and changing the physical characteristics of both terrestrial and hydrological systems.

These changes, in turn, have often resulted in the reduction of both local and regional biodiversity. One way to reintroduce biodiversity into large-scale monocultures is by establishing crop diversity by enriching available field margins and hedgerows which may then serve as biological corridors allowing the movement and distribution of useful animals and insects.

From the biodiversity point of view, ecological farming systems, agroforestry and sylvopastoral systems, and perennial cultivations help to reduce the pressure on the fragments and deforested areas (Breman and Kessler 1997; Nair *et al.* 1999; Sharrow and Ismail 2004). They improve the water cycle, and also have a positive influence on fauna and flora dispersion. They offer better resources and habitat for the survival of plants and animals than cattle and horticultural systems. Also, they play an important role as biocorridors and buffering reserves by introducing a modest biodiversity level in these depredated areas of the Atlantic Forest.

There are some partnerships programs between farmers and private companies, where the first provide land and the work face while the companies offer support with some species such as *Eucalyptus* seedlings, fertilizers and technical assistance. Those programs are highly advantageous for the companies mainly because the transportation costs are reduced and they do not need to invest in land acquisition, infrastructure and staff. The benefits for the farmers are related to second activities such as agroforestry practices mainly during the first years of the plantations, and for the environment it is considered that due to a larger offer of wood from small-farm plantations, there is the potential for an improvement of the local areas because of the reduced pressure to cut natural forest (Ceccon and Miramontes 2008).

The forest systems have the highest values of eco-volume, varying between 44 500m^3 ha^{-1} for semi-arid forest in Northeast Brazil up to 250,000 m^3 ha^{-1} for primary mountain rain forest in the Atlantic region. The highest values of eco-volume in agricultural systems (average 90,000 m^3 ha^{-1}) correspond to agroforestry systems (coffee and cocoa) and ecological systems (Torrico 2006). Eco-volume is the above-ground quantifiable space or volume limited by a uniform stand of vegetation and its height, within which coexist wide interactions among biotic and abiotic components (Torrico 2006).

It seems contradictory to say that agricultural systems can positively influence biodiversity, although they are the main factor responsible for imbalances of natural systems, and hence, for loss of biodiversity.

Amazonia

In many tropical countries, the majority of deforestation results from the actions of poor subsistence cultivators. Although small farmers account for only 30% of the deforestation activity, the intensity of deforestation within the area they occupy is greater than for the medium and large ranchers that hold 89% of the legal Amazon's private land. Deforestation intensity, or the impact per km^2 of private land, declines with increasing property size. This means that deforestation would increase if forest areas now held large ranches were redistributed into small holdings (Fearnside 1999).

However, in Brazil only about one-third of recent deforestation can be linked to "shifted" cultivators (term used for people who have moved into rainforest areas and established small-scale farming operations). A large portion of deforestation in Brazil can be attributed to land clearing for pasture land by commercial and speculative interests, misguided government policies, inappropriate projects, and commercial exploitation of forest resources. For effective action it is imperative that these issues be addressed. Focusing solely on the promotion of sustainable use by local people would neglect the most important forces behind deforestation in Brazil (Butler 2007a).

Brazil's deforestation is strongly correlated to the economic health of the country: the decline of deforestation from 1988-1991 nicely matched the economic slowdown during the same period, while the rocketing rate of deforestation from 1993-1998 paralleled a period of rapid economic growth. During lean times, ranchers and developers do not have the cash to rapidly expand their pasturelands and operations, while the government lacks funds to sponsor highways, colonization programs, grant tax breaks, and subsidies to forest exploiters (Butler 2007a).

A relatively small percentage of large landowners clear vast sections of the Amazon for cattle pastureland. Large tracts of forest are cleared and sometimes planted with African savanna grasses for cattle feeding. In many cases, especially during periods of high inflation, land is simply cleared for investment purposes. When pastureland prices exceed forest land prices (a condition made possible by tax incentives that favor pasture land over natural forest), forest clearing is a good hedge against inflation (Butler 2007a).

Such favorable taxation policies, combined with government subsidized agriculture and colonization programs started in the 1970-80s, promoted deforestation in the Amazon. Now "benefits" even ceased are still effective (Ibama 2002). The practice of low taxes on income derived from agriculture and tax rates that favor pasture over forest overvalues agriculture and pastureland and makes it profitable to convert natural forest for these purposes when it normally would not be so (Benhin 2006; Butler 2007a).

Understanding change in land use and land cover has been identified as a key for research in the Amazon, because changes in the land surface can affect energy, water, carbon and trace gas and nutrient cycles in the region (Nobre *et al.* 1997). While the rates of forest clearing have been carefully examined across the Amazon, less is known about the fate of land that has been converted to human use (Cardille and Foley 2003).

It is assumed that most natural pastures are established from and abandoned to grassland savannas (Cerrado), while

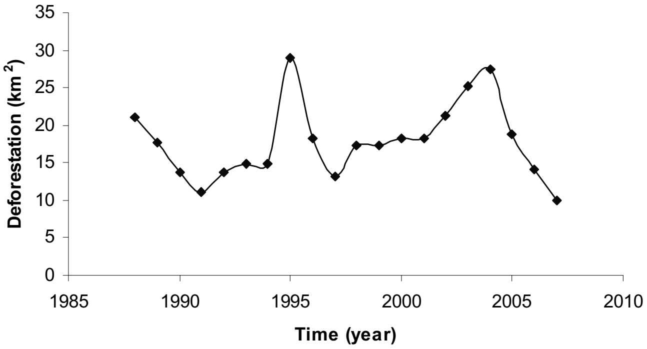

Fig. 2 Total deforestation areas in the Brazilian Amazon 1988-2007. (Adapted from Butler 2007a)

most planted pastures are established in former forest. As a result, changes in the amount of natural pasture are probably not linked to the deforestation process, while changes in planted pasture are directly tied to patterns of forest clearing and secondary re-growth (Cardille and Foley 2003).

Yet despite the tens of millions of hectares of deforestation in Brazil in the legal Amazon between 1980–1995, Houghton *et al.* (2000) estimated a net increase during that time of only 7.04 Mha in active agriculture, with a total of deforested areas of 25.32 Mha between 1980-1995. Legal Brazilian Amazon encompasses the entire states of Acre, Amazonas, Rondônia, Roraima and Tocantins as well as part of Pará and Mato Gosso (Cardille and Foley 2003). **Fig. 2** shows the areas of deforestation in the Brazilian Amazon.

The total agricultural changes in the Brazilian Amazon between 1980-1995 included cropland increase, loss of natural pasture, and increase in planted pasture. Unlike the increase in planted pasture and cropland, losses in natural pasture were probably not closely related to deforestation activities. Though some natural pasture may have been converted to cropland (e.g. Mato Grosso), Cardille and Foley (2003) assumed that the loss of natural pasture estimated during this period was due abandonment of formerly used lands to degraded pastures. Nowadays, deforestation in the Amazon is the result of several activities, the foremost of which include: clearing for cattle pasture, colonization and subsequent subsistence agriculture, commercial agriculture and logging (Butler 2007a). **Fig. 3** shows different causes of deforestation in the Amazon.

Cattle ranching is the leading cause of deforestation in the Brazilian Amazon. This has been the case since at least the 1970s. Government figures attributed 38% of deforestation from 1966-1975 to large-scale cattle ranching. However, today the situation may be even worse. According to the Center for International Forestry Research (CIFOR), between 1990 and 2001 the percentage of Europe's processed meat imports that came from Brazil rose from 40 to 74% and by 2003 for the first time ever, the growth in Brazilian cattle production – 80% of which was in the Amazon – was largely export driven (Butler 2007a). Even being common in the Amazon, it is ecologically unsuitable and economically unprofitable after the first few years (Hetch 1985). One of the most promising alternatives to cattle ranching is the use of regenerating forests to cultivate economically valuable species that provide fruit, timber, rubber, pharmaceuticals and fibers.

The Brazilian Amazon has the highest rates of deforestation in the world (Skole and Tucker 1993). Deforestation has been higher in Latin America than in Asia or Africa not only in terms of area (4.3 Mha $year^{-1}$), but also in percentage of forest cleared (0.64% $year^{-1}$) (Anderson 1990). From the Latin American forests that remained in 1850, 370 Mha (28%) had been cleared by 1985. Among this cleared area, 44% was converted to pasture, 25% to cropland, 20% became degraded and 10% changed to shifting cultivation (Houghton 1991).

