

# **Agroforestry, Reforestation and the Carbon Problem: The Role of Land and Tree Tenure**

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## **Abstract**

Large scale reforestation in the tropics has the potential to sequester large amounts of carbon and help to mitigate the buildup of atmospheric carbon dioxide. However unless the causes of deforestation are addressed, reforestation efforts will be in vain. The link between deforestation and reforestation operates within the domain of human intervention on the landscape, and includes the patterns of land resource use and access. This paper considers the role that land and tree tenure (resource use and access) of agroforestry can have in reducing both the rate of conversion of forest to agriculture--the largest biotic emission of carbon--and forest degradation; thereby allowing both natural forests as well as reforestation to participate in carbon uptake. The operational land use and tenure aspects of agroforestry, and the impacts of these on deforestation, and in overcoming the obstacles to large scale reforestation, are presented. The utilization of marginal lands, and the adoption, growth, and spread of agroforestry systems in the carbon context, are also discussed.

## **Introduction**

Recent investigations into the atmospheric accumulation of carbon dioxide have proposed, and to varying degrees explored, reforestation as an approach which could mitigate the carbon dioxide buildup through the creation of a carbon sink.<sup>9,14,17,31,37,43,55,59,60,77,82,86,90,96,97.</sup>

A number of studies have used as a starting point the amount of carbon that needs to be sequestered, and have proceeded to estimate the land area needed, and/or the area potentially available to be put under growing forests in order to accomplish various levels of carbon storage or an atmospheric carbon equilibrium. Houghton<sup>43</sup> estimates that 500 million ha of primarily degraded and abandoned lands in the tropics, might be available for reforestation. Plus an additional 365 million ha if shifting cultivation were converted to low-input continuous agriculture. The total 865 million ha, if reforested, might be able to withdraw  $1.5 \times 10^9$  tons of carbon from the atmosphere each year over the next century for a total of  $1.5 \times 10^{11}$  tons. Sedjo<sup>77</sup> estimates that about 465 million ha of new plantations would be needed to sequester the estimated annual increase of  $2.9 \times 10^9$  tons of free carbon. And that 758 million ha of degraded land in the tropics, including 203 million ha under forest fallow have the potential for such forest "replenishment". Breuer<sup>9</sup> calculates that man has cleared about 750 million ha of tropical rain forest in the last 25 years, or about 5% of the total land surface of the globe. Under the assumption that it should be possible to reforest at least 2% of the land surface within 20-30 years, approximately 150 million ha of new temperate evergreen forest could be put in areas where it was destroyed centuries ago; in addition to the 150 million ha of tropical rain forest which could be restored. These forests would end up storing about  $5 \times 10^9$  tons of carbon per year as long as the forest are growing, which corresponds to approximately two-thirds of the

present annual increment of atmospheric carbon dioxide.<sup>9</sup> Marland<sup>55</sup> calculates that an increase in forest area of 1,201 million ha in the tropics and 1,736 million ha in the temperate zone would be required for an annual uptake of  $5 \times 10^9$  tons of carbon. This would, in 18 to 36 years, sequester all of the carbon emitted over the last 100 to 200 years.<sup>44</sup> This is equivalent to roughly doubling the mean annual volume increment of the world's existing closed forests. Grainger<sup>37</sup> estimates that 114.9 million ha of degraded tropical lands are available for afforestation and reforestation. And Woodwell<sup>97</sup> estimates that the establishment of forests on approximately 200 million ha of land would store about  $1 \times 10^9$  tons of carbon per year during the time the forest is accumulating carbon.

These important studies describe the significance of reforestation in mitigating carbon emissions, and detail the biophysical feasibility of large scale reforestation. However unless the causes of deforestation are addressed, reforestation efforts will be ineffective.<sup>43</sup> In this context, aspects of the human environment which operate at the site level in many developing countries become important. The link between deforestation and reforestation operates within the domain of human intervention on the landscape, and involves the patterns and processes of land resource use and access. This paper will consider some of the site level land use issues likely to be encountered in the implementation of such large scale reforestation efforts in tropical areas, and will explore the role that land and tree tenure (resource use and access) of agroforestry can have in addressing these issues, and in reducing both the rate of conversion of forest to agriculture, and forest depletion, thereby allowing both natural forests and reforestation greater participation in carbon uptake.

Site level tenure considerations have yet to be considered in the carbon reforestation/deforestation context; primarily because the topic spans not only the physical (change in land cover, carbon estimations) and social (reasons for land use) sciences, but also the scales of human impact which must be linked together in order for site level activities to be interpreted in the global carbon context. Within this framework this paper addresses the unusual topics of: 1.) a "critical mass" of agroforestry, which constitutes the connection between the accumulation of carbon in woody biomass and agroforestry adoption rates; 2.) tenure problems associated with degraded lands; and 3.) the significance of the indirect aspects of agroforestry on slowing deforestation and the important--although difficult to quantify--contribution of these to carbon storage.

