THE POTENTIAL FOR CARBON SEQUESTRATION IN AGROFORESTRY SYSTEMS

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ABSTRAK

Potensi Agroforestri untuk Penyerapan Karbon. *Sistem agroforestri memiliki potensi untuk mengatasi perubahan lahan karena dapat menyerap karbon dan secara bersamaan memberikan keuntungan ekonomi kepada petani melalui berbagai produk-produk pertanian secara berkelanjutan. Sistem tersebut merupakan sistem penggunaan lahan terintegrasi yang terdiri dari berbagai pohon dan tumbuhan perenial berkayu lainnya yang tumbuh di lahan pertanian dan lahan produksi tahunan lainnya untuk memaksimalkan keuntungan ekonomi dari berbagai produk dan interaksi ekologi. Potensi agroforestri dalam penyerapan karbon sangat bervariasi tergantung pada beberapa faktor antara lain tipe sistem agroforestri yang digunakan, komposisi spesies, umur komponen spesies, lokasi geografis, faktor-faktor lingkungan dan praktek-praktek pengelolaan. Review literatur menunjukkan bahwa potensi penyerapan karbon dalam sistem agroforestry di daerah tropis berkisar dari 1,5 t C /ha/tahun sampai dengan 10 t C /ha/tahun, hamper sama dengan karbon yang diserap oleh hutan tanaman untuk pulp dan kertas yang sebesar 10 t C /ha/tahun. Di Sumberjaya, sebuah sistem agroforestri berbasis tanaman kopi diselidiki untuk mengetahui potensi sistem ini untuk penyerapan karbon. Hasil studi menunjukkan bahwa di survey pertama, rata-rata biomassa di kebun kopi umur 2-30 tahun adalah sekitar 92 Mg/ha. Survey kedua mengindikasikan bahwa rata-rata stok karbon dalam biomassa di atas tanah dari pohon kopi umur 6-40 tahun adalah 18,4 Mg/ha dengan standard deviasi 4,0, dan rata-rata stok karbon untuk pohon-pohon non-kopi adalah 29.6 Mg/ha dengan standar deviasi 18.9. Peningkatan stok karbon per tahun diperkirakan sebesar 2 Mg C/ha/tahun. Menghubungkan potensi agroforestri dalam penyerapan karbon dan perubahan iklim akan memberikan insentif yang besar bagi petani-petani kecil di daerah tropis. Pemberian reward atau kompensasi kepada petani atas keuntungan lingkungan yang telah disediakan seperti pengurangan emisi akan membantu mengurangi kemiskinan di banyak areal pedesaan. Mengambil kesempatan dalam upaya mitigasi emisi karbon melalui sistem agroforestry juga dapat meningkatkan kapasitas negara berkembang seperti Indonesia untuk menghadapi perubahan iklim.*

Keywords: agroforestri, karbon, biomassa, emisi, perubahan iklim

INTRODUCTION

Forests constitute a major storage of carbon, although there is still considerable uncertainty in all the data on global carbon uptake by, storage in, and release from forests. The world's forest ecosystems account for approximately 1146 billion t of carbon (Kimmins, 2004): 66% of this is above-ground terrestrial carbon and 45 % is all below-ground terrestrial carbon (Smith *et al.*, 1993).

During the past decades, there has been an increase in the amount of greenhouse gases from the burning of fossil fuels, conversion of forests and other human activities. Among these activities, deforestation is estimated to account for approximately 1,000 millions tons of carbon dioxide to the atmosphere for the past 20 years or 10-30 % of the total human-induced carbon emission is due to land use change (Houghton *et al.*, 2001). However, as human population increases, conversion of forest to agriculture is inevitable.

Agroforestry systems have the potential to deal with land-use changes because they can sequester carbon and provide economic benefit to farmers through various sustainable products (Dixon *et al.*, 1994; Palm *et al*; Niles *et al.*, 2002; Albrecht & Kandji, 2003; Mutuo *et al.*, 2005; Palm *et al.*, 2005; Schoeneberger, 2009). Agroforestry could also benefit the global carbon pools as it can lessen the pressure on forests and produce timber and/ or cash income to farmers. However, the potential for agroforestry in sequestering and storing carbon has not been fully recognized. Consequently, agroforestry is under-recognised in many carbon sequestration efforts (Schoeneberger, 2009) despite also its rewards in reducing rural poverty and benefits to the society at large. This paper aims to investigate the potential of agroforestry systems for carbon sequestration by looking at the global carbon cycle, agroforestry system practices, and a case study of from a coffee-based agroforestry system in Sumberjaya, Lampung, Indonesia.