Laurance *et al.* (2001) identified several factors that

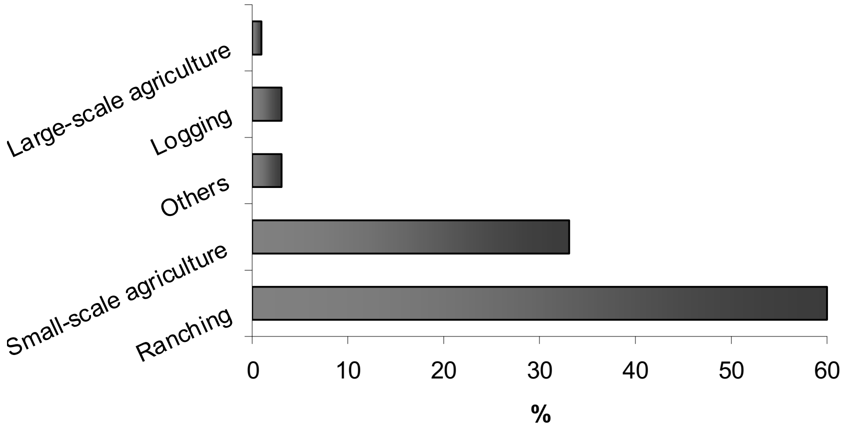

Fig. 3 Causes of deforestation in the Amazon, 2000-2005. (Adapted from Butler 2007a)

have led to this rapid rate of deforestation. First, non-indigenous populations in the Brazilian Amazon, have increased 10-fold since the 1960s, from about 2 to 20 million people, as a result of immigration from other areas of Brazil and high rates of intrinsic growth. Second, industrial logging and mining are growing dramatically in importance and road networks are expanding, increasing access to forests for ranchers and colonists. Third, the spatial patterns of forest loss are changing, past deforestation has been concentrated along the densely populated eastern and southern margins of the basin, however, new highways, roads, logging projects and colonization are now penetrating deep into the heart of the area (Cerri *et al*. 2007). Despite the expansion of the deforested area, the Brazilian Amazon still accounts for approximately 40% of the world's remaining tropical rainforest and plays a vital role in maintaining biodiversity, regional hydrology and climate, and terrestrial C storage (Laurance *et al*. 2001).

The forest accounts for ~10% of the world's terrestrial primary productivity and for a similar percentage of the C stored in land ecosystems (Keller *et al*. 1997).

Deforestation usually results in fragmentation, a patchwork of isolated forests surrounded by agriculture or development. These fragments usually are not large enough to support economical animal populations. The larger the animal, the more land it needs. Species with very specific requirements, however, regardless of size, need large areas of forest to survive. Fragmentation is one of the most prejudicial impacts suffered by tropical forests, being responsible for species extinctions, alterations in the composition of plant and animal communities, and changes in ecological processes (Harris and Silva-Lopez 1992). Forest fragmentation drives populations to subdivision and isolation, increases human pressure, causes microclimatic changes and enhances forest invasion by exotic species (Zuidema *et al.* 1996). As a result, several groups of organisms, notably mammals, birds, amphibians and trees, are suffering drastic changes in their local abundance and regional distribution in fragmented portions of tropical forests (Turner 1996; Bierregaard *et al*. 2001).

Deforestation in Brazil already makes a significant contribution to the global load of greenhouse gas (GHG) emissions and complete or nearly complete replacement of Brazil's Amazon forest by pasture contributing to global warming and greatly reducing evapotranspiration in the region. The principal reason for using cattle pasture as the replacement vegetation has been the lack of more realistic scenarios for changes in the landscape after its initial conversion from forest to pasture (Fearnside 1996).

Conversion of natural ecosystems to agriculture involves a range of activities that affect rates of addition and decomposition of soil organic matter (SOM). Decomposition of SOM is especially increased by physical disturbance with tillage, which disrupts macroaggregates and exposes previously protected soil C to microbial processes (Cambardella and Elliot 1992; Tisdall 1996).

The native vegetation of the Brazilian Amazon is increasingly being replaced by agricultural crops and cultivated pastures. A significant amount of deforestation is caused by the subsistence activities of poor farmers who are encouraged to settle on forest lands by government land policies. In Brazil, each squatter acquires the right (known as a usufruct right – lei do usocapião. www.senado.gov.br) to continue using a piece of land by living on a plot of unclaimed public land (no matter how marginal the land) and "using" it for at least one year and a day. After five years the squatter acquires ownership and hence the right to sell the land (Butler 2007a). Those farmers use fire for clearing land and every year satellite images pick up tens of thousands of fires burning across the Amazon. Typically undestroyed shrubbery is cleared and then forest trees are cut. The area is left to dry for a few months and then burned. The land is planted with crops like bananas, palms, cassava, maize, or rice. After a year or two, the productivity of the soil declines and the transient farmers press a little deeper and clear new forest for more short-term agricultural land. The old, now infertile fields are used for small-scale cattle grazing or left for waste (Butler 2007a).

Recently, soybeans have become one of the most important contributors to deforestation in the Brazilian Amazon. Thanks to a new variety of soybean developed by Brazilian scientists to flourish in rainforest climate, Brazil is on the verge of supplanting the United States as the world's leading exporter of soybeans (Butler 2007a). Even that the Federal government insists that recently there has been no deforestation for the production of soybean, Cerri *et al.* (2007) estimates that by the year 2015 there would be approximately 60% of new deforested area in the Brazilian Amazon used for soybean cultivation. Pasture will be established on the remaining 40% of the newly cleared area. By 2030, the proportion of soybean to pasture would be even greater with approximately 70% of the newly cleared areas used for soybean and only 30% for pasture. Moreover, the pasture areas would also be split according to the management system: 20% of the areas would be under well managed systems and the remaining 80% under degrading systems. Degraded pasture can further split into three main categories: 1) remained as degraded pasture, 2) become well managed pasture after rehabilitation and/or 3) be converted to row crops (mainly soybean) (Cerri *et al*. 2007). According to the same authors, it is difficult to devise scenarios for 2015 and 2030 for such a large area that is currently under development, but those predictions are in agreement with FAO on agricultural land use and land use changes for the years 2015 and 2030 (FAO 2002).

Virtually all forest clearing, by small farmers and plantation owners alike, is done by fire. Though these fires are intended to burn only limited areas, they frequently escape agricultural plots and pastures and char pristine rainforest, especially in dry years like 2005. These fires cover a vast area of forest. The burning produced carbon dioxide containing more than 500 million tons of carbon, 44 million tons of carbon monoxide, and millions of tons of other particles and nitrogen oxides (Butler 2007a).

Cerrado

The Brazilian savanna vegetation called Cerrado covers about 2 million km^2 of central Brazil, representing 23% of the land surface of the county, the same as Western Europe. It is characterized by high average temperature (22-27°C), rainfall (800-1600 mm) and solar radiation (475-500 Cal/cm^2/day) (Adamoli *et al*. 1987).

In terms of area it is exceeded by only one vegetation formation in Brazil, the Amazon Forest which covers approximately 3.5 million km^2. The Cerrado itself is very varied in form, ranging from dense grassland, usually with a sparse covering of shrubs and small trees, to almost closed woodland with a canopy height of 12-15 m (Ratter *et al*. 1997). It is estimated that about 70% of the Cerrado is suitable for agriculture and this area is rapidly being converted to mechanized agricultural management (Bahia and Lopes 1998).

The Cerrado was pretty much intact until the 1960s, when most of the relevant economic activity was cattle ranching. During the 1970s, when new technologies and new varieties of plants (soybean, corn, rice, wheat, eucalyptus, and grasses for livestock) where introduced, the Cerrado became an important region for Brazilian agribusiness. More and more native areas were cleared to be converted into planted pastures (using African grasses) or croplands (Butler 2007b). It is estimated that the area of Cerrado has fallen from around 73% in 1985 to around 43% in 2004, and the area occupied by pastures and croplands has likely increased since then, given the substantial rise in Brazil's agricultural production and land prices, and pegs annual loss at 2.2 million hectares every year, or about 1.1% of the remaining Cerrado (Butler 2007b).

The Cerrado, considered as the world's most biologically rich savanna, is home for more than 10,000 species of plants (4400 of which are endemic), 847 species of birds, and almost 300 mammals, and a recent research indicates that the ecosystem provides important watershed services and plays an integral role in carbon cycling (Butler 2007b).

In a dramatic change of land use, the Cerrado is rapidly being replaced with crops and pasture. Over the past 35 years, more than half of the Cerrado's original expanse has been taken for agriculture with the active encouragement of the Brazilian government (Ratter *et al*. 1997). It is now among the world's top region of beef and soybean production (Marris 2005).

Only 2.2% of the Cerrado is protected, and it is losing soils faster than the Amazon. At the current rate of loss, the ecosystem could be gone by 2030, according to estimates of Conservation International in Washington. Yet the Cerrado has little of the global recognition advocacy that has helped advance the cause of conservation in the Amazon. Brazil's Forest Code (www.senado.gov.br) requires owners of Amazon land to set aside 80% as a reserve. In the Cerrado, the requirement is just 20%, and the enforcement is poor. Agriculture is one of the largest and most dynamics impacts of Brazil's economy and those working to save the Cerrado are unlikely to be able to slow or stop the expansion of this sector. For a while, clearing of savanna was encouraged by the government, because it eased development pressure on the Amazon (Marris 2005).