### **Site Level Aspects of Large Scale Reforestation Efforts**

#### **Deforestation**

In many of the world's natural forests, especially in Latin America, land-hungry peasants are drawn by the promise of land and tenure to clear forests and begin cultivation. But titling can be a difficult and protracted process for small scale farmers and the land is often of poor quality and cannot sustain agriculture for very long under available technologies.<sup>12</sup> Such a situation is often the result of claims by the state that it owns all uncultivated land, together with the idea that individuals can establish their claims to land by clearing it<sup>12</sup> (Figure 1). The failure of the state to perceive or acknowledge pre-existing local claims and management practices of these forests

lies at the root of this cause of deforestation. The subsequent "free land" policy can promote deforestation as much as the land hunger of peasants.<sup>12</sup> And in areas of latin America, instead of forests regrowing on land abandoned by small holders as they move on to clear new land, large scale ranching operations which are able to obtain title to vast areas, move in behind them to enlarge and maintain clearings.<sup>12,19,30,39</sup> (Figure 2). In addition, tenure insecurity, frequently combined with land degradation, growing populations, migration, inequitable land distribution, and the cultivation of export crops in the most fertile and well watered areas have substantially reduced the area available to subsistence farmers. Small scale producers then must clear progressively more land in order to grow food.<sup>72</sup> Conversion of forest to cropland is the leading cause of deforestation in the tropics,<sup>72</sup> and the largest biotic source of atmospheric carbon.<sup>40,42,43,98</sup> Large scale plantation reforestation alone will not resolve the need for more agricultural land and more agricultural production, and may, by denying other uses of this land, contribute to forest clearing in other areas.<sup>51</sup> With deforestation still a growing problem, reforested areas will be cleared for agriculture sooner or later. In a fuelwood scarce situation for example, a reforested tract in a deforested and degraded area that is regarded locally as a commons would attract the attention of fuel hungry residents from an area larger than a similar sized natural forest parcel would have when deforestation was underway and the remaining forest patches were more numerous over a large area. The monitoring and enforcement costs of protecting such a reforested area would be related to the severity and spatial extent of the surrounding degradation, and to the number of people who perceive a tenure shift away from a commons; as inhabitants from a wide area with pronounced fuelwood needs become interested in the reforestation project as a potential immediate source of fuelwood, and concerned over the tenure designation of the project area. Such a situation may be exacerbated by the high price for fuelwood in urban markets. A recent project to afforest 48,000 ha of land in India that was designated as "wasteland" met with considerable opposition from the local village population who used the land to collect fodder, fuel, and fertilizer. These forest products were especially critical for the poor and landless. Wasteland development in India has generated a popular resistance movement for saving these commons. Because these "wastelands" were used for satisfying basic biomass needs, and wasteland development can be seen locally as a tenure change, affected villagers have uprooted the newly planted seedlings of afforestation projects in large numbers.<sup>79</sup> Similarly, large-scale reforestation with eucalyptus in Thailand has resulted in dislocation of rural populations, rural activism, and greater encroachment on natural forest.<sup>51</sup> These instances point out that regardless of the official classification of land, if there are clear communal rights to the existing trees because they are growing on locally recognized community land, or if there are ambiguous or unenforceable rights to exclude others from their use, then the reforestation project will be in difficulty.<sup>32</sup> While using land for agriculture presents specific barriers to large scale reforestation efforts, it is also where the greatest potential for agroforestry exists. However agroforestry itself is a reforestation technique with considerable carbon storage potential. In Kenya the number of trees planted by villagers on their own exceeds the number established in government plantations.<sup>71</sup> In Rwanda, the 200,000 hectares collectively planted in trees by rural inhabitants covers more than the combined area of the country's remaining

natural forest and all state and communal plantations.<sup>71</sup> Smallholder plantations of oil palm, cacao, coffee, cola nut, plantain and banana cover approximately 67% of the farmland in southern Nigeria.<sup>35</sup> And in Pakistan 90% of the nation's fuelwood needs and 41% of the timber demand is met from trees planted on farmlands.<sup>3</sup>

### **Reforestation in Tropical vs. Temperate Countries**

Tropical reforestation efforts based on temperate experiences can underestimate the differences in land use and human production systems. A Douglas fir forest constituting a defined reforestation project in the temperate zone (either private or public) could realistically be expected to sequester carbon for over 100 years.<sup>86</sup> And barring natural events such as forest fires, disease, or insect infestations, there would be little chance that such a forest would be lost due to human activities. The dominant feature of such an arrangement is its predictability.<sup>86</sup> This allows calculation of optimal rotation times for harvest, relatively precise estimates of growth rates, estimation of yield, area under forest, and the implementation of long-term planning objectives and therefore calculation of the forest's role in sequestering carbon.