PROBLEM SOLVING

The Global Carbon Cycle

The global carbon cycle involves various chemical, physical, geological, and biological processes by which carbon is moved among pools (IPCC, 1997). The major carbon pools that are interconnected by pathways of exchange are: (1) the atmosphere; (2) terrestrial, including fresh water systems, living biomass and non-living organic materials such as soil; (3) the oceans; and (4) the fossil fuel reserves.

According to Griffin and Seeman (1996), carbon in the atmosphere, the terrestrial ecosystem and the ocean are always changing but these changes are balanced by respiration and decomposition processes. During the past centuries, the massive burning of fossil fuels and deforestation has added to the carbon concentrate in the atmosphere more than 1% per year. Deforestation and land cover change have reduced carbon stocks in the terrestrial and land capacity to sequester and store atmospheric carbon in the future. Figure 1 illustrates the global carbon cycle and its components.

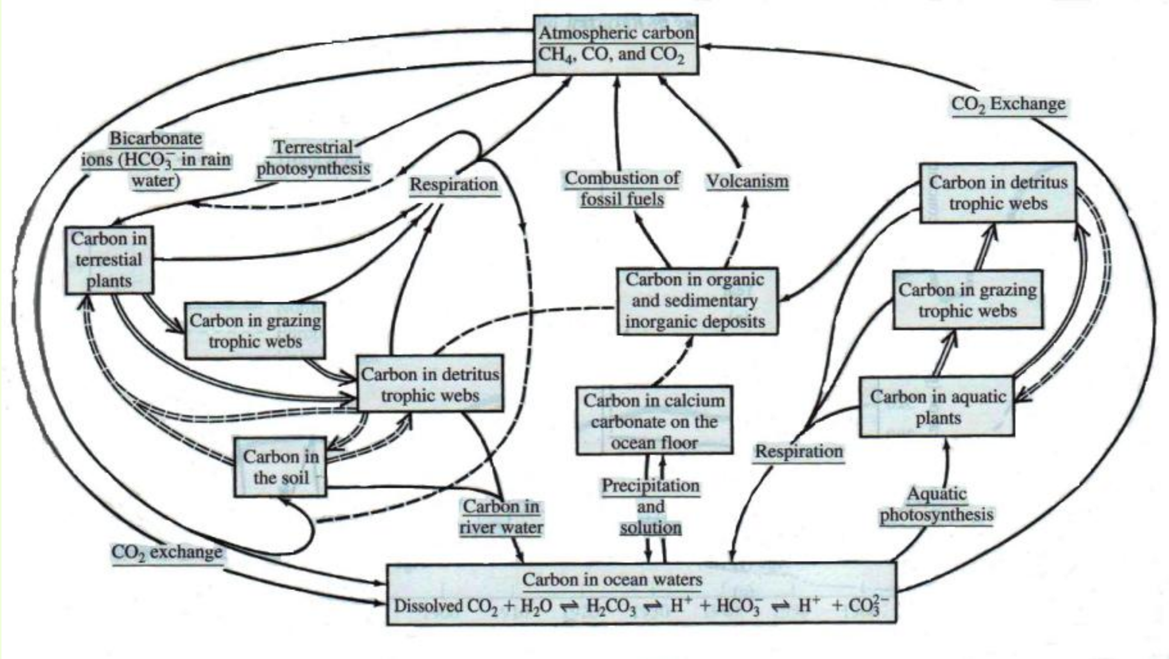

Figure 1. Distribution and transfers of carbon in the biosphere. Double lines indicate the geochemical cycle; solid lines indicate major transfers; dashed lines indicate transfers of secondary importance.