Agricultural practices are often seen as a primary cause of the disappearance of the remaining forest by well-intentioned conservationists, and are frequently viewed as a wasteful and destructive technique (Brady 1996; Piperno and Pearsal 1998).

In the past, the Cerrado domain was sparsely populated by Brazilian county people (backwoodsmen and Indians). Much of it was so remote that it only became incorporated into modern Brazilian life relatively recent, with construction of railways and roads. The population practiced little more than subsistence agriculture based largely on low density cattle-grazing in the Cerrado vegetation, raising small crops in clearings in the gallery or deciduous forest, charcoal-burning (if there was an accessible market), and some hunting and fishing (Ratter *et al*. 1997). The native vegetation provides materials for housing (timber, palm thatch, etc), seasonal fruits, fiber, firewood and many other products for the rural economy.

The extent of alteration in soil chemical properties of cleared native Cerrado for agricultural use is dependent on the subsequent management. Compared to undisturbed native Cerrado no-tillage agricultural production decrease potential acidity and increase soil pH, available P, exchange cations and base saturation, especially due to the absence of lime application (Carvalho *et al*. 2007). Those land use changes have the potential to degrade native chemical soil characteristics that are inherently low in fertility, but when managed properly have a great agricultural potential (Carvalho *et al*. 2007).

Nevertheless, not everyone agrees that clearing of the Cerrado is a problem. Butler (2007b) presented different opinions like those who think that environmental groups should be happy that growth of Brazilian agriculture is concentrated in the Cerrado rather than the Amazon rainforest; or that in less than a generation the Cerrado has helped Brazil become the world's largest exporter of beef, cotton, and sugar, among other products; or another point of view like landowners in the region have seen their land values double every 4-5 years in areas that just decades ago were wild lands (Butler 2007b).

Studies dealing with soil transformations followed by different land use practices after Cerrado clearing are crucial for selection of the most adequate management system in order to rehabilitate soil efficiency.

Caatinga

Between the Amazon and Atlantic Forest is located an ecosystem of the regions of Brazil with the lowest availability of edaphic water, called 'caatinga', a South-American Indian name that means 'white forest', because most of the vegetation has a white or silver aspect - xerophytic and dry forest due to the deciduous habit of the species (**Fig. 4**), but well adapted to support the deficiency of water (Rodrigues 2008).

It covers an area of 834,666 km^2 of the Northeast Brazil, almost 10% of the national territory, encompassing the states of Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Sergipe, Alagoas, Bahia, south and east of Piauí and north of Minas Gerais (Andrade-Lima 1981). The caatinga as a whole correspond to 80% of the 'Polígono das Secas' (drought polygon), inhabited by approximately 28 million people and corresponding to the largest demographic semi-arid area of the world located in a single country (Batista Filho and Batista 1996) of which 38% live in agricultural areas (Castro 2008). The caatinga is conditioned by the BSH Koeppen's climate, with a high evapotranspiration potential (1500-2000 mm annually) all over the year and low

Fig. 4 Caatinga vegetation in the State of Ceará, Northeast Brazil.

Table 1 Total and rural population in the semiarid in 1991, firewood and charcoal production in 1989*, and degraded areas in the northeast Brazil in 1994**.

State	Population (10^6)		Firewood (10^6 m^3)	Charcoal (10^3 Mg)	Degraded areas (10^3 km^2)			
	Total	Rural			VS	S-MS	S	M
Piaui (PI)	2.6	1.2	1.73	6.3	5.9	0.5	7.9	0.6
Ceará (CE)	6.3	2.2	12.16	49.9	42.5	8.8	5.1	20.6
Rio Grande do Norte (RN)	2.4	0.7	5.36	23.4	9.0	1.4	2.6	6.0
Paraiba (PB)	3.1	1.1	1.90	22.5	21.1	6.9	3.0	4.3
Pernambuco (PE)	3.4	1.6	2.81	70.1	16.3	7.2	1.5	-
Alagoas (AL)	0.9	0.5	1.30	6.4	0.9	-	-	-
Sergipe (SE)	0.5	0.3	0.87	6.4	2.7	-	-	-
Bahia (BA)	5.8	3.2	20.36	136.3	20.3	6.7	1.6	-
TOTAL	25.0	10.8	46.49	320.3	118.7	31.6	21.8	31.5

* Gondim (1994); ** Sá *et al.* (1994). VS: Very strong, S: Strong, M: Moderate

precipitation (300-1000 mm annually), usually concentrated in 3-5 months (Reddy 1983). It is the only biome exclusively Brazilian, meaning that part of its biodiversity is not found at any other place but the Northeast Brazil (Ambiente Brasil 2007).

According to Sampaio (1995), the flora is little known, but includes species of trees and shrubs, being *Leguminosae*, *Euphorbiaceae* and *Cactaceae* the families with the higher number of species. The caatinga vegetation does not form a homogeneous structural and floristic complex, but varies according to several factors as soil, xerothermic index, physiognomy and genera characteristic (Sampaio 1995). Regarding only shrub vegetation, botanists have already identified almost 600 species of a total of 1354 species, all of them with an ecological importance. For example, there are always some species flowering or with fruits even during the dry season assuring the feeding for bees or other insects or wild animals in general. But the pristine caatinga was higher, more closed and with more biodiversity than the one that is found nowadays. This is a direct consequence of human activities that led the current caatinga to become poor, devastated, more open and smaller, thinner, and with less species in comparison to the pristine state (Maia 2004). Nonetheless, there are yet innumerable interactions between the caatinga live beings allowing the subsistence of the biome even under unfavorable conditions.

The demand for natural resources is very high due to the poverty and lack of alternatives by the local population. The vegetation is the main natural resource explored as a source of income. Hunting wild animals and burning the areas used for agricultural production are promoting the reduction of habitats, leading to the processes of land degradation and desertification, which represent the main threats to biodiversity conservation in the semi-arid zone (Castro 2008). In the last 15 years, 40,000 km^2 of caatinga have being transformed into deserts due to anthropogenic action. Another significant problem is the water contamination by agrotoxics (Ambiente Brasil 2007).

The caatinga is covered by relatively fertile soils, but in some areas there are soil P and N deficiencies. The conversion of caatinga for crops or grass production is concentrated in the region regardless of the irregularity of the precipitation which occurs most of the year. However, it does not present a potential for wood extraction compared to other areas such as the Amazon forest (Menezes and Sampaio 2000).

Changes in land use increases C and N losses (up to 50%) and the conversion of organic P into inorganic P (Tiessen *et al.* 1992; Fraga and Salcedo 2004), besides favoring the erosion processes as stated in some experiments by Albuquerque *et al.* (2001) and Fraga and Salcedo (2004). In another experiment, Bernardi *et al.* (2007) determined that stocks of soil organic carbon (SOC) and N under secondary forest in the 0-0.4 m layer were 27.6 and 2.4 Mg ha^{-1}, respectively, and decreased to 5 to 23% and 4 to 21% on soil C and N stocks respectively, after forest clearing and fruit orchard cultivation.

Those losses are mainly due to lack of fertilizer application, soil erosion, nutrient leaching and organic residues burning to prepare the soil (Sampaio *et al.* 1995). The inorganic fertilization is hardly practiced, since it can not afforded by small-scale farmers.

The substitution of native vegetation for itinerant agriculture, which uses fire to clean the areas after felling, is particularly harmful in relation to soil C and N losses. The increase of soil temperature does not induce instant losses (Kauffman *et al.* l993) but may affect the soil organic matter stability. A profitable soil use of the non-agricultural areas in the semiarid region in general, is felling the natural vegetation for firewood and charcoal production. Some people might think that this is not representative, but considering that the vegetation takes 10-15 years to recover >90% of the original biomass, the effect is comparable to affect more and bigger areas. Together with agricultural production these practices are responsible for the most devastated areas in the Northeast, corresponding to 53% in Ceará, 66% in Rio Grande do Norte, 49% Paraíba and 55% in Pernambuco states, increased 5, 21, 9 and 10% respectively, in the 1970s and 1980s (PNUD-FAO-IBAMA 1992).

The State of Ceará is considered one of the most degraded states of the Northeast of Brazil, with almost 30% of its land classified as very strong degraded (**Table 1**). These values correspond to 77,000 km^2 out of 148,016 km^2. Most of this area is located in the semi-arid region, and is dominated by Luvisols, Planosols and Litolithic Neosols (Sá *et al*. 1994).