The situation in tropical countries however presents a much more difficult problem in the context of this predictability. There is imprecise information concerning land ownership, human population densities and population growth rates and land use; and incomplete understanding of subsistence and small producer production systems and modes of resource utilization. This combines with widespread rural impoverishment, and the exclusion of large sectors of the rural population from national or even regional economies. Such non-participation together with low institutional capabilities and monitoring and enforcement capacities, can result in a national society which effectively fails to account for the activities of these groups. In addition, few reforestation schemes in the developed world are subject to the kinds of subsistence pressures caused by land hungry peasants, or pressures for large-scale commercial cutting generated by the need for foreign exchange which exist in the developing world.<sup>12</sup> This presents a human environment whereby planting and maintaining large areas of long-rotation new forests may be very difficult. In these situations it can be extremely difficult to realistically estimate normal forestry parameters and thus the reforested stands' ability to sequester carbon. The very large areas being proposed for storing carbon in the tropics under different strategies, give some indication as to the enormity of the area in which these problems may be encountered.

Forestry approaches to carbon sequestration in the tropics need to consider, in addition to implementing reforestation and afforestation, indirect avenues to long-term slowing of deforestation, avenues which take into consideration the nature of the human dimension in developing countries. The force behind such indirect approaches is the need to provide benefits to local populations so that forestation efforts occur in their interest. The trees or their products must be of such value locally that continued planting, protection, and harvesting of trees or forest products occurs by the local population exclusively as a function of their local value. This can involve singularly valuable tree species and/or multipurpose species in constructs which are able to incite local participation.

## **Replanting on Degraded Lands**

The potential for reforestation of degraded and abandoned lands in the tropics is large, and the land areas under this classification that are available and/or needed from a carbon viewpoint, have received significant examination. In this context then the realization of this potential will necessitate considerations of aspects of the human and institutional environment which operate at the site level. Aside from the political and economic aspects of obtaining or gaining permanent access (tenure) to large expanses of land for reforestation, degraded areas of the tropics present specific tenure and classification problems. Contrary to land currently under use, where the owner or defacto user is evident, the situation with apparently degraded and uninhabited lands is more complex. Previously forested, presently degraded and unused lands have undergone or are presently undergoing, a non-sustainable land use which effectively eliminates forest regrowth. And while these areas do have potential for reforestation, it is almost certain that such areas are already problematic in terms of land policy, land use, population density, tenure, poverty, etc., which is why they are degraded. If it is determined locally that a tract of land is in fact not presently owned or inhabited, the establishment of a forestation project can bring to the surface historical claims (which may or may not be verifiable) brought on by a perceived increase in land value due to the establishment of, or even the possibility of a project in the area. Such situations can cause a flurry of tenure activity on previously abandoned uninhabited, unused or even unclaimed land as locals and outsiders attempt to "cash in" on perceived increases in land values due to project site consideration. And, the actual functional and procedural components of tenure systems in many cases do not adequately deal with equitable titling procedures, inheritance, transfer, renting and sharecropping arrangements, ownership and boundary dispute resolution, and defacto users of land. Tenure dispute resolution and compensation can take long periods of time and become very involved. The resulting problems can include project delays, larger than expected expenditures, and a host of informal "special arrangements" which more than anything serve to highlight the transient nature of the project context. From a tenure perspective reforestation of degraded lands presents special problems that require tailored solutions that recognize local realities.

## **Agroforestry and Reforestation**

### **Agroforestry - Background**

As a form of reforestation, the human element is essential for the successful functioning of agroforestry systems. Over 90% of agroforestry in the tropics is carried out on agricultural land.<sup>100</sup> In this sense agroforestry would be in addition to other reforestation efforts, greatly expanding the total area which could potentially be put into trees. However unlike plantation forestry, agroforestry is generally not viewed locally as usurping rights because it complements local agricultural land uses and claims, making it a suitable reforestation method for both productive and degraded lands. Agroforestry is currently receiving considerable attention as an economically viable form of land use in the ecologically and culturally diverse tropics. Agroforestry systems can be readily adapted to highly variable site conditions, present potential savings to labor intensive farming, and are capable of being relatively easily adopted into most

traditional farming systems. According to Young<sup>100</sup> "Agroforestry systems could be designed to suit virtually any set of environmental conditions in the tropics and subtropics". Because of its many hundreds of forms, agroforestry can have a rather vague definition. There are, however, general characteristics which are true of all agroforestry systems. These include: the deliberate association of trees and shrubs with crops, pastures, livestock, and other forms of agricultural production; and, identifiable ecologic and economic interactions between the woody plants and other components of the production system so as to increase and diversify the total production from a given area of land".<sup>95</sup> Agroforestry is not any one system, but a principle common to many potential and existing systems where optimal use is made of space and time in the horizontal and vertical directions.<sup>52</sup>

### **Agroforestry Effects on Land Area and Marginal Lands**

Because agroforestry focuses on the human aspects of land use, its mitigating effects on biotic emissions of carbon are greater and more varied than simply uptake of carbon by the trees themselves.