Source: Kimmins (2004)

Although the terrestrial ecosystem can only store carbon to a much lesser extent than the ocean, the carbon flux between the earth and the atmosphere is greater than the carbon flux between the oceans and the atmosphere. Plants play an important role in storing and sequestering carbon in the terrestrial ecosystems (Schroeder, 1994). Carbon sequestration refers to the uptake of carbon (CO_2) in the atmosphere by plants in the photosynthesis process. Within this process, CO2 is converted into carbohydrates and oxygen is released into the atmosphere. Figure 2 shows the carbon fluxes in the terrestrial.

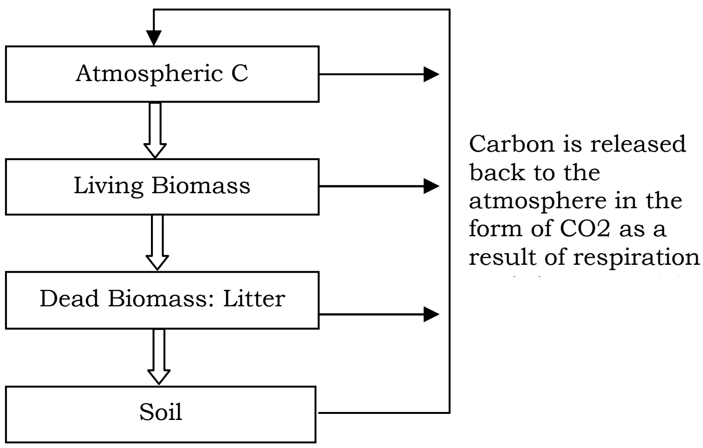

Figure 2. The terrestrial ecosystem carbon fluxes.

Adapt from: Goldewijk et al. (1994)

Many authors suggest that agroforestry systems can play a prominent role in reducing carbon emission in the atmosphere (i.e. Dixon *et al*., 1994; Schroeder, 1994; Dixon, 1995; Montagnini and Nair, 2004; Schoeneberger, 2009). Schroeder (1994), in particular, pointed out the role of agroforestry for climate change: (1) the tree component in agroforestry systems fixes and stores carbon from the atmosphere via photosynthesis; (2) agroforestry provides an alternative land-use to agriculture, reducing the pressure on forests.

Montagnini and Nair (2004) suggested that calculating the extent of carbon sequestered in agroforestry systems should be included in the amount of carbon in standing biomass, the carbon remaining in the soil, and carbon sequestered in wood products. This is also supported by Schoeneberger (2009), who states that carbon pools in agroforestry can be measured from the above-ground woody biomass, below-ground woody biomass, understorey vegetation, litter or dead wood and soil carbon.

Agroforestry System Practices

Agroforestry is an integrated land use that comprises a mixture of trees and other woody perennials in crop or annual production to maximise economic benefits from various products as well as ecological interaction (Nair, 1985; Schroeder, 1994). Subsequently, the ecological interactions in the systems maintain soil and water quality, sequester carbon from the atmosphere and in some cases the systems also promote local biodiversity.

Within these systems, farmers plant a wide range of tree species, organized around a few commercial species, most often with food crops during the first year(s). After a few years, the field becomes a productive mixed tree crop plantation whose products, either cash or household consumption, will be harvestable for decades (de Foresta and Michon, 1997).

Trees, an important part of agroforestry systems, have produced food supplements as their main purpose or other non timber forest products rather than timber, but they should also provide timber for building materials. For example, in a rubber-based agroforestry system in West Kalimantan, Indonesia has, as its main purpose produced latex as a source of cash income for the farmers and other fruit trees in the garden produce foods. In addition, the trees can function as a carbon sink and aid in water management. However, despite the sustained long-term productivity and the many environmental benefits of agroforestry systems, they tend to have relatively low returns per hectare of land. Consequently, this triggers the farmer to transfer to intensive monoculture farming systems (Koester *et al*., 2008).

Types and Profile of Agroforestry Systems in Indonesia

Private industrial companies have been managed many natural resources in many regions in Indonesia. This has led to less contribution of natural forests to rural economies although forests resources are still essential for rural livelihoods. In many cases, people often start to domesticate and integrate some forest species in adjacent areas and establish agroforestry systems. These systems provide economic benefits as well as taking over the roles of natural forests for rural livelihoods.