PLANT RICHNESS AND SOIL CARBON IN TROPICAL FOREST SYSTEMS

The plant richness found in the Cecropia second growth (126 species and morphospecies) is high compared to other regenerating sites in Amazon. Uhl (1987) found as many as 24 species growing in an 8-year-old second growth following pasture abandonment. Uhl *et al*. (1982) found only nine species growing in much younger (16 months since fallow) second growth established after cassava (*Manihot esculenta*) cultivation for 3 years. The number of woody species found in secondary forests of Manaus, State of Amazon, is among the highest reported (Brown and Lugo 1990), with the exception of two sites, one in Nigeria (Hall and Okali 1979) and one in Puerto Rico (Birdsey and Weaver 1982). The recovery of species richness in the 10-year-old Cecropia second growth forest suggest that this logged system did not lose its ability to regenerate and had better recovery ability than other areas cut and used for shifting cultivation and pastures in the region. Elsewhere, Mesquita (1995) showed that biomass recovery was also higher in this system than in areas used for shifting cultivation and pastures.

The effects of deforestation include greenhouse gases emissions, losses of biodiversity, losses of cultural diversity, degradation of land and water resources and possible impacts on the regional climate.

The forest plots store 200 t ha^{-1} C, with 75% in living trees aboveground, 16% in the form of organic soil C and

Table 2 Deforestation (ha) and estimated tons of carbon released into the atmosphere, Theobroma, State of Rondônia - Brazil, 1973-1993

Year	Area deforested (ha)	% of total area	C released (million t)
1973	1690	0.8	0.25
1978	6810	3.0	1.0
1987	54600	25.0	8.2
1993	93200	43.0	14.0

Adapted from Fujisaka *et al.* (1998)

4% in the roots. With slashing and burning (for annual crop production) C declined to a total 76% t ha^{-1}, with 45% in the form of soil organic C, 38% in the form of standing or fallen dead logs and 7% in the roots (**Table 2**) (Fujisaka *et al.* 1998).

It should be stressed that following deforestation, large amounts of C are also lost from biomass, much of which is emitted to the atmosphere as CO_2.

According to Dias Filho *et al.* (2001), forest to pasture conversion releases 100-200 Mg C ha^{-1} from above ground forest biomass to the atmosphere. Thus the loss of forest area in the scenario represents a total additional loss of C from above ground biomass of 8000 Tg between 1990 and 2030 (Cerri *et al.* 2007).

Carbon sequestration is now a recognized forest management strategy with enormous economic implications, due primarily to the advent of "carbon credits".

The current tropical land-use have a significant impact on the global C cycle through increased rates of C emissions to the atmosphere and the loss of above – and below-ground C accumulation and storage capacity. Current estimates suggest that approximately 1.6 (±0.5) Pg (petagram = 10^{15} g) of C are lost annually from the conversion of tropical forest to agricultural land (Brown *et al.* 1996). In their aboveground biomass, secondary forest accumulates approximately 94 Mg C ha^{-1} (30 years old and 20 m high) (Puig 2005). Tropical secondary forests that typically occur on land abandoned due to low soil fertility (Brown and Lugo 1990) have been reported to accumulate up to 5 Mg C ha^{-1} y^{-1} during the first 10 to 15 years of re-growth (Brown and Lugo 1990). Rates of aboveground C accumulation in plantations range from 0.8 to 15 Mg C ha^{-1} y^{-1}, during the first 26 years following establishment (Lugo 1988). Globally, tropical secondary forest reclaimed a sixth of all primary forest that were clear-cut in the 1990s (Wright 2005), while the coverage of tree plantations in the tropics increased from ~17.8 Mha in 1980 to ~70 Mha in 2000 (Brown 2000; FAO 2001), 50% of which were dominated by *Eucalyptus* species (Evans and Turnbull 2004). Secondary vegetation establishes itself through four main processes: 1) regeneration of remnant individuals, 2) germination from the soil seed bank, 3) spouting from cut or crushed roots and stems, and 4) dispersal and migration of seed from other areas (Tucker *et al.* 1998). In addition, farmers' land use decision (such as clearing size, clearing procedures, frequency and duration of use and crops) influence their establishment and the pathways of secondary succession. At the regional scale, soil fertility and land use history are the critical factors influencing the rate of forest re-growth (Tucker *et al.* 1998). On the other hand, primary forests plots have low levels of anthropogenic influence (although a few stems of fiber in the genera *Manilkara* and *Dinizia* were felled 30-40 years ago for latex or wood). All secondary and plantation sites were cut, burned and bulldozed between 1970 and 1980. Plantations are felled for cellulose production at 6-7 years, and fallow lands are frequently converted back to plantations after 20 years (Barlow *et al.* 2007).

Soil organic matter quantity and distribution are affected by soil tillage. When crop residues remain on the soil surface, the oxidation rate of organic matter is reduced and soil organic matter accumulates at the soil surface (Six *et al.* 1998). However, differences in soil organic C (SOC) and total N between tillage treatments diminished 5 cm below the surface. Soil organic C does not always change rapidly upon conversion to a different soil management regime, especially in arid or cold climate where organic matter turnover is slow (Franzluebbers and Arshad 1996).

In the Brazilian Amazon, areas that have been converted from pasture to agriculture are mainly cropped with soybean, associated with cover crop (usually millet) and cultivated under conventional tillage during the first 1-2 years before moving to a no tillage system. Conversion of native vegetation to cultivated cropland under a conventional tillage system has resulted in a significant decline in soil organic matter content (Paustian *et al.* 2000; Lal 2002). Farming methods that use mechanical tillage, such as the mouldboard plough for seedbed preparation or disking for weed control, can promote soil C loss by several mechanisms, they disrupt soil aggregates, which physically protects soil organic matter from decomposition (Karlen and Cambardella 1996; Six *et al.* 1999); they stimulate short-term microbial activity enhancing aeration, resulting in increased emissions of CO_2 and other radioactively active gases to the atmosphere (Bayer *et al.* 2000a, 2000b; Kladivko 2001); and they mix fresh residues into the soil where conditions for decomposition are often more favorable than on the surface (Karlen and Cambardella 1996). Furthermore, tillage can make soils more prone to erosion, resulting in further loss of soil C (Lal 2002). Conversely, no tillage practices cause less soil disturbance, often resulting in significant accumulation of soil C (Sa *et al.* 2001) and consequent reduction of gas emissions (especially CO_2) to the atmosphere (Lal 1998). However, there is considerable evidence that the main impact occurs on the topsoil with little overall effect on C storage in deeper layers (Six *et al.* 2002).

Land use changes usually alter land cover and terrestrial C stocks (Bolin and Sukumar 2000). The change from one ecosystem to another can occur naturally or through human activity. Anthropogenic changes are prominent in tropical rainforest, which is a diverse and complex ecosystem occupying approximately 17% of the worlds land area and is a habitat for about 40-50 % of earth's species (Meyers 1981).

Tropical rainforests represent significant sources/sinks of trace gases and the exchange of CO_2 between forest and the atmosphere and are an important component of the global C cycle (Cerri *et al.* 2007).

Due to the adoption of no tillage systems, SOC stocks are projected to increase under soybean cultivation in the period of 2030. Estimates of SOC stocks in the Brazilian Amazon are presented in **Table 3**. There are no estimates for SOC stock change rate or SOC stocks for soybean in the year 1990; the area of agricultural expansion was dominated by SOC stock class of 20-40 Mg C ha^{-1}. In the year 2000, some areas began to be cultivated with soybean and finally in 2030, most of this region is projected to move to a higher class of SOC stock (40-60 Mg C ha^{-1}) (Cerri *et al.* 2007).

Pastures have the potential to reintroduce large amounts of organic matter into the soil (Rezende *et al.* 1999; Guo and Gifford 2002). Increased soil C concentrations on surface horizons are a common consequence of pasture formation after forest clearance in the Amazon basin (Moraes *et*

Table 3 Estimates of soil organic carbon (SOC) stocks in the Brazilian Amazon obtained from different studies.

Source	Soil depth (cm)	SOC stocks (Pg)
Moraes *et al.* (1995)	0-20	21
Batjes and Dijkshoorn (1999)	0-30	25
Bernoux *et al.* (2002)	0-30	22.7 ± 2.3
Batjes (2005)	0-30	23.9 - 24.2
GEFSOC project [a]		
Century	0-20	32.6
Roth C	0-20	27.0
IPCC	0-30	26.9

[a] Estimates for the year 2000 and includes land use changes and management practices. Adapted from Cerri *et al.* (2007)

Table 4 Carbon stocks in soils under land uses in steady state landscapes

Soil layer (cm)	**C stock in soil** (T C ha^{-1})[a]						
	Forest	**Farmland**[b]	**Productive pasture**	**Degraded pasture**[c]	**Secondary forest from agriculture**[d,e]	**Secondary forest from pasture**[d,f]	**Equilibrium landscape**
0-20	42.0	27.3	35.2	34.5	36.8	39.1	36.6
20-100	52.0	42.5	47.7	46.4	52.0	52.0	49.4
100-800	142.8	142.2	142.0	142.2	142.7	142.6	142.3
Total (0-800)	236.8	212.1	224.9	223.2	231.6	233.7	228.4

[a] Stock in layer compacted from specified depth of forest soil; no compaction is assumed to occur below 20 cm depth.
[b] Assumes 35% reduction in the 0–30 cm layer, this being the midpoint of the 20–50% range reported by Sombroek *et al.* (1993).
[c] Assumed same as pasture under 'typical management'.
[d] Secondary forests are assumed to recover soil carbon stocks characteristic of mature forests in a linear fashion over a period of 15 yr.
[e] Average age of secondary forest derived from agriculture is 3.2 yr. Fearnside (1996)
[f] Average age of secondary forest derived from pasture is 3.9 yr. Fearnside (1996)

al. 1996; Neill *et al.* 1997). Moraes *et al.* (1996) found that total soil C contents of a 30 cm layer from a 20 year old pasture were 17-20% larger than in the original forest sites of the Western part of the Amazon.