#### Agroforestry and agricultural production

The essence of an agroforestry land use system is in finding advantageous ways to mix landscape components such that the mixes require less land area than the individual components grown or gathered separately, together with synergistic aspects of production which result from the mixes.<sup>41</sup> Such positive interactions mean that agroforestry land use systems can have a higher output value at the same resource cost and/or the same output value at a lower resource cost than do non-agroforestry land use systems. This is due to both a greater physical output, and because most agricultural capital and labor costs are directly related to the land area used.<sup>41</sup> It is this reduction in land area, together with the permanence generated by established systems that is the key to reducing agriculture related deforestation, and subsequent biotic emissions of carbon. These interactions and their results may be realized immediately or after some time. The long-term biologically and economically advantageous interactions, can result in decreases in labor, capital and resource use costs<sup>41</sup> and increases in yield.<sup>95</sup> Thus the introduction of valuable or service trees onto the agricultural landscape discourages deforestation in two ways. By enhancing agricultural production clearing new land to obtain a required level of production is less necessary, and, the permanence afforded by trees provide an incentive to remain in one location, as opposed to moving into new areas. As an example, through agroforestry fuelwood production, farmers are able to apply dung and crop residues to their fields to improve the soil instead of having to use them as supplementary sources of fuel. Investigations in Nepal and Ethiopia reveal that burning dung as a household fuel instead of fertilizing fields with it, leads to a 15% decrease in grain yields.<sup>65,99</sup> Using dung for fuel instead of fertilizer then feeds back on the amount of land that needs to be cleared to keep up the production lost by not using dung and other agricultural wastes as fertilizer.<sup>28</sup> Land area can also be affected when Nigerian swidden farmers influence the species composition of fallows by encouraging *Gliricidia sepium*, which helps reduce the fallow period to only two years.<sup>35</sup> *Leucaena leucocophala* trees, planted in

conjunction with field terracing on the islands of Timor and Flores, has reduced the cropping/fallow ratio from 1:7 to 1:2.48,58 In some cases, where L. leucocophala leaves have been incorporated into the soil of terraced slopes, permanent agriculture has become possible.<sup>58</sup> Again for Nigeria, a new agroforestry system of alley cropping in areas where maize production is constrained by nitrogen shortages, comprises closely spaced rows of Leucanea trees and maize that result in higher yields in addition to satisfying the fuelwood needs for four people per hectare.<sup>95</sup> In China, windbreaks around fields have reduced wind velocity, increased air humidity, reduced evaporation, and increased soil moisture. As a result crop yields have increased 16% for maize, 36% for soybeans, 43% for sorghum, and 44% for millet.<sup>95</sup> In Chiapas, Mexico, local Mayans plant up to 75 crop species in one hectare plots for up to 7 years. After soil fertility declines, tree crops are planted that yield produce as the natural forest regrows. It has been estimated that this system uses two to three times less forest than traditional shifting cultivation in the area.<sup>26</sup>

### Utilization of marginal lands

Historically third World agriculture has met increased food needs by increasing the areas under cultivation and irrigation. Today however additional fertile land is scarce. The FAO has estimated that the amount of land per inhabitant in developing countries will fall from 0.85 ha at the beginning of the 1980s to 0.6 ha by the year 2000.<sup>24</sup> Most new land being brought into agriculture is of poor quality that is only briefly useful. the FAO further estimates that by 2025 no new high quality arable land will be available.<sup>24</sup>