Agroforestry systems in Indonesia vary from very simple to extremely complex systems, depending on land availability, the native species area, climate, soil and the culture of the rural community (de Foresta *et al*., 2000). The homegarden is a typical agroforestry system found in most villages across Indonesia. The system utilizes the area surrounding the home for planting various types of plants which benefit daily needs. In general, the homegarden involves fruit trees, vegetables, and medicinal plants and in some cases people also integrate other plants that are believed to have supernatural powers. The Dayak people in the upper-catchment of the Apo Kayan River, Kalimantan, plant more than 100 species of plants in their homegardens and more than 50 species of plants can be found in a typical homegarden of 400 m^2 in West Jawa (de Foresta *et al.*, 2000).

In Krui, West Lampung, the decline of *damar* trees (*Shorea javanica*) in natural forests has encouraged people to design *damar* agroforest to produce resin for export. Besides *damar* trees, farmers also plant fruit trees, wild plants from primary or secondary forests such as timber trees, palms, and bamboo to create complex agroforestry systems (Figure 3). *Damar* and *durian* trees (*Durio zibethinus*) which can reach 40 meters dominate the upper layer, while *duku* (*Lansium domesticatum*), mangosteen, *tangkil* (*Gnetum gnemon*) and *rambutan* (*Nephelium lappaceum*) occupy the layer within 10 to 20 meters. The middle storey (20 to 35 meters) comprises *cempedak* (*Artocarpus heterophyllus*), *embacang* (*Mangifera* spp.) and *petai* (*Parkia speciosa*). Grasses and shrubs occupy the lowest layer of the systems (de Foresta *et al.*, 2000).

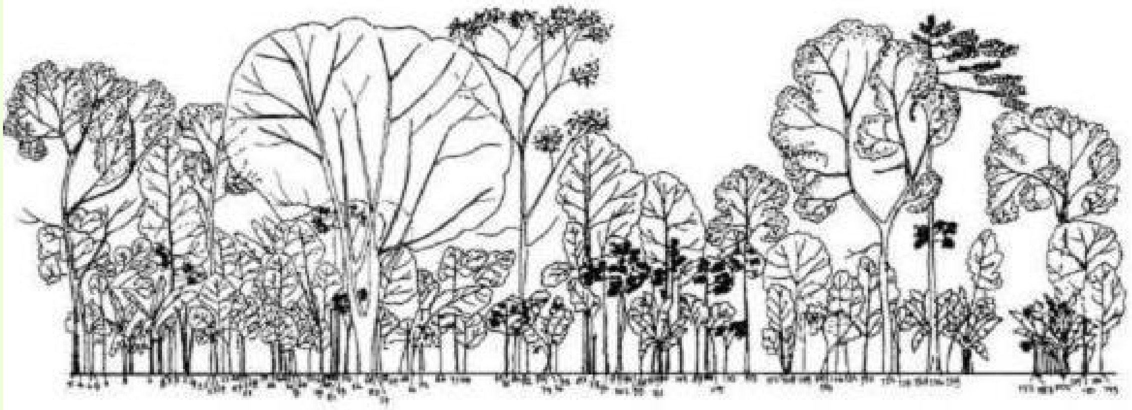

Figure 3. A profile of agroforestry systems in Indonesia: a complex agroforestry system

Source: de Foresta et al. (2000)

Other agroforest systems found in Indonesia are tembawang in Kalimantan which is dominated by tengkawang trees (Dipterocarpaceae) and durion; rubber-based agroforestry systems in West Kalimantan and the eastern part of Sumatra Island; cinnamon agroforests in Kerinci Seblat, Jambi (Sumatera Island); rattan agroforest in East Kalimantan; and sugar palm agroforests in Lombok and North Sulawesi (de Foresta *et al.*, 2000).

Thus, agroforestry plays an important part in most rural livelihoods in Indonesia. The systems provide a source of livelihood or cash income for many households, in the form of fuel wood, fodder, fibres, and building materials. The forest-like environment also provides environmental benefits to adjacent areas and the community at large. In some cases, agroforestry could also offer an alternative for conflict resolution over forest resources. The role of agroforestry in carbon sequestration is the focus of the next section.