Carbon below 1 m depth has traditionally been considered as inert and presumed to be unaffected by changes in land use (Fearnside and Barbosa 1998). The conversion of forest to pasture causes net releases of carbon (mostly from biomass) in the form of CO_2, in addition to trace gases (Fearnside 1997).

Recent studies in the Amazon have found pasture burning to cause no significant instantaneous changes of C in the upper soil layer (Fearnside and Barbosa 1998). The instantaneous release of soil C at the time of burning is followed by establishment of a new equilibrium over the medium to the long term. Studies of medium and long term changes (>1 year) indicate mixed results on increases or decreases of soil C when tropical forest are converted. Conversion of forest to pasture reduces the water storage capacity of the soil (Chauvel *et al.* 1991) and confines the distribution of C inputs C from the roots to the surface layers (Nepstad *et al.* 1994).

When conversion of forest to pasture results in a new equilibrium with lower soil C stocks, the losses occur in small amounts over the time (Davidson *et al.* 1993; Barbosa 1994). These losses can occur due to incomplete substitution of the organic C source that had been provided by the forest. Although pastures provide a strong source of soil C, these inputs are not enough to compensate for losses of initial forest soil C (Desjardins *et al.* 1994).

Over the long term, global calculations have shown losses of C stocks when forests are converted to other land uses (Fearnside and Barbosa 1998).

The management quality of tropical pastures is critical to the conclusions drawn about whether the soils under this land represent a source or a sink of atmospheric C. In well managed pastures in formerly forested areas, the root system of the pasture grass can redistribute C to deeper layers, where it is less susceptible to decomposition. Unfortunately, the vast majority of cattle pastures in Brazilian Amazon are poorly managed: grass productivity declines within a decade, regardless of whether the pastures are on formerly forested or on former savanna land (Fearnside and Barbosa 1998). Following deforestation, each point in the landscape will pass through periods under a variety of land uses, such as agriculture, pasture and secondary forest. The deforested area as a whole will eventually approach an equilibrium landscape (**Table 4**) and assuming that land use behavior patterns remain unchanged, would consist of 4.0% farmland, 43.8% productive (actively used) pasture, 5.2% degraded pasture, 2.0% secondary forest from agriculture and 44.9% secondary forest from pasture (Fearnside 1996).

FINAL REMARKS

To lessen future forest losses we must increase and sustain the productivity of farms, pastures, plantations, and scrubland in addition to restoring species and ecosystems to degraded habitats. Brazil is a land of remarkable beauty and incomparable biological diversity, for this reason, deforestation is especially troubling. While environmental losses and degradation of the forest lands have yet to reach the point of collapse, the continuing disappearance of wild lands and loss of its species is disheartening. We must not only be concerned with the transformation of existing natural ecosystems, but also impose a rational utilization of already cleared and degraded areas.

Brazil, with highly diverse biomes ranging from evergreen tropical rain forests to semi-arid ecosystems, all conspire to make it one of the top mega diversity countries. But, over about 20 years, this large, exotic, and diverse region of South America has lost perhaps as much as 18% of its area, almost 400 000 km^2, to human activities, such as farming, wood production, logging, and mining.

The government has always special interest in the preservation of the natural areas, and it has financially supported different projects with this aim. Examination of the location of Brazilian protected areas reveals that their creation started in the populated and industrialized southeast region, in the division of São Paulo-Minas Gerais and Rio de Janeiro States, and only after 1960, due to the expansion of urbanization and agricultural frontier, that protected areas were created in other regions (Diegues 1994). In fact, most protected areas were designated in the period of military dictatorship (1964-86), and two major factors led to a systematic implementation of protected area policy: Firstly, the pressure of international organizations such as the World Bank and Inter-American Development Bank, which began to include environmental protection clauses as a condition of loans for large development projects, and secondly, military interest to kept sovereignty and national security of frontier regions (Abaquerli 2001).

In the last few decades, a concern about the quality of Brazil's agriculture productive in terms of environmental aspects (agro ecosystems) has greatly influenced the adoption of different strategies for environmental conservation called "conservationist cropping systems" that are based on lower soil disturbance and leaving plant residue on soil surface. Those "conservation cropping systems" most used by Brazilians farmers include no tillage systems that use direct seeding, green manure, minimum tillage and green harvesting (mainly for sugar cane) and are highly related to sustainable development (Christoffoleti *et al.* 2007). The two principles of sustainable development for the management of renewable resources are that harvest rates should not exceed regeneration rates and waste emission rates should not exceed natural assimilative capacities of the ecosystems, as these regenerative and assimilative properties should be regarded as natural capital (Daly 1990).

A long term ecological research program (B-LTER Program) sponsored by the National Research Council of Brazil (CNPq), was designed as a collaborative effort of scientists and graduate students working in different biogeographical regions throughout the country. The B-LTER was coordinated within the Integrated Ecological Program (IEP) of the National Research Council of Brazil (CNPq) and of

CAPES (Ministry of Education). The IEP, a network of 13 graduate programs in ecology and conservation dedicated to a common research agenda, was implemented during the period of 1996-2005, which was also responsible for the definition of regional and thematic priorities for ecological investigation (Barbosa *et al*. 1998).

In 2002, the government became concerned with both agrarian development and the environment protection and designed a three-step strategy to address this issue: First, launched an extensive program to review the ownership documents for land contracts in the Amazon region. Second, as a result of this program, were cancelled the title deeds of 3065 rural properties larger than 10,000 hectares, totaling 93 million hectares. Finally, and considering only federal areas, the National System for Conservation Units - SNUC withholds 168 conservation units, corresponding to 5.64% of the Brazilian territory equal to 48.03 million hectares or 480.3 thousand km^2, being 89 for indirect use (not shifted) and 79 for direct use. The classified conservation units as of indirect use are: 39 National Parks, 24 Biological Reserves, 21 Ecological Stations and 5 Ecological Reserves; and of direct use are: 9 National Reserves, 46 Forests and 24 Environmental Protection Areas (APAs). These are areas under the protection of the Brazilian Environmental and Renewable Natural Resources Institute (IBAMA – www.ibama.gov.br) for sustainable use. These reserves are important for maintaining the biodiversity of the region. Even that, Brazil's efforts to conserve the Cerrado, Caatinga, and Mata Atlantica date only to the last 5 years or so.

A prerequisite to any program to slow deforestation is that the causes driving it must be understood. Our knowledge of deforestation process is still vague; contributions to better understanding the process therefore represent a key area in which effort is needed in order to avoid forest loss and consequent greenhouse gas emissions. We can conclude that the resilence of a devastated area can be done in a simple but efficient way, always considering the natural recovering processes. In areas strongly devastated, this process should begin with the re-introduction of native species that are conditioned to support unfavorable environmental conditions, as soil compaction, saline soils, low water availability and so on. Stimulating and applying those processes, we can assure the success of restoration and optimization of the production, stability and sustainability of natural ecosystems.

ACKNOWLEDGEMENTS

We thank José Renato César and Eduardo de Sá Mendoça who helped revising the manuscript.