The quality of land under cultivation can have direct relevance on tenure and rates of deforestation, because land that is only briefly useful offers very little permanence of tenure, because new land must constantly be cleared to maintain production. Marginal lands experience a rapid decline in productivity after the natural cover is removed, and as a result are areas where deforestation rates are likely to be highest. However such lands can offer the basic conditions that favor the adoption of agroforestry systems: arid, stony, or steep terrain, low fertility, increasing scarcity of fuelwood, fodder, and agricultural land, high agricultural risk, and unemployment; areas where agricultural production would either rapidly degrade the land, or where it would not otherwise be possible<sup>2,61,95,100</sup> (Figures 3 and 4). Thus the greatest contribution of agroforestry is often in the worst of situations. In places of constrained land area (islands, etc.) where agricultural problems have become critical and the land can no longer support the resident population, there can in some cases be a conversion to permanent, sustainable, tree-based land use; where such opportunities exist and local populations are aware of them.<sup>34,95</sup> By their perennial nature valuable trees are able to change the land tenure of a given situation, or add another aspect to them. Such effects are particularly relevant to marginal areas because they can introduce productivity, and permanence of tenure resulting from improvements made on the land (investing in valuable trees). Greater agricultural investment then further enhances productivity.<sup>12</sup> The security of tenure, permanence of tree investments and greater productivity then discourage the small farmer from moving elsewhere to clear new sites.

In Cebu, the Philippines, marginal lands on steep slopes of over 100% are successfully cultivated with maize and tobacco using a 3 - 8 year fallow cycle of involving Leucanena leucocephala trees, which fertilize and stabilize the soil<sup>54</sup> (Figure 3). In Sonora, Mexico, living fencerows of cottonwood (Populus frimontii), and willow (Salix gooddingii) with brush weaved between the trees, enable the expansion and maintenance of fertile fields in a rocky, eroded, infertile, arid environment subject to frequent flash floods. The trees and brush slow the velocity of the floodwaters, so that sediment deposition occurs in desired locations. By repositioning the fencerows over the years, fields are expanded<sup>62</sup> (Figure 4). In the relatively infertile soils of the Sahel, the presence of Acacia albida trees in fields of millet or sorghum increases crop yields by up to 2.5 times the normal production.<sup>95</sup> Such techniques can also be used to re-introduce agricultural productivity onto degraded landscapes. The rehabilitation of such areas is as important to reducing pressure on natural forests, as preventing the degradation of marginal lands.

### **Tenure, Establishment and Expansion of Agroforestry Systems**

#### Land and tree tenure: adoption of agroforestry systems

The tenure arrangements involving land and trees can, in many cases be an important link between the present form of land use and the introduction of agroforestry both as a form of reforestation, thus lessening the pressure on forests and allowing further reforestation. This link can sometimes be used as a tool in order to begin the process of change in land use and/or production system.<sup>12,33</sup> Very diverse arrangements are common with respect to tree and tree product use and access rights, and are of direct relevance to agriculturalists considering planting trees.<sup>12,13</sup> While tenurial arrangements can be complex, they are not uncontrollable and unpredictable. In fact, such multi-faceted situations are often pregnant with options and opportunities for the implementation of agroforestry systems.<sup>11</sup> The works edited by Fortmann and Riddell<sup>33</sup> and Raintree<sup>73</sup>, and research by Bruce et al,<sup>13</sup> and Bruce and Fortmann<sup>12</sup> have contributed much to our understanding of land and tree tenure in the agroforestry context.

Tree and tenure issues in the developing world must necessarily begin with departure from the "fixture presumption" common to western law: the presumption that a tree belongs to the owner of the land on which it is a fixture. Some other cultures share this presumption, but many do not.<sup>6,12,13</sup> The owner of the land, can (and often is) different from the person who planted, and the person who receives the produce from the tree.<sup>1,16,32,57,60,75,94</sup> Gum arabic (Acacia senegal) in the Sudan is a good example. Grown either on its own or in a fallow rotation with annual crops,<sup>29</sup> pastoralists graze their animals on the ground cover, crop residue, new seedlings and lower branches, while local farmers collect dead-fall for firewood, and merchants purchase collection rights from tree owners. The land itself upon which the trees grow is part of a larger group's communal holding.<sup>13</sup> Additional dimensions to such an arrangement are created by loaning, borrowing, pledging, inheriting and transferring rights to different components of the tenure system. In the Sudan, a tree and its fruits may belong in shares to the owner of the land, the person who provided the seedling, and the owner of the water wheel that irrigates the land.<sup>13</sup> Thus tree tenure (ownership and access rights in trees) can in many cases be arranged completely



separate from land tenure. Tree tenure regimes can be complex, and just as variable as land tenure, water rights, or mineral rights.<sup>12</sup>