The Potential for Carbon Sequestration in the Agroforestry Systems

The potential of agroforestry systems in sequestering carbon is highly variable depending on several factors such as the type of the system, species composition, age of component species, geographic location, environmental factors, and management practices (Jose, 2009). This potential has been recognised by several authors. For example, Dixon (1995) reveals that the potential for carbon accretion via biomass accretion is greatest within the humid tropics. Extensive agricultural, agroforestry, and alternative land-use systems established on degraded land could sequester 0.82-2.2 Pg C per year, globally, over a 50-year time-frame. Moreover, slowing oil degradation by alternative grassland management and by impeding desertification could conserve up to 0.5-1.5 Pg C annually (Dixon *et al.*, 1994).

Palm *et al.* (1999) estimate that the rate of carbon sequestration of jungle rubber in Indonesia is 3.6 t C/ha which is similar to that of cacao systems in Cameroon. In more intensive plantation systems, industrial timber plantations of fast growing trees (*Paraserianthes*, *Eucalyptus*, *Acacia*) with 8-year rotation had much higher carbon sequestration rate, almost reaching 10 t C/ha. In addition, in the humid tropics, more carbon can be sequestered per hectare by changes in above-ground than below ground biomass. Furthermore, Palm *et al.* (2005) show that the amount of carbon sequestration above-ground ranges from 5 t C/ha for coffee plantation to 60 t C/ha for complex agroforestry systems over a 20-25 year period; while in the top-soil, carbon sequestration varies from 5 to 25 t C/ha.

Montagnini and Nair (2004) find that direct potential carbon sequestration rate of agroforestry systems in the tropics ranges from 1.5 to 3.5 Mg C/ha/year. They also point out the systems, indirect effect on carbon sequestration which helps decrease pressure on natural forests. In the humid tropics, the potential of agroforestry tree-based systems to sequester carbon in vegetation can be over 70 Mg C/ha, and up to 25 Mg/ha in the top 20 cm of soil (Mutuo *et al.*, 2005). Winjum *et al.* (1992) report that the potential of carbon sequestration (Gt C over 50-year period) in tropical area are 6.5 to 13 for reforestation project; 19.5 to 39.0 for natural forest; and 9.5 to 19.0 for agroforestry. Schroeder (1994) estimated carbon sequestration of agroforestry systems in three different zones. The calculation is estimated from stem-wood volume converted to total above-ground biomass. The system can sequester carbon up to about 2.6 t C/ha/year in the semi-arid zone; 6.1 t C/ha/year in sub-humid zones; 10.0 t C/ha/year in humid; and 3.9 t C/ha/year in temperate zones.

All studies above show that agroforestry systems have a great potential in carbon sequestration. The next section discusses this potential in a particular agroforestry system in Indonesia, the coffee multi-strata garden in Sumberjaya, Lampung, Indonesia.

A Case Study: The Potential of Carbon Sequestration in Coffee Multi-strata in Sumberjaya, Lampung

Sumberjaya is a government-sponsored settlement and has been inundated by migrants since 1970s. As the population increased rapidly, massive forest conversion also occurred in the area. Conflict of interest over land-use and land status aroused when the government started to control the utilisation of state forestland in the area. Government efforts to rehabilitate state forestland used for agriculture purposes (mostly coffee gardens) and settlements created serious conflicts. Conflicts between forest officers and the people who lived in the state forests escalated from protests to physical violence. The objectives of reforestation were not only hard to meet but the people also suffered (Budidarsono *et al.*, 2000).

Subsequently, the government introduced a program called *Hutan Kemasyarakatan* (HKm) or social forestry in 2001. The people having coffee gardens in the state forest land were allowed to continue growing coffee under timber trees. They were given the responsibility to maintain trees and carry out management practices for soil and water conservation. The government also supported the farmers with timber tree seedlings and limited technical assistance (Pender *et al.*, 2007).

The vegetation structure and complexity of coffee gardens vary from simple-shaded coffee systems to complex agroforestry (multi-strata coffee system). Farmers usually plant upland paddy in the first year(s); in some cases farmers also plant vegetables to meet subsistence needs before coffee reaches production age (around three years old). *Coffee robusta* dominates coffee cultivation in Sumberjaya (Budidarsono *et al.*, 2000).

