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Agroforestry Systems for Sustaining Rural Development and Protecting Environmental Quality

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ABSTRACT

The future of rural ecosystems is increasingly dependent on the pattern of landscape or land utilization. Agroforestry systems are recognized as the most common rural landscape in Tropical Asia. They are characterized by complex interactions among social, cultural, economic, institutional, and environmental variables. These interactions create complex man-made landscapes, which significantly affect the function of local and global ecosystems and the services they provide to humans. Agroforestry systems improve natural habitat, species diversity, carbon sequestration, hydrological systems, and modify energy flows and nutrient cycling. Change in ecological conditions within these systems ultimately influences human health and well-being. This paper presents the empirical evidences on the effects of different types of agroforestry systems on the ecosystem functions with regard to rural growth and environmental quality. The research reveals that interaction between rural development and ecosystem dynamics is important to determine the environmental services provided by agroforestry system. In conclusion, study cases have shown that agroforestry is a promising system with respect to enhanced land productivity and better environmental quality as compared to other systems, such as monoculture-plantation, grain cropping and fallowing.

Keywords: *Agroforestry, Asia, biodiversity, carbon sequestration, rural development, environment services.*

INTRODUCTION

The projected increase of human population from six to eight billion people by the year 2020 has caused more pressure on natural resources and the capacity of the land to feed the world. Agricultural land needs to be intensified in an efficient way to avoid further expansion into fragile land and protected forests. Strengthening farming systems with diversification and green economy solution without degrading the environment would be required. Combining the benefits of plants, soil, water, and animals to ensure food-feed-fiber production and environmental sustainability is fundamental for future. Agroforestry systems offer approaches that address the challenges for future environmental systems, while improving green economy and conserving the natural resources on which farming systems depend.

The main concept of agroforestry is long-term stabilization instead of achieving maximum yield. The system requires more than a simple modification of traditional farming. Considerations toward self-sufficiency, diversification, economically viable small-scale farming, and technology adapted to local resources are necessary (Altieri, 1987; Gliessman, 2001). Agroforestry systems allow farmers to utilize their indigenous knowledge of soil, plants, and resource conservation and incorporate it into everyday farming practices (Handayani and Prawito, 2008). Culture strongly influences the practice of agroforestry which permits unique strategies for farmers to develop land sustainability according to local environmental conditions. The integration of indigenous knowledge into agroforestry science and practice plays a critical role in maintaining ecosystem stability and strengthening agricultural production from a non-industrial perspective (Handayani *et al*., 2006). Therefore, agroforestry systems are varied country to country depending on physical and social characteristics of a particular country.

The main goal of modern agriculture is to increase agricultural production at a maximum level. These differences show that the values of agroforestry need to be further highlighted to empower the sustainability of future agriculture. Based on the environmental attributes, agroforestry systems have more values toward sustainability compared to modern agriculture. This paper provides reviews on benefits of agroforestry management for people and the environment.

VALUES OF AGROFORESTRY

People and environment are two main components in sustainability. Providing food security, eradication of hunger and poverty and maintaining standard environmental quality are the priority goal to be achieved on the way of reaching sustainable agroecosystem. In this review, we examine the key benefits of agroforestry based on lessons from various countries.

Agroforestry for nutrition and health

Agroforestry development has many links with improving nutrition and health of the rural community. The quantity and expansion of fruit trees and vegetable on farms have a significant impact on the quality of nutrition for children and adults. This is important especially for countries facing a problem of indigenous fruit tree exploitation. Domestication of wild indigenous fruit trees is popular in Africa and Asian countries.

There is potential for agroforestry to generate much-needed income, improve nutrition, reduce labor demands (Rao *et al.*, 2004). They reported that natural medicinal plants are important sources to heal many diseases and ailments of the poor throughout the developing world. For example, more than 80% of the population in Africa depends on medicinal plants from farmland and forest for their medical needs.