While it has been argued that clear and secure land tenure arrangements must be in place before agroforestry can be implemented because people will not be motivated to plant and maintain trees on land that they do not own or control,<sup>81</sup> this is frequently not the case. Where individual rights to land are few or precarious, tenure in trees may offer the "security of expectation" necessary for continued use and control of trees and/or tree products<sup>12</sup> as well as continued planting. Likewise where there exists a disadvantaged class in terms of land rights (for example, women) tree tenure for such a class may provide this same security.<sup>12</sup> In other cases tree cultivation may increase security of tenure in land and enhance rights to land, which if unchallenged can eventually evolve into proof of rights or ownership.<sup>12</sup> In agricultural areas of Africa and elsewhere trees are planted not only to delimit clear boundaries, but also as permanent improvements to the land; both of which serve to establish tenure rights.<sup>10,15,22,32,54,57,66,75,83,95</sup> This illustrates the perception-based nature of "improvements to the land" upon which subsequent ownership or rights can be based. In the Brazilian Amazon--as in many of the world's natural forests--tenure secured and verified by "improvements to the land" means clearing the land<sup>12</sup> (Figure 1), whereas in Costa Rica and Tanzania squatters attempt to make their tenure more secure by planting trees; either because (for Costa Rica) the law requires compensation for improvements,<sup>78</sup> or (for Tanzania) permanent use rights can be obtained.<sup>5</sup> In the Peruvian Amazon, management of swidden-fallows for locally valuable or economic trees establishes "ownership" of the fallow in a situation where land ownership is usually abandoned along with the fallow after the swidden cycle<sup>20,88</sup> (Figure 5). And, planting valuable trees in order to define and secure tenure can subsequently encourage the adoption of larger scale and longer term agroforestry systems that must have secure tenure in order to successfully operate.<sup>89</sup>

Bruce et al<sup>13</sup> considers tree tenure as a bundle of rights which can be broken up, redivided, and passed on to others, to be held by different people at different times. For any land and/or tree tenure system, each of the rights in the bundle has three primary dimensions: people, time, and space, all of which operate within the context of tenure security.

The people aspect of the bundle can be boiled down to rights as a result of human interaction. Such interactions are an expression of the social relationships and expected behavior of others in response to actions taken by an individual or group concerning a piece of ground. If a forestry plan increases the ambiguity, ie., decreases the security of, relationships with others over a parcel that an individual or group depends on or claims, the chances of cooperation decreases in direct proportion to the level of tenure insecurity created.<sup>75</sup> Important in this aspect is community diversity. Local communities are not homogeneous and are often divided by class, caste, religion, ethnicity, gender, geographical origin, length of settlement, and even household cycle.<sup>12</sup> Tenure systems have a number of alternative "tenure niches" available to different strata and sectors of the community, different members of the household, and different households, all of which differ in their needs over time, and consequently concentrate resource use in different tenure niches or make different uses of the same niche over time.<sup>12</sup>

The time dimension of the bundle begins with the universal concept that since land survives any holder of rights in land, all societies have mechanisms which enable the transfer of land rights, and for determining how long rights last. By their slow maturation time relative to crops, trees, if purposely planted, protected or claimed, can carry with them the intention of maintaining rights to the tree or the land or both depending on the situation, for an extended period of time. Thus while establishing rights to trees can be used to gain rights to, or security of rights to land, the same practice, depending on the situation, can be used by "outsiders" to claim land, effectively transferring that land to the outsider's group. This is an important consideration when a Forestry Department "borrows" land from a local community to plant trees. Many communities have learned that where trees are concerned, what began officially as a temporary transfer of land, can mean long-term ownership.<sup>75</sup>

The spatial dimension of the tenure bundle can become quite involved, as the gum arabic example illustrates. In whatever way the spatial exploitation of land and/or trees is arranged, those with rights will seek to ensure security of access at least, and expansion of access at best. As a general rule, "the greater the change in the way the land is used, the more people will have to be involved in acceptance of the idea".<sup>75</sup> Any design which invokes a large change in land use will remove the rights of some, make more ambiguous the rights of others, and allow the opportunity for the expansion of rights of still others. Agroforestry, as a "compatible" technology that targets the local community, mixes with the existing land use, is much less of a change, and in most cases operates completely within, or from, existing tenure structures. This approach sidesteps the very problematic fact that national legislated land ownership and customary tenure systems very frequently do not agree in developing countries. Many rural groups recognize individual or family ownership of land and/or trees based on occupancy and use, but governments can ignore traditional tenure systems and regard such areas as part of the public domain.<sup>6,11,12,21,93</sup>

The importance of fusing proposed forestry schemes with in-place tenure regimes and land use ecologies should not be over looked. Existing production systems function because participant familiarity and knowledge of them enables established exchange relationships to operate within the variability and constraints of the local ecology. These systems usually already contain the complicated and long-evolving risk reduction and coping strategies necessary for survival in difficult environments given the reigning cultural and socio-political constraints and opportunities.<sup>8,23,36,46,49,56,67,69,80,87</sup> Likewise, the role of long standing, traditional cultural attitudes and preferences in the use of the environment in the context of development efforts, can be profound. The preferences for using specific domesticated plants and animals in specific ways in established land use practices, and the exclusion of others are major factors in the economic functioning and potential development of the landscape. Such attitudes--often rooted in history--allow the development of certain opportunities of the environment and ignore or reject others.<sup>76,80</sup>

### The "critical mass" needed for agroforestry

For many agroforestry arrangements, a certain number of producing trees, or "critical mass" is required in order for the agroforestry system to be viable enough to produce the quantity of useful items that makes the labor and land allocation worthwhile, and ultimately for effects on deforestation and the storage of carbon to take place.