Simple-shaded coffee systems typically consist of coffee with Gliricidia, Erythrina and/or Leucaena spp. as shade trees, while multi-strata coffee involves Gliricidia, Erythrina and/or Leucaena and other trees (fruit trees and or timber trees) as shade trees (Hairiah *et al.*, 2006). The median mid-range wood density for tree species found in multi-strata coffee gardens was 0.75 Mg m-3 (light 39%, medium 38.5%, heavy 15.2%, and very heavy 6.5%) (van Noordwijk *et al.*, 2002).

The calculation of carbon sequestration in the case study area is drawn from ICRAF sample plots. Van Noordwijk *et al.* (2002) estimated tree biomass using the allometric equation on the basis of stem diameter at 1.3 m above ground:

$W = 0.11\rho D2 + c$,

where ρ is the wood density and the coefficient c is 0.62

The calculation also includes root biomass (coffee roots) which is derived from the following allometric equation:

$W = 0.281D2.06$,

c = 0.08 (H = 1.79 D0.008)

Soil carbon was estimated from 24 sample plots which was collected from 0-5, 5-15, and 15-30 cm depth layer and analysed for texture, pH, exchangeable bases (Na, K, Ca and Mg), exchangeable Al and acidity.

In the first survey, the total biomass average in shade coffee gardens, from 2-30 years old, was around 92 Mg/ha. The second survey indicated that the average carbon stock in above-ground biomass of coffee trees in shade coffee gardens between 6 and 40 years of age was 18.4 Mg/ha, with a standard deviation of 4.0, and the average for non-coffee trees was 29.6 Mg/ha with standard deviation of 18.9. The annual carbon stock increment is estimated as roughly 2 Mg C/ha/year (van Noordwijk *et al.*, 2000).

Many estimations of carbon sequestration in agroforestry systems in the tropics show variations in the calculations. Carbon sequestered in such systems ranges from 1.5 t C/ha/year up to 10 t C/ha/year. The annual carbon sequestration of a coffee multi-strata garden in Lampung, Indonesia, is within the interval, about 2 t C/ha/year. Variation in calculations depend on several factors, for example, in some calculations, root biomass or below-ground biomass is not taken into account; the difference in soil, vegetation species and structure, management practices in the sample plots are not measured; and also the local climate is not taken into coordination. Most of the literature calculated the carbon sequestration in agroforestry systems based solely on the attributes of the tree component, however, the total components of complex agroforestry are not only trees.

The potential of carbon sequestration only is a measure of the direct effect of agroforestry in reducing CO_2 in the atmosphere. As Dixon (1994) remarks, agroforestry systems would give greater benefit in terms of global climate change if the systems could lessen the pressure on natural forests.

Regarding global carbon pools, the previous land-use of the agroforestry systems should also be considered. The rate of carbon sequestration will be significant in reducing CO_2 if the systems are established on degraded land. Forest clearing offsets should also be taken into account; otherwise the net carbon flux will be inadequate.

Palm *et al.* (2005) reported that the carbon losses from natural forests to log forests in Indonesia are 200 t C/ha and further losses from logged forest conversion to tree-based systems range from 40 to 90 t C/ha above-ground and 6 to 12 t C/ha from soil. Kandji *et al.* (2006) also point out that while agroforestry systems contain less carbon than natural forests, the systems can maintain higher carbon stocks than row crops or pastures. Therefore, agroforestry has the potential for carbon sequestration, in addition to rehabilitating degraded land.

Moreover, regardless of the great benefits offered by agroforestry, particularly in carbon sequestration, most agroforestry farmers in Indonesia live below poverty line (their income is less than $ US 1 per day). On average, the farmers only control less than five hectares per household. Yet, land ownership of many farmers is only about 0.25 hectare. Land productivity is also low as they use poor planting materials taken straight from the forest without appropriate treatment or technological improvement. As their incomes are low, most farmers illiterate and lack both the capital and the knowledge to improve their land productivity.