REFERENCES

Abaquerli S (2001) A critique of development and conservation policies in environmentally sensitive regions in Brazil. *Geoforum* **32**, 551-565

Adámoli J, Macêdo J, Azevedo LG, Netto JM (1987) Caracterização da região dos Cerrados. In: Goedert WJ (Ed) *Solos dos Cerrados – Tecnologias e Estratégias de Manejo*, Nobel e Embrapa, São Paulo e Brasília, pp 33-74

Adams C, Motta RS da, Ortiz RA, Reid J, Aznar CE, Sinisgalli PAA (2007) The use of contingent valuation for evaluating protected areas in the developing world: Economic valuation of Morro do Diabo State Park, Atlantic Rainforest, São Paulo State (Brazil). *Ecological Economics* in press

Albuquerque AW, Lombardi Neto F, Srinivasam VS (2001) Efeito do desmatamento da caatinga sobre as perdas de solo e água num Luvissolo em Sumé (PB). *Revista Brasileira da Ciência do Solo* **25**, 121-128

Ambiente Brasil (2007) *Caatinga*. Available online http://www.ambientebrasil.com.br/composer.php3?base=./natural/index.html&conteudo=./natural/biomas/caatinga.html

Anderson A (1990) Deforestation in Amazônia: dynamics, causes, and alternatives. In: Anderson AB (Ed) *Alternatives to Deforestation: Steps Towards Sustainable Use of the Amazon Rain Forest*, Columbia University Press, New York, pp 3-23

Andrade-Lima D (1981) The caatingas dominion. *Revista brasileira de Botânica* **4**, 149-153

Bahia AFC, Lopes MA (1998) State of the art-developing grain cultivars for acid savannas of Brazil. In: Schaffert RE (Ed) *A Workshop to Develop a Strategy for Collaborative Research and Dissemination of Technology in Sustainable Crop Production in Acid Savannas and Other Problem Soils of the World*, Purdue University, West Lafayette, IN, pp 27-45

Barbosa RI (1994) Efeito estufa na Amazônia: estimativa da biomassa e a quantificação do estoque e liberação de carbono na queima de pastagens convertidas de florestas tropicais em Roraima, Brasil. MSc Thesis, Instituto Nacional de Pesquisas de Amazônia and Universidade Federal do Amazonas, Manaus, Amazonas, Brazil, 85 pp

Barbosa FAR, Fonseca GAB, Cavalcanti RB, Fonseca MT (1998) The Brazilian long term ecological research program – present status and perspectives. In: *US LTER Network*, The international long term ecological research network, University of New Mexico, USA, pp 7-13

Barlow J, Gardner TA, Ferreira LV, Peres CA (2007) Litter fall and decomposition in primary, secondary and plantation forests in the Brazilian Amazon. *Forest Ecology and Management* **247**, 91-97

Bastos EGM, Araújo AFB, Silva HR (2005) Records of the rattlesnakes *Crotalus dirissus terrificus* (Laurenti) (Serpentes, Viperidae) in the State of Rio de Janeiro, Brazil: a possible case of invasion facilitated by deforestation. *Revista Brasileira de Zoologia* **22**, 812-815

Batista Filho M, Batista LV (1996) Alimentação e nutrição no nordeste semi-árido do Brasil. Situação e perspectivas. *Sitientibus* **15**, 287-289

Bayer C, Martin-Neto L, Mielniczuk J, Ceretta CA (2000a) Effect of no-till cropping systems on soil organic matter in a sandy clay loam Acrisol from southern Brazil monitored by electron spin resonance and nuclear magnetic resonance. *Soil and Tillage Research* **53**, 95-104

Bayer C, Mielniczuk J, Amado TJC, Martin-Neto L, Fernandes SV (2000b) Organic matter storage in a sandy clay loam Acrisol affected by tillage and cropping systems in southern Brazil. *Soil and Tillage Research* **54**, 101-109

Benhin J KA (2006) Agriculture and deforestation in the tropics: A critical theoretical and empirical review. *Ambio* **35**, 9-16

Bernardi CA, Machado C, Almeida PLO, Madari BE, Tavares LSR, Campos BDV, Crisóstomo AL (2007) Carbon and nitrogen stocks of an arenosol under irrigated fruit orchards in semiarid Brazil. *Scientia Agricola* **64**, 169-175

Bierregard Jr. RO, Laurance WF, Gascon C, Benitez-Malvido J, Fearnside PM, Fonseca CR, Ganade G, Malcolm JR, Martins MB, Mori S, Oliveira M, Rankin-de Mérona J, Scariot A, Spironello W, Willianson B (2001) Principles of forest fragmentation and conservation in the Amazon. In: Bierregaard Jr. RO, Gascon C, Lovejoy TE, Mesquita RCG (Eds) *Lessons from Amazonia: The Ecology and Conservation of A Fragmented Forest*, Yale University Press, New Haven, USA pp 371-385

Birdsey RA, Weaver PL (1982) *The Forest Resources of Puerto Rico*, SO-85, US Department of Agriculture Forest Service, Southern Forest Experiment Station, New Orleans, LA, USA, 59 pp

Bolin B, Sukumar R (2000) Global perspective. In: Watson RT, Noble IR, Bolin B, Ravindranath NH, Verardo DJ, Dokken DJ (Eds) *Land Use, Land Use Change, and Forestry*, Cambridge University Press, Cambridge, UK, pp 23-51

Brady NC (1996) Alternatives to slash-and-burn: a global imperative. *Agriculture Ecosystems and Environment* **58 (1)**, 3-11

Breman H, Kessler JJ (1997) The potential benefits of agroforestry in the Sahel and other semi-arid regions. *European Journal of Agronomy* **7**, 25-33

Brown C (2000) The global outlook for present and future wood supply from forest plantation. Working Paper No. GFPOS/WP/03, FAO, 146 pp

Brown S, Lugo AE (1990) Tropical secondary forests. *Journal of Tropical Ecology* **6**, 1-32

Brown SJ, Cannell SM, Kauppi PE (1996). Mitigation of carbon emissions to the atmosphere by forest management. *Commonwealth Forestry Review* **75**, 80-91

Butler RA (2007a) Amazon Destruction: Why is the rainforest being destroyed in Brazil? Available online: http://rainforests.mongabay.com/amazon/amazon_destruction.html

Butler RA (2007b) Biofuels driving destruction of Brazilian Cerrado. Available online: http://news.mongabay.com/2007/0821-Cerrado.html

Cambardella CA, Elliott ET (1992) Particulate organic matter changes across a grassland cultivation sequence. *Soil Science Society of American Journal* **56**, 777-783

Cardille J A, Foley JA (2003) Agricultural land-use change in Brazilian Amazônia between 1980 and 1995: Evidence from integrated satellite and census data. *Remote Sensing of Environment* **87**, 551-562

Cardoso MA, Provan J, Powell W, Ferreira PCG, de Oliveira DE (1998) High genetic differentiation among remnant populations of the endangered *Caesalpinia echinata* Lam. (Leguminosae-Caesalpinioideae). *Molecular Ecology* **7**, 601-608

Carvalho JLN, Cerri CEP, Cerri CC, Feigl BJ, Píccolo MC, Godinho VP, Herpin U (2007) Changes of chemical properties in an Oxisol after clearing of native Cerrado vegetation for agricultural use in Vilhena, Rondonia State, Brazil. *Soil and Tillage Research* **96**, 95-102

Castro R (2008) Reservas privadas do bioma caatinga. Abstract. Available online: http://www.sbpcnet.org.br/livro/57ra/programas/CONF_SIMP/textos/rodrigocastro.htm

Ceccon E, Miramontes O (2008) Reversing deforestation? Bioenergy and society in two Brazilian models. *Ecological Economics* in press

Cerri CEP, Easter M, Paustian K, Killian K, Coleman K, Bernoux M,

Falloon P, Powlson DS, Batjes NH, Milne E, Cerri CC (2007) Predicted soil organic carbon stocks and changes in the Brazilian Amazon between 2000 and 2030. *Agriculture, Ecosystems and Environment* **122**, 58-72

Chauvel A, Grimaldi M, Tessier D (1991) Changes in pore-space distribution following deforestation and revegetation: An example from the Central Amazon Basin, Brazil. *Forest Ecology and Management* **38**, 247-257

Christoffoleti PJ, Carvalho SJP, López-Ovejero RF, Nicolai M, Hidalgo E, Silva JE (2007) Conservation of natural resources in Brazilian agriculture: Implications on weed biology and management. *Crop Protection* **26**, 383-389

Daly HE (1990) Toward some operational principles of sustainable development. *Ecological Economics* **2**, 1-6

Davidson EA, Nepstad DC, Trumbore SE (1993) Soil carbon dynamics in pastures and forests of the eastern Amazon Abstract. *Bulletin of the Ecological Society of America* **74**, 208

Dean W (1996) *A Ferro e Fogo. A História e a Devastação da Mata Atlântica Brasileira*, Companhia das Letras, São Paulo, 48 pp

Desjardins T, Andreux F, Volkoff B, Cerri CC (1994) Organic carbon and ^{13}C contents in soils and soil size-fractions, and their changes due to deforestation and pasture installation in Eastern Amazonia. *Geoderma* **61**, 103-118

Dias-Filho MB, Davidson EA, Carvalho CJR (2001) Linking biogeochemical cycles to cattle pasture management and sustainability in the Amazon basin. In: McClain ME, Victoria RL, Richey JE (Eds) *The Biogeochemistry of the Amazon Basin*, Oxford University Press, New York, pp 84-105

Diegues ACS (1994) *O Mito Moderno da Natureza Intocada*, NUPAUB/USP, São Paulo, Brazil 163 pp