In the Amazon, if a swidden-fallow contains only a few valuable plants, it will be a candidate for clearing once a new field is needed. If however there are a large number of valuable managed plants in the fallow, the site will not be cut because it produces enough of a valuable commodity so as to be worth sparing. Either another site will be chosen or the valuable trees will be left standing and the crops planted beneath.<sup>88</sup> On a larger scale, when enough farmers in a region are cultivating a certain tree crop or assemblage of tree crops, there is another "critical mass" which must be reached in order for the area to be seen as a region capable of consistent production of a certain item. This regional "critical mass" engages the necessary market elements (middlemen; transport infrastructure, arrangements and facilities, etc.) and processing arrangements which further promote the cultivation and/or protection of the tree crop(s) in question. Gum arabic provides a consistent example. The entire world's production comes from smallholder harvests, and demand for Gum arabic has grown. As a result more farmers have become engaged in cultivation of these trees.<sup>29</sup> Other agroforestry arrangements have experienced similar success. Such is the case for cocoa (*Theobroma cacao*) in west Africa,<sup>7</sup> rattan (*Calamus* spp) in southeast Asia,<sup>93</sup> frankincense (*Boswellia* spp.), and other aromatic gum producing trees on the horn of Africa, the "man-made" dipterocarp forests of Sumatra,<sup>84</sup> babassu (*Orbignya* spp.) in Brazil,<sup>4</sup> sago palm (*Metroxylon sagu*) in southeast Asia,<sup>85</sup> and tree crop combinations in the Philippines,<sup>25</sup> West Africa,<sup>35</sup> and tropical Asia.<sup>50,64,70</sup>

Arriving at these two "critical mass" stages in agroforestry is one of the hurdles in the growth and establishment of large scale agroforestry systems. Time is an important variable. By their nature, trees take a significant amount of time to begin producing a useful item or material (depending on the species). Time is also required for enough people to adopt a certain agroforestry system and then grow the trees so that a regional "critical mass" can be realized allowing the system to grow further in scale and become an economically viable mainstay over a wide area.

The avenues or "pathways" by which an agroforestry "critical mass" is arrived at involves an alteration or transition in land use during which subsistence must still be met. While a small scale, integrated agroforestry system involving a few trees over a large area of annual crops, fallowing, or grazing land will not mean much in terms of meeting tree product demands, slowing deforestation, or sequestering carbon, the eventual arrival at large scale/intensive agroforestry occurs by passing through such initial stages of development.

The potential of agroforestry to store carbon is related to the rate of adoption of practices that will allow agroforestry and its effects on deforestation, to be a long-term sink for carbon. Rapid arrival at the stages of "critical mass" necessary for further and more widespread adoption is, as mentioned previously, dependent on the appropriate fit of an agroforestry design with existing land use practices and patterns, in order to take full advantage of specific in-place socio-cultural,

tenurial, ecological and land use specifics of a given location, without sacrificing long-evolving risk avoidance strategies. Once the stages of "critical mass" are arrived at, subsequent adoption rates may become more rapid as the popularity of a proven design engages more participants, especially at the regional level.

### **Carbon and Agroforestry**

The total carbon sequestered via agroforestry as a reforestation technique, will, unlike other methods of reforestation, be difficult to calculate given the many forms of agroforestry systems, varying rates of adoption, and the multidimensional nature of the indirect, or secondary effects of agroforestry on deforestation and reforestation. However these secondary effects may be just as significant from a carbon perspective as direct uptake of carbon by tree growth. The brief list which follows summarizes some of the more important of these. Carbon loss from soils on lands cleared for agriculture<sup>18,45</sup> would likely be less under agroforestry systems due to the greater tree cover. Fuelwood carbon contributions from agroforestry systems is different from that harvested from natural forests because of the difference in tenure regimes. Forests and other areas used for fuelwood collection are often viewed as open access land--especially where considerable ambiguity surrounds the awareness and recognition of customary and state legislated tenure systems--and no replanting typically occurs to replace the wood gathered. In agroforestry systems the tenure regime could be varied but can encourage replanting of trees in an on-farm agroforestry system. Such that agroforestry for fuelwood would not be the net source of carbon to the atmosphere as fuelwood gathering from commons would be. In addition, readily available, renewable woodfuel at little or no cost to the farmer could mean that fossil fuels might not be used as they would by farmers in a fuelwood deprived area, thus ensuring the use of woodfuels instead of fossil fuels. This could be important because utilization of fossil fuels is a one-time carbon emission, whereas carbon released from woodfuels in a rotation agroforestry context can be recaptured and is not a net source of carbon. And, through fuelwood production, farmers are able to apply dung and crop residues to their fields to improve soil fertility instead of using them as supplementary sources of fuel. Land area requirements can also be reduced by mixing landscape components as opposed to growing or gathering them separately. This can lead to increased productivity, thereby encouraging permanence; as would the long-term nature of any valuable trees planted. The productivity and permanence afforded by valuable trees may be particularly relevant to occupation of marginal lands, especially since these are areas where deforestation rates can be highest. Increased security of tenure provided by agroforestry trees can discourage moving to clear more lands, and can encourage further investment in holdings, which can increase productivity, which in turn feeds back on permanence and investments.