Linking the potential of agroforestry in carbon sequestration to climate change adaptation would give enormous incentive for smallholder farmers. Rewarding them for providing environment benefits such as reducing emissions would help poverty alleviation in many rural areas. Taking up this opportunity would also improve the capacity of developing countries such as Indonesia to deal with climate change. Lipper and Catavasi (2004) argue that ‘to extent that the land-use changes required for poverty alleviation coincide with those required for carbon sequestration, significant synergies can be harnessed in meeting both objectives’ (p. s374).

CONCLUSION

Agroforestry systems provide an alternative land-use which can benefit the rural economy in developing countries and also has the potential for reducing emissions, particularly sequestering carbon dioxide from the atmosphere via photosynthesis process in the tree component. The review of the literature showed that the potential of carbon sequestration in agroforestry systems in tropics ranges from 1.5 t C /ha/year up to 10 t C/ha/year almost similar to the carbon sequestered in pulpwood plantation, which is 10 t C/ha/year. Because of the importance of agroforestry in rural areas and the potential for the systems in reducing emissions, it is important to recognize and reward the farmers for maintaining their agroforestry systems. It would enhance the mitigation of carbon emissions as well as addressing poverty alleviation in rural areas.

REFERENCES

Albrecht, A., and Kandji, S.T., 2003., Review: Carbon sequestration in tropical agroforestry systems, *Agriculture, Ecosystems and Environment*, 99: 15-27.

Budidarsono, S., Kuncoro, S.A., and Tomich, T.P., 2000. *A profitability assessment of robusta coffee systems in Sumberjaya Watershed, Lampung, Sumatera, Indonesia*, Southeast Asia Policy Research Working Paper, No.16, Bogor, Indonesia.

de Foresta, H., and Michon, G. 1997. The agroforest alternative to Imperata grasslands: when smallholder agriculture and forestry reach sustainability, Agroforestry Systems, 36: 105-120.

de Foresta, H., Kusworo, A., Michon, G., and Djatmiko, W.A., 2000. *Ketika kebun berupa hutan – Agroforest khas Indonesia – Sumbangan masyarakat bagi pembangunan berkelanjutan (Garden-like forest – Typical agroforests in Indonesia – Community contribution to sustainable development)*, International Centre for Research in Agroforestry, Institu de Recherche pour le Dévelopment, Ford Foundation, Bogor.

Dixon, R.K., 1995. Agroforestry systems: source or sinks of greenhouse gases?, *Agroforesty Systems*, 31: 99-116.

Dixon, R.K., Winjun, J.K., Andrasko, K.J., Lee, J.J., and Schroeder, P.E., 1994., Integrated land-use systems: assessment promising agroforest and alternative land-use practices to enhance carbon conservation and sequestration. Climatic Change Journal, 27: 71-92.

Goldewijk, K.K., van Minnen, J.G., Kreileman, G.J.J., Vloedbeld, M., and Leemans, R., 1994. Simulating the carbon flux between the terrestrial environment and the atmosphere, *Water, Air, and Soil Pollution*, 76: 199-230.

Griffin, K.L. and Seemann, J.R., 1996, Plants, CO2, and photosynthesis in the 21st century, *Chemistry & Biology*, 3: 245-254.

Hairiah, K., Sulistyani, H., Suprayogo, D., Widianto, Purnomosidhi, P., Widodo, R.H., and van Noordwijk, M., 2006. Litter layer residence time in forest and coffee agroforestry systems in Sumberjaya, West Lampung, Forest Ecology and Management, 224: 45-47.

Houghton, J.T., Ding, Y., Griggs D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K., and Johnson, C.A. (eds), 2001. *Climate Change 2001: The scientific basis*, The Intergovernmental Panel on Climate Change (IPCC) Report, Cambridge University Press, Cambridge.

IPCC (International Panel on Climate Change), 1997.

Jose, S., 2009. Agroforestry for ecosystems services and environmental benefits: an overview, *Agroforestry Systems*, 76: 1-10.

Kandji, S.T., Verchot, L.V., Mackensen, J., Boye, A., van Noordwijk, M., Tomich, T.P., Ong, C., Albrecht, A., and Palm, C., 2006. *Opportunities linking climate change adaptation and mitigation through agroforestry systems*. In Garrity, D., Okono, A., Grayson, M., and Parrott, S. (eds). World Agroforestry into the Future, World Agroforestry Centre, Nairobi, Kenya, pp. 113-121.