Evans J, Turnbull J (2004) *Plantation Forestry in the Tropics*, Oxford University Press, Oxford, 488 pp

FAO (2001) *Global Forest Resources Assessment 2000*, Rome, Italy. Available at: www.fao.org/forestry

FAO (2002) World agriculture: towards 2015/2030. Food and Agriculture Organization of the United Nations, Rome, 97 pp

Fearnside PM (1996) Amazonian deforestation and global warming: carbon stocks in vegetation replacing Brazil's Amazon forest. *Forest Ecology and Management* **80**, 21-34

Fearnside PM (1997) Greenhouse gases from deforestation in Brazilian Amazonia: net committed emissions. *Climate Change* **35**, 321-360

Fearnside PM (1999) Forests and global warming mitigation in Brazil: opportunities in the Brazilian forest sector for responses to global warming under the "clean development mechanism". *Biomass and Bioenergy* **16**, 171-189

Fearnside PM, Barbosa RI (1998) Soil carbon changes from conversion of forest to pasture in Brazilian Amazon. *Forest Ecology and Management* **108**, 147-166

Feehan J (2001) Wild and flora in Irish Agro-ecosystems: a practical perspective on indicators selection. In: OECD, *Expert meeting on Agri-Biodiversity indicators. Group 2-A. Wild species dependent or impacted by agricultural activities*, Zurich, Switzerland, 15 pp

Flechet G (2007) Refugia of the Brazilian Atlantic rainforest could be the basis for its regeneration. Available at: http://news.mongabay.com/2007/0906-atlantic_forest.html

Fraga VS, Salcedo IH (2004) Declines of organic nutrient pools in tropical semi-arid soils under subsistence farming. *Soil Science Society of America Journal* **68**, 215-224

Franzluebbers AJ, Arshad MA (1996) Soil organic matter pools during early adoption of conservation tillage in northwestern Canada. *Soil Science Society of America Journal* **60**, 1422-1427

Fujisaka S, Escobar G, Veneklaas E (1998) Plant community diversity relative to human land use in an Amazon colony. *Biodiversity and Conservation* **7**, 41-57

Torrico JC, Gaese H, Janssens MJJ, Schluter S, Kretschmer N (2005) Agriculture and Biodiversity in Fragmented Landscapes of the Atlantic Rainforest of Rio de Janeiro. Tropentag 2005. In: Tielkes E, Hulsebusch C, Hauser I, Deininger A, Becker K (Eds) *International Research on Food Security, Natural Resource Management and Rural Development. The Global Food & Product Chain –Dynamics, Innovations, Conflicts, Strategies*. Deutscher Tropentag, University of Hohenheim, Stuttgart. Available online: http://www.tropentag.de/2005/proceedings/node3.html

Gondim Filho JGC (1994) Sustentabilidade do desenvolvimento do semi-árido sob o ponto de vista dos recursos hídricos. Uma estratégia de desenvolvimento sustentável para o Nordeste. Projeto Áridas, Brasília, 126 pp

Groombridge B, Jenkins MD (1996) Assessing biodiversity status and sustainability. WCMC Biodiversity Series N° 5. World Conservation Monitoring Centre, United Kingdom, 104 pp

Guo LB, Gifford RM (2002) Soil carbon stocks and land use change: a meta analysis. *Global Change Biology* **8**, 345-360

Hall JR, Okali DUU (1979) A structural and floristic analysis of woody fallow vegetation near Ibadan, Nigeria. *Journal of Ecology* **67**, 321-346

Harris LD, Silva-López G (1992) Forest fragmentation and the conservation of biological diversity In: Fiedler PL, Jain SK (Eds) *Conservation Biology: The Theory and Practice of Nature Conservation, Preservation and Management*, Chapmand and Hall, New York, pp 197-237

Hetch S (1985) Environment, development and politics: capital accumulation and the livestock sector in Eastern Amazonia. *World Development* **13**, 663-684

Houghton RA (1991) Tropical deforestation and atmospheric carbon dioxide. *Climate Change* **19**, 99-118

Houghton RA, Skole DL, Nobre CA, Hackler JL, Lawrence KT, Chomentowski WH (2000) Annual fluxes of carbon from deforestation and regrowth in the Brazilian Amazon. *Nature* **403**, 301-304

Hoynck S, Gaese H, Morawetz W (2003) Farming systems and regional natural and economic stability issues in the Mata Atlantica, Brazil. In: Wollny C, Deininger A, Bhandari N, Maass B, Manig W, Muuss U, Brodbeck F, Howe F (Eds) *International Research on Food Security, Natural Resource Management and Rural Development*. Deutscher Tropentag, Georg August Universitat, Gottingen, Available online: http://www.tropentag.de/2003/proceedings/node3.html

Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renovávei s -IBAMA (2002) Relatório perspectivas do meio ambiente no Brasil. Capítulo 2. Estado do Meio Ambiente. Available online: http://ibama2.ibama.gov.br/cnia2/download-nao-vale/publicacoes/geobr/docs/drafts/florestas.doc

Karlen DL, Cambardella CA (1996) Conservation strategies for improving soil quality and organic matter storage. In: Carter MR, Stewart BA (Eds) *Structure and Organic Matter Storage in Agricultural Soils. Advances in Soil Science*, CRC Press, Boca Raton, pp 395-420

Kauffman J B, Sanford RL, Cummings DL, Salcedo IH, Sampaio EVSB (1993) Biomass and nutrient dynamics associated with slash fires in neotropical dry forests. *Ecology* **74**, 140-151

Keller M, Melillo JM, de Mello WZ (1997) Trace gas emissions from ecosystems of the Amazon basin. *Ciência e Cultura* **49**, 87-97

Kelley DW, Nater EA (2000) Historical sediment flux from three watersheds into Lake Pepin, Minnesota, USA. *Journal of Environmental Quality* **29**, 561-568

Kladivko E (2001) Tillage systems and soil ecology. *Soil Tillage and Research* **61**, 61-76

Lal R (1998) Soil processes and the greenhouse effect. In: Lal R, Blum WH, Valentine C, Stewart BA (Eds) *Methods for Assessment of Soil Degradation*, CRC Press, Boca Raton, pp 199-212

Lal R (2002) Soil carbon dynamic in cropland and rangeland. *Environmental Pollution* **116**, 353-362

Laurance SGW (2004) Landscape connectivity and biological corridors. In: Schroth G, da Fonseca GAB, Harvey CA, Gascon C, Vasconcelos HL, Izac AMN (Eds) *Agroforestry and Biodiversity Conservation in Tropical Landscapes*, Island Press, Washington, D.C., pp 50-63

Laurance WF, Cochrane MA, Bergen S, Fearnside PM, Delamônica P, Barber C, D'Angelo S, Fernandes T (2001) The future of the Brazilian Amazon. *Science* **291**, 438-439

Lugo AE (1988) The future of the forest. Ecosystem rehabilitation in the tropics. *Environment* **30**, 16-20

Maia SMF, Xavier FAZ, Oliveira TS, Mendoça ES, Araújo Filho JA (2007) Organic carbon pools in a Luvissol under agroforestry and conventional systems in the semi-arid region of Ceará, Brazil. *Agroforest System* **71**, 127-138

Maia, GN (2004) *Caatinga: Árvores e Arbustos e Suas Utilidades*, D&Z Computação Gráfica e Editora, São Paulo, Brazil, 413 pp

Marris E (2005) The forgotten ecosystem. *Nature* **437**, 944-945

Menezes RSC, Sampaio EVSB (2000) Agricultura sustentável no semi-árido nordestino. In: Oliveira TS, Romero RE, Assis Jr RN, Silva JRCS (Org) *Agricultura, Sustentabilidade e o Semi-árido*, Sociedade Brasileira de Ciência do Solo, Viçosa, MG, pp 20-46

Mesquita RCG (1995) The effect of different proportions of canopy opening on the Carbon cycle of a central Amazonian secondary forest. PhD thesis, University of Georgia, Athens, Georgia, USA, total pp

Meyers N (1981) Conversion rates in tropical moist forests. In: Mergen F (Ed) *Tropical Forests Utilization and Conservation*, Yale University, New Haven, pp 48-66

Ministerio do Meio Ambiente (MMA) (2005) Plano de Controle e Prevenção ao Desmatamento. Secretaria de Biodiversidade e Florestas. Available online: http://www.mma.gov.br/doc/desmatamento2003_2004.pdf

Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB, Kent J (2000) Biodiversity hotspots for conservation priorities. *Nature* **403**, 853-858

Mittermeier RA, Myers N, Mittermeier CG (2000) *Hot Spots: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions*, Cemex and Conservation International, Mexico, 430 pp

Moraes JFL, Volkoff B, Cerri CC, Bernoux M (1996) Soil properties under Amazon forest change due to pasture installation in Rondônia, Brazil. *Geoderma* **70**, 63-81