In Indonesia, about 60% to 80% of the rural population relies on medicinal plants because of the high cost of commercial drugs. Most agroforests in Asia and Africa involving medicinal plants both trees and shrubs to provide everyday need for medicine. Supports from local government regarding to domestication of medicinal plants from forests improve the understanding of local community to preserve the species.

Agroforestry for economic values

Nearly 75% of the people who live on less than $1 a day are found in the rural areas of developing countries (Dixon *et al.*, 2001). Thus, agriculture development is the main controlling factor to improve people's access to both food and income. In developing countries, agricultural activities always provide benefits poor people, with greatest gains going to those most in need (Thirtle *et al.*, 1995). Mellor (2001) stated that empirical work indicates a strong relationship between agricultural productivity and poverty. Rising farm incomes automatically reduces poverty level. Research shows that a 1% yield increase is associated with a 1% drop in the number of people living on less than $1 a day (Dixon *et al.*, 2001).

Lessons from existing agroforests in Africa, Asia, Europe, and the United States indicate that trees play a critical role for economic growth. For example, cacao, coffee, tea, cardamom, rubber trees have been mainstays of the economics in countries of Asia and Africa. Poplar, willows and eucalyptus provide economics values for several states in the United States and countries in Europe. Sharma *et al*. (2000) reported that cardamom agroforestry in Nepal provides profits approximately 6 times more than rainfed agriculture.

The cardamom systems seem to be economically beneficial for farmers having marginal lands who largely depend on subsistence farming practices (Table 1). Alston and Pardey (2002) estimated the rate of return to investment in tree crop research from the 108 studies was 88%, while the rate of return in field crop research was averaged of 74% from 916 studies. In Bangladesh, it is estimated that 90% of the wood used is produced on agroforests. In India, about 50% of the timber need is supplied by agroforests owned by local people (Bellefontaine *et al*., 2002). Therefore, in some parts of developing countries, the smallholder may be the wood producer of the future and consequently it can become a provider of high quality of tropical wood. The World Agroforestry Centre and the Forestry Department of the Food and Agriculture Organization of the United Nations (FAO) are working together to draw international attention to the need of farm-grown wood. This will provide a fundamental focus on smallholder timber production systems in the future (Omamo and Lynam, 2003).

Table 1. Comparison of inputs and outputs using cash equivalents (in USD per ha) in cardamom agroforestry and rainfed agriculture in Nepal.

Input/Output	Cardamom agroforestry	Rainfed agriculture
	Input	
Labor	53	80
Firewood	40	-
Chemicals	-	50
Manure	-	80
Seed/planting stock	30	100
Input total	123	310
	Output	
Yield	1533	544
Firewood	79	-
Fodder/crop residue	7	30
Output total	1619	574
Output : Input ration	13.16	1.85

Source: Sharma and Sharma (1997)

Agroforestry for spiritual and cultural practices and scenic beauty

In most of the countries in Asia, the indigenous communities still believe that plants, animals, forests, soil, and water are considered sacred and culturally important (Handayani and Prawito, 2008; Ramakrishnan, 1998). In general, ecosystems play an important role in cultural and spiritual traditions for the local people. Agroforests contribute in spiritual services and recreation for the culturally diverse ethnic communities and therefore they can attract more tourists and visitors from outside the region. For example, the beauty of agroforests in the mountain of Himalaya called *Ney-Pemathang* or *Shangri-La* (the hidden paradise on earth) is worshipped during various religious traditional festivals. This opportunity gives social harmonization among various ethnic communities, such as *Lepchas, Bhutias*, and *Napalis* and strengthen traditional institutions like *Dzumsa* (a traditional governance system) (GIAHS, 2007).

Sacred agroforests resulting from cultural interactions have also been described in some countries in Africa such as Kenya, Ghana, and Congo (Falconer, 1992). In Indonesia, the Baduy sacred the forests in west part of Java Island. Temedak agroforests in Sumatra is considered a sacred place that has cultural values and also connect to economical needs. These agroforests promote traditional garden landscape and can be used as good means of preserving biological and cultural diversity. This area now attracts more tourists each year which makes indigenous people are proud to show about their cultural values and practices.