Kimmins, J.P., 2004, *Forest Ecology: a foundation for sustainable forest management and environmental ethics in forestry*, Prentice Hall, New Jersey.

Kusters, K., Pérez, M.R., de Foresta, H., Dietz, T., Ros-Tenen, M., Belcher, B., Manalu, P., Nawir, A., and Wollenberg, E., 2008. Will agroforests vanish? The case of damar agroforests in Indonesia, *Human Ecology*, 36: 357-370.

Lipper, L. and Cavatassi, R., 2004. Land-use change, carbon sequestration and poverty alleviation, *Environmental Management*, 33 (1): S374-S387.

Montagnini, F. and Nair, P.K.R., 2004., Carbon sequestration: an underexploited environmental benefit of agroforestry systems, *Agroforestry Systems*, 61: 281-295.

Mutuo, P.K., Cadischi, G., Albrecht, A., Palm, C.A., and Verchot, L., 2005., Potential of agroforestry for carbon sequestration and mitigation of greenhouse gas emissions from soils in the tropics, *Nutrient Cycling in Agroecosystems*, 71: 43-54.

Nair, P.K.R., 1985. Classification of agroforestry systems, *Agroforestry Systems*, 3: 97-128.

Niles, J.O., Brown, S., Pretty, J., Ball, A.S., and Fay, J., 2002. Potential carbon mitigation and income in developing countries from changes in use and management of agricultural and forest lands, *Journal Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 360 (1797): 1621-1639.

van Noordwijk, M., Rahayu, S., Hairiah, K., Wulan, Y.C., Farida, A., and Verbist, B., 2002. Carbon stock assessment for a forest-to-coffee conversion landscape in Sumberjaya (Lampung, Indonesia): from allometric equations to land-use change analysis, *Jurnal of Science in China*, 45: 75-86.

Palm, C.A., Woomer, P.L., Alegre, J., Arevalo, L., Castilla, C., Cordeiro, D.G., Feigl, B., Hairiah, K., Kotto-Same, J., Mendes, A., Moukam, A., Murdiyarso, D., Njomgang, R., Parton, W.J., Riese, A., Rodrigues, V., Sitompul, S.M., and van Noordwijk, M., 1999., *Carbon sequestration and trace gas emissions in slash-and-burn and alternative land uses in the humid tropics*. ASB Climate Change Working final Report, Phase II. ASB Coordination Office, ICRAF, Nairobi.

Palm, C.A., Woomer, P.L., Alegre, J., Arevalo, L., Castilla, C., Cordeiro, D.G., Feigl, B., Hairiah, K., Kotto-Same, J., Mendes, A., Moukam, A., Parton, W.J., Riese, A., Rodrigues, V., Sitompul, S.M., 2005. Carbon losses and sequestration following land use change in the humid tropics, in. Palm, C., Vosti, S.A., Sanchez, P.A., Eriksen, P.J., and Juo, A. (eds), *Slash and burn: the search for alternatives*, Columbia University Press, New York. pp. 41-63.

Pender, J., Suyanto, Kerr, J., and Kato, E., 2007. Impacts of the *Hutan Kemasyarakatan* (HKm) social forestry program in the Sumberjaya Watershed, West Lampung District of Sumatera. International Food Policy State University (MSU) and IFRI. *Paper is presented for "The American Agricultural Economics Association Annual Meeting"*, Portland.

Schoeneberger, M.M., 2009. Agroforestry: working trees for sequestering carbon on agricultural lands, *Agroforestry Systems*, 75:27-37.

Smith, T.M., Cramer, W.P., Dixon, R.K., Leemans, R., Neilson, R.P., and Solomon, A.M., 1993. The Global Terrestrial Carbon Cycle, *Water, Air, and Soil Pollution*, 70: 19-37.

Winjum, J.K., Dixon, R.K., and Schroeder, P.E., 1992. Estimating the global potential of forest and agroforest management practices to sequester carbon, *Water, Air, and Soil Pollution*, 64: 213-227.