Nail PKR, Buresh RJ, Mugendi DN, Latt CR (1999) Nutrient cycling in tropical agroforestry systems: myths and science. In: Buck LE, Lassoie JP, Fernandes ECM (Eds) *Agroforestry in Sustainable Agricultural Systems*, CRC Press, Boca Raton, FL, USA, pp 1-31

Neill C, Cerri CC, Melillo JM, Feigl BJ, Steudler PA, Moraes JFL, Piccolo MC (1997) Stocks and dynamics of soil carbon following deforestation for pasture in Rondonia In: Lal R, Kimble JM, Follett RF, Stewart BA (Eds) *Soil Processes and the Carbon Cycle*, CRC Press, Boca Raton, pp 9-28

Nepstad DC, Carvalho CR, Davidson EA, Jipp PH, Lefebvre PA, Negreiros GH, Silva ED, Stone TA, Trumbore SE, Vieira S (1994) The role of deep roots in the hydrological cycles of Amazonian forests and pastures. *Nature* **372**, 666-669

Nobre C A, Artaxo P, Becker A, Brown I F, Dolman H, Dunne T, Gash JH C, Grace J, Janetos AC, Kabat P, Keller M, Krug T, Marengo JA, McNeal RJ, Prince SD, Silva Dias PL, Tomasella J, Victoria RL, Vörösmarty CJ, Wickland DE (1997) Large scale biosphere-atmosphere experiment in Amazônia (LBA) extended science plan. *Cachoeira Paulista*, LBA Project Office, SP-Brazil, 44 pp

Paustian K, Six J, Elliott ET, Hunt HW (2000) Management options for reducing CO_2 emissions form agricultural soils. *Biogeochemistry* **48**, 147-163

Pimentel D (1993) *World Soil Erosion and Conservation*, Cambridge University Press, Cambridge, UK, 349 pp

Piperno DR, Pearsall DM (1998) *The origins of Agriculture in the Lowland Neotropics*, Academic Press, San Diego, CA, 400 pp

PNUD-FAO-IBAMA (1992) Plano de manejo florestal para a região do Seridó do rio Grande do Norte. Natal, IBAMA, 3 Vol, 322 pp

Puig CJ (2005) Carbon sequestration potential of land-cover types in the agricultural landscape of eastern Amazonia, Brazil. ZEF - *Ecology and Development Series* **33.** Cuvillier Verlag, Gottingen, Germany, 159 pp

Ranta P, Blom T, Niemelã J, Joensuu E, Siitinen M (1998) The fragmented Atlantic forest of Brazil: size, shape, and distribution of forest fragments. *Biodiversity and Conservation* **7**, 385-403

Ratter JA, Ribeiro JF, Bridgewater S (1997) The Brazilian Cerrado vegetation and threats to its biodiversity. *Annals of Botany* **80**, 223-230

Reddy SJ (1983) Climatic classification: the semiarid tropics and its environment - a review. *Pesquisa Agropecuaria Brasileira* **18**, 823-847

Rezende CP, Cantaruti RB, Braga JM, Gomide JA, Pereira JM, Ferreira E, Tarre R, Machado R, Alves BJR, Urquiaga S, Cadish G, Giller KE, Boddey RM (1999) Litter decomposition and disappearance in Brachiaria pastures in the Atlantic forest region of the South of Bahia, Brazil. *Nutrient Cycling in Agroecosystems* **54**, 99-112

Rodrigues UMT (2008) Meio ambiente, ecossistemas, caatinga. Available online: http://www.mre.gov.br/cdbrasil/itamaraty/web/port/meioamb/ecossist/caatinga/index.htm

Rosegrant MW, Paisner MS, Meijer S, Witcover J (2001) Global food projections to 2020: Emerging trends and alternative futures. International Food Policy Research Institute, Washington D.C., 206 pp

Sá IB, Fotius GA, Riché GR (1994) Degradação ambiental e reabilitação natural do Trópico Semi árido brasileiro. In: *Conferência Nacional e Seminário Latino-Americano da Desertificação*, ESQUEL, Governo do Ceará, Fortaleza, pp 310-332

Sá JCM, Cerri CC, Lal R, Dick WA, Venzke Filho SP, Piccolo MC, Feigl B (2001) Organic matter dynamics and carbon sequestration rates for a tillage chronosequence in a Brazilian Oxisol. *Soil Science Society of American Journal* **65**, 1486-1499

Sampaio EVSB (1995) Overview of the Brazilian caatinga. In: Bullock S.H., Mooney HA, Medina E (Eds) *Seasonally Dry Tropical Forests*, Cambridge University Press, New York, pp 35-63

Sampaio EVSB, Salcedo IH, Silva FBR (1995) Fertilidade de solos do semiárido do Nordeste. Reunião Brasileira de Fertilidade dos Solos e Nutrição das Plantas, 21, Petrolina, 1994. Anais do Simpósio: Fertilizantes: insumo básico para a agricultura e combate à fome. Petrolina, EMBRAPA-CPATSA/SBCS, pp 51-71

Schoups G, Hopmans JW, Young CA, Vrugt JA, Wallender WW, Tanji KK, Panday S (2005) Sustainability of irrigated agriculture in the San Joaquin Valley, California. *Proceedings of the National Academy of Sciences* USA **102**, 15352-15356

Schroth G, da Fonseca GAB, Harvey CA, Gascon C, Vasconcelos HL, Izac AMN (2004) *Agroforestry and Biodiversity Conservation in Tropical Landscapes*, Island Press, Washington DC, 523 pp

Sharrow SH, Ismail S (2004) Carbon and nitrogen storage in agroforests, tree plantations and pastures in western Oregon, USA. *Agroforestry Systems* **60**, 123-130

Six J, Elliot ET, Paustian K, Doran JW (1998) Aggregation and soil organic matter accumulation in cultivated and native grassland soils. *Soil Science Society of American Journal* **62**, 1367-1377

Six J, Feller C, Denef K, Ogle SM, Sa JCM, Albrecht A (2002) Soil organic matter, biota and aggregation in temperate and tropical soils – effects of no-tillage. *Agronomie* **22**, 755-775

Six J, Elliott ET, Paustian K (1999) Aggregate and soil organic matter dynamics under conventional and no-tillage systems. *Soil Science Society of American Journal* **63**, 1350-1358

Skole D, Tucker C (1993) Tropical deforestation and habitat fragmentation in the Amazon satellite data from 1978 to 1988. *Science* **260**, 1905-1910

Sombroek WG, Nachtergaele F, Hebel A (1993) Amounts, dynamics and sequestering of carbon in tropical and subtropical soils. *Ambio* **22**, 417-426

Tengberg A, Ellis-Jones J, Kiome R, Stocking K (1998) Applying the concept of agrodiversity to indigenous soil and water conservation practices in eastern Kenya. *Agriculture, Ecosystems and Environment* **70**, 259-272

Thurston HD, Salick J, Smith ME, Trutmann P, Pham JL, Mcdowell R (1999) Traditional management of agrobiodiversity. In: Wood D, Lenne JM (Eds) *Agrobiodiversity: Characterisation, Utilisation and Management*, CAB International, Wallinsford, UK, pp 211-243

Tiessen H, Salcedo IH, Sampaio EVSB (1992) Nutrient and soil organic-matter dynamics under shifting cultivation in semiarid northeastern Brazil. *Agriculture Ecosystems and Environment* **38**, 139-151

Tisdall JM (1996) Formation of soil aggregates and accumulation of soil organic matter. In: Carter MR, Stewart BA (Eds) *Structure and Organic Matter Storage in Agricultural Soils*, Lewis Publishers, Boca Raton, pp 57-96

Turner IM (1996) Species loss in fragments of tropical rain forest: a review of the evidence *Journal of Applied Ecology* **33**, 200-209

Torrico JC (2006) Balancing natural and agricultural systems in the Atlantic rainforest of Brazil. Doctoral Dissertation, Universität Bonn, 154 pp

Tucker JM, Brondizio ES, Moran EF (1998) Rates of forest re-growth in Eastern Amazonia: a comparison of Altamira and Bragantina regions, Pará State, Brazil. *Interciencia* **23**, 64-73

Uhl C (1987) Factors controlling succession following slash-and burn agriculture in Amazonia. *Journal of Ecology* **75**, 377-407

Uhl C, Clark H, Clark K, Maquirino P (1982) Successional patterns associated with slash-and-burn agriculture in the upper Rio Negro region of the Amazon basin. *Biotropica* **14**, 249-254

Wright SJ (2005) Tropical forests in a changing environment. *Trends in Ecology and Evolution* **20**, 553-560

Zuidema PA, Sayer JA, Dikman W (1996) Forest fragmentation and biodiversity: the case for intermediated-sized conservation areas. *Environmental Conservation* **23**, 290-297