Agroforestry for environmental services

Valuing environmental services of agroforests uses the concept of welfare economics meaning the value of public good is the sum of what individuals would be willing to pay for it (Varian, 1992). This concept has been extensively used to value environmental services associated with forestry and agricultural practices (Cameron *et al.*, 2002; Loomis *et al.*, 2000).

Involvement of trees in the agroforestry systems increases the amount of C stored in the fields, while still allowing the growing of food crops (Kürsten, 2000). Agroforestry plays an important role in carbon sequestration because of carbon storage potential in its multiple plant species and soil as well as its benefit in agricultural lands and in reforestation and or restoration (Montagnini and Nair, 2004). However, there are three factors controlling the rate of C sequestration in the ecosystems such as (i) soil fertility, (ii) monoculture versus polyculture, and (iii) the age of the agroforests.

Nair (2001) reported that agroforests are able to significantly improve soil fertility, particularly in the tropics and they entail mixed stands of species, so the systems have a unique advantage in terms of C sequestration compared to plantation and pasture. The potential for carbon sequestration seems to be substantial; but it has not been adequately recognized (Montagnini and Nair, 2004).

Average C storage by agroforestry systems has been estimated to be 9, 21, 50, and 63 Mg C ha^{-1} in semiarid, subhumid, humid, and temperate regions, respectively, assumingratios of tree-stem biomass to C content of 1:2 (50% of stem is to be C) (Schroeder, 1994). The higher levels in temperate regions indicate the longer cutting cycles in these regions resulting in long-term storage. Globally, agroforests can store approximately 12 to 228 Mg C ha^{-1} under the prevalent climatic and edaphic conditions (Dixon, 1995). He also observed that 1 ha of sustainable agroforestry can potentially offset 5 to 20 hectares of deforestation in tropical regions. Lessons from Africa, Asia, Europe and the United States demonstrate agroforestry systems can be either sinks or sources of C. Agroforestry systems which involve trees and crops (agrisilviculture) can be C sinks and temporarily store C, while others (e.g. ruminant-based agrosilvopastoral systems) are probably sources of C and other greenhouse gases.

Nair and Nair (2003) determined that the total C sequestration potential through agroforestry practices in the United States could amount to 90 Tg C yr^{-1} (Table 2). On average of 2.0 Tg C yr^{-1} could be presented as the C sequestration potential of agroforestry practices in the United States (Lal *et al*., 1999). According to Sharrow and Ismail (2004), the agroforests (silvopastures) in Oregon, United States were more efficient to sequester C than tree plantations or grass monocultures. This was caused by higher biomass production and active nutrient cycling in both forests stands and grasslands, compared to those of pastures or timber stands alone.

Table 2. Predicted carbon sequestration potential in agroforests in the USA by 2025.

Agroforest type	Estimated area[Θ]	Potential C sequestration (Tg C yr^{-1})[@]
Alleycropping	80 x 10^6 ha	73.8
Silvopasture	70 x 10^6 ha	9.0
Windbreaks	85 x 10^6 ha[§]	4.0
Riparian Bffer	0.8 x 10^6 km of 30-m-wide forested riparian buffers	1.5
Short rotation woody crops (SRWC), forest farming, etc.	2.4 x 10^6 km conservation buffer including SRWC	2.0
Total		90.3

[Θ] Area that is currently under or could potentially be brought under the practice
[§] Area of exposed cropland, 5% of which to be planted to windbreaks
[@] Assuming their implementation by 2010, the estimated C sequestration benefits could be appropriate for 2025; potential benefits thereafter will depend on expansion or shrinkage of areas under the different practices.
Source: Nair and Nair (2003)