Although individually and perhaps totally these indirect effects do not amount to much carbon stored on a per hectare basis compared with plantation reforestation, what is important is the very large area over which agroforestry constructs and its effects can be applied. Considering the diversity of tenure structures and land use in the tropics, and the varying capacities for monitoring and enforcement of formal forestry projects, realistically there may be considerable land available for agroforestry compared to other reforestation scenarios. The rate of carbon

sequestered and long term storage of carbon (including secondary effects) depends heavily on the rate of adoption of agroforestry designs, which occurs in two dimensions. Spatially the adoption of popular, proven agroforestry systems over progressively wider areas can be significant. Temporally an increasing density of valuable trees can be planted in any single location, as the system proves itself as an economically preferred alternative to other land uses.

Because conversion of forests to cropland in the tropics is the largest biotic source of atmospheric carbon<sup>40,42,43</sup> the importance of agroforestry's contribution to slowing deforestation may be more important than first realized, for several reasons. First, if present trends continue, the amount of carbon that will be released through deforestation will exceed that sequestered by reforestation because the area presently under tropical forests is greater than the area available for reforestation.<sup>43</sup> And, the conversion of mature, well stocked forests via deforestation to commercial reforestation plantations on a sustained yield basis will result in a net release of carbon.<sup>17,38,90</sup> Such that slowing deforestation will ultimately store more carbon than reforestation on the same land subsequent to clearing. Second, carbon is emitted more quickly from deforestation than it can be taken up through reforestation, because burning releases carbon quicker than tree growth can sequester it; meaning that there is a significant time lag for carbon between deforestation and reforestation.<sup>43</sup> Third, as stated earlier, attempts at reforestation will mean very little if the causes of deforestation have not been addressed. Newly planted forests can be cut down just as easily as the original forested areas. And finally, it is much more difficult biophysically to undertake reforestation (especially on lands that have been degraded) than to stop deforestation. Ultimately of course the conversion of forests to agriculture involves a systemic relationship between growing subsistence-oriented populations and low agricultural productivity on ill-suited lands. And while agroforestry will not itself be a panacea for carbon sequestration, it has the potential to play a significant role, considering that agroforestry adoption rates are highest among the most disadvantaged populations who must subsist in situations of very low agricultural productivity.<sup>27,52,53,74,95,100</sup>

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### Figure Legends:

Figure 1. NOAA AVHRR 1.1 km resolution satellite image covering an area of 550 x 550 km. The lighter colored spaces are areas cleared in colonization schemes.

Figure 2. Landsat satellite image showing deforestation in an area 180 x 180 km in Rondonia, Brazil. August 4, 1978 Landsat 3 MSS Visible Red Band, 80 m resolution. The extension and maintenance of clearings occurs as small farmers are drawn to the area with the expectation of land and tenure, and ranching operations acquire land abandoned by or purchased from small farmers. Source: Purchased from INPE (Brazilian National Space Institute) CNPq/MCT

Figure 3. Agroforestry on very steep slopes in the Philippines. The dark areas are tree fallows of Leucaena leucocephala and the lighter areas are cultivated.<sup>54</sup>

Figure 4. The maintenance and expansion of fertile fields in the arid, eroded environment of Sonora, Mexico using live trees in fencerows which are planted anew every few years, allowing expansion of the fields. In this photo both remnant fencerows and more recent continuous fencerows are apparent.<sup>62</sup>

Figure 5. Agriculturalist in the Peruvian Amazon carrying fruits of peach palm (Bactris gasipaes) and chambira fronds (Astrocaryum chambira) harvested from a ten year old fallow managed for agroforestry.<sup>20</sup> In such managed fallows ownership is maintained long after annual crop cultivation has ended.