Follett *et al.* (2001) estimated the average of soil C sequestration potential for U.S. grazing lands was 69.9 Tg C yr^{-1} and the potential for silvopastures could be about 9.0 Tg C yr^{-1}. To protect the 85 million ha of exposed cropland in the North Central United States by planting 5% of the field area to windbreaks would sequester more than 58 Tg C (215 Tg CO_2) in 20 years, or an average of 2.9 Tg C yr^{-1} (National Agroforestry Center, 2000, *www.unl.edu/nac*). In addition, planting windbreak in the 300 000 unprotected farms in the U.S. would yield about 120 million trees (at the rate of 400 trees/home), storing around 3.5 Tg C in 20 years or 0.175 Tg C yr^{-1}. (Montagnini and Nair, 2004).

Agroforests in tropical regions can contribute significant sources of greenhouse gases due to cultivation practices such as tillage, burning, manuring, and chemical fertilization. Silvopastoral systems can also result in soil compaction and erosion if the practices are not properly applied. In addition, ruminant-based agrosilvopastoral systems are well considered as sources of methane (Dixon, 1995). Finally, whether agroforestry systems can be a sink and a source of C depends on the land-use systems that they replace; if they replace forests, they will have lower biomass and C, but if they are established on degraded or deforested areas, their C sequestration value is significantly increased (Nair, 2001).

Facing of C markets, C sequestration ability in agroforestry systems becomes an additional output that landowners might consider in their management decision. In this case, the dynamics of agroforestry management include the rotation age of trees, crop-tree mixture, soil fertility, landscape design and other management practices *in situ* will be important. Introducing carbon payments as incentive for farmers causes agroforestry systems may become more attractive, but research addressing both physical and socioeconomic issues of C sequestration is needed.

Agroforestry systems found in Africa, Asia, Europe and the United States are also efficient in controlling soil erosion and landslides as the trees and the understory crops help in binding the soil through their roots and mycorrhiza (Sharma *et al*., 1997). Research suggests that soil loss from agroforestry systems is lower than other land-use types (Sharma *et al*., 2002).

The conservation value for water in the agroforestry systems was found to be about 80% higher compared to monocrop fields. The shade trees provide buffered environment at ground level providing to microclimate regulation while agroforestry patches along the mountain slope control it at a landscape level. The agroforests also can be used as habitat for pollinators and biological agents of pests and disease (Gleissman, 2001; Nair, 2001).

DISCUSSION AND CONCLUSIONS

The value of agroforests to promote people's life and the environment is being increasingly recognized. The presence of trees and crops at the same landscape unit provide benefits for people and the surrounding environment. Food, nutrition, and health are the basic needs of people that can be fulfilled by agroforests. In most developing countries, agroforests have values with regard to spiritual and cultural tradition as well as providing a scenic beauty for the society.

At the global level, agroforestry systems provide environmental values related to C sequestration, resource conservation, and improving biodiversity. Study cases from different countries provide general information on the status of the agroforests, as well as their benefits to people and the environment. The use of legumes, grasses and trees in agroforestry systems increased farmers' income in Philippines due to improvement in livestock and crop productions and less labor. Planting of various cardamom species in traditional agroforests significantly increased farmers' income in Vietnam, Thailand, China and Laos. Different plant species with various level of tolerance to soil pH also helped to maintain soil productivity. In Indonesia, rubber-tree based agroforests is considered the best option to improve C sequestration, biodiversity conservation, prevent deforestation, and farmer income.

Combining fruits, trees and vegetables remains as a common design for agroforests in Europe, but the benefits from the system are still limited. The economic returns are difficult to assess due to limited research and high variability of incentives for local farmers. In Florida, USA, agroforestry system can act as phytoremediator while producing fuelwood and timber products. Additional benefits of agroforests along streams were for windbreak, erosion control, water quality improvement, and provided better habitat for fish and wildlife. Agroforests also provide sources of natural medicinal plants about 80% of the population in Africa and 70% of the rural areas of Indonesia. In general, agroforests in Asia and Africa involving medicinal plants supplied about 75% of everyday need of medicine in the rural areas.

The main trees in agroforests such as cacao, coffee, tea, cardamom, and rubber have economic values, especially in Asia. Poplar, willows, and eucalyptus are beneficial for the United States and some countries in Europe. In addition, 90% and 50% of wood was supplied by agroforestsin Bangladesh and India, respectively. Sacred agroforests have been found in some countries in Africa (i.e., Kenya, Ghana, Congo) and Asia (India, Indonesia, Himalaya).

These agroforestry systems are places for spiritual - cultural practices and tourisms. Environmental services provided by agroforests include C storage, preventing from deforestation, improving soil fertility and soil biodiversity, controlling soil erosion and microclimate, can be used as habitat for pollinators and biological agents of pests and diseases.

These examples above show the contribution of agroforestry systems within global environment and eventually will ensure better values for sustainability. However, to develop effective means of managing the benefits of agroforests will require robust and dynamic knowledge. Altering circumstances over time can bring new perceptions and new demands on agroforestry. Better understanding about the roles of trees and forests in carbon, other nutrient, climatic and water cycles will enhance integrated innovations in agroforestry management and biodiversity conservation. Agroforest products (e.g. biodiversity) must have market values, if not, they tend to be undervalued and are likely to be degraded (McNeely, 2003).

Farmers now are seeking diverse combinations of compatible agroecosystem uses. For example, they find that conserving biodiversity, reducing soil erosion and storing C are highly compatible agroforestry services, in addition to non-timber production, soil and water conservation, recreation and tourism. These services are incompatible with clear-cutting or slash-burning, but may be compatible with well-managed agroforestry. The trend of multi-product forestry is continuing, giving more benefits for people living in and around the agricultural lands.

REFERENCES

Alston, J. M. P. G. Pardey, J. S. James, and M. A. Andersen. 2002. The Economics of Agricultural R&D. Annual Review of Resource Economics. Vol. 1: 537-566.

Altieri, M.A. 1987. Agroecology: The scientific basis of alternative agriculture. Boulder, Westview Press.

Bellefontaine R, Petit S, Pain-Orcet M, Deleporte P, Bertault J-C (2002). Trees outside forests.Towards better awareness. FAO Conservation Guides 35, Rome, 216 pp

Cameron, T.A., G.L. Poe, R.G. Ethier, and W.D. Schulze. 2002. Alternative non-market value-elicitation: Are the underlying preference the same? J. Environ. Econ. Manag. 44:391-422.

Dixon, J., Gulliver, A., Gibbon, D., Hall, M. (2001). Farming Systems and Poverty. Improving Farmer's Livelihoods in a Changing World. FAO and World Bank, Rome, Italy and Washington D.C. USA. Available Online at: *http://www.fao.org/ DOCREP/003/Y1860E/y1860e00.htm*

Dixon, R.K. 1995. Agroforest system: Sources or sinks of greenhouse gases. Agroforest syst. 31:99 – 116.

Falconer, J. 1990.The major significant of ”minor” forest products. The local used and value of forests in the West African Forest Zone. FAO. Rome. Community Forest Note. No. 6

Follett, R.F., S.E. Samson-Liebig, J.M. Kimble, E.G. Pruessner, and S.W. Waltman. 2001. Carbon sequestration under the CRP in the historic grassland soils in the USA. In: R.Lal and K. McSweeney (eds) "Soil Management for Enhancing Carbon Sequestration," SSSA Special Publication, Madison, WI. (in press)

Gleissman, S.R. 2001. Agroecosystem sustainability developing practical strategy.

Globally Important Agriculture Heritage Systems (GIAHS).2007. *http://www.fao.org/nr/giahs/giahs-home/en/*

Handayani, I.P., and P. Prawito. 2008. Exploring folk knowledge of soil. International Journal of Soil Science 3:83-91.

Handayani, I.P., P. Prawito, Z. Muktamar, and M.S. Coyne. 2006. Nurturing soil science in Indonesia by combining indigenous and scientific knowledge. Soil Survey Horizons 47:79-80.

Kürsten, E. 2000. Fuelwood production in agroforestry systems for sustainable land use and CO_2-mitigation. In: Forests in Focus, Proceedings Forum "Forests and Energy" 17 - 21 January 1998, NNA Reports, Vol. 12, Special Issue 1, 1999, 141-143 (pdf-download (69 KByte)) + Ecological Engineering 16, Supplement 1, (2000), 69-72

Lal, R., J. M. Kimble, R.F. Foleit, and C.V. Cole. 1999. The potential for US croplands to sequester carbon and mitigate the greenhouse effect. Lewis Publ. Boca, Raton. Pp 55 - 82

Loomis, J.B., P. Kent, L. Strange, K. Fausch, and A. Covich. 2000. Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from 2 contingent valuation survey. Ecol. Econ. 33:103-117.

McNeely, J.A., and S.J. Scherr. 2003. Ecoagriculture: Strategies to feed the world and save wild biodiversity. Island Press. 296 p.

Mellor, John W. 2001. Rapid Employment Growth and Poverty Reduction: Sectoral Policies in Rwanda. Washington, DC: Abt Associates, Inc.

Montagnini, F., Nair, P.K.R. 2004. Agroforestry has an importance as a carbon sequestration. Agroforestry Sys. Vol.61-62.

Nair M.A. and Sreedharan C. 1986. Agroforestry farming systems the homesteads of Kerala, southern India.AgroforestSyst 4: 339-363.

Nair, P.K.R. 2001. Do tropical homegardens elude science, or is it the other way around. AgroforestSyst. 53:239-245.

Nair, P.K.R., and V.D. Nair. 2003. Carbon Storage in North American Agroforestry Systems: Myth and Science. P. 1-31. In: Buck, L.E., Lassoie, J.P., and Fernandez, E.C.M. (eds). Agroforestry in Sustainable Agricultural Systems. CRC Press, Boca Raton , FL. , USA .

National Agroforest Centre. 2000. Agroforest. Working trees for agriculture.*www.unl.edu.nac*

Omamo, S.W. and J. Lynam. 2003. Agricultural science and technology policy in Africa. Research Policy, 32: 1681-1694.

Ramakhrishnan, P.S., K.G. Saxena, and U.M. Chandrashekara. 1998. Conserving the sacred for biodiversity management. Oxford and IBH, New Delhi.

Rao, M. R., G. Schroch, SA. William, S. Namirembe, M. Scaller, J. Willson, and D. Vandemeer. 2004. Managing belowground interactions in agroecosystem. *In*. vanNoorwijk. M, G. Candish, and C. K. Ong. (eds) Belowground interactions in multiple agroforest systems. CAB International, Willingford, UK

Schroeder, P. 1994. Carbon storage benefits of agroforestry system.Agroforest Sys. 27:89 – 97.

Sharma, E., Sharma, R., Singh, K.K., Sharma, G. (2000) A Boon for Mountain Populations.Large Cardamom Farming in the Sikkim Himalaya.Mountain Research and Development20(2): 108-111.

Sharma, G., Sharma, E., Sharma, R. Singh, K. K. (2002) Performance of an age series of *Alnus-cardamom* plantations in the Sikkim Himalaya. Biomass, Productivity and Energetics.*Annals of Botany* 89: 261-272.

Sharma, R., Sharma, E., Purohit, A. N. (1997) Cardamom, mandarin and nitrogen-fixing trees in agroforestry systems in India’s Himalayan region. II. Soil nutrient dynamics. Agroforestry Systems. 35, 235-253.

Sharrow, S.H., and S. Ismail. 2004. Carbon and nitrogen storage in western Oregon agroforests, forests, and pastures. Agroforestry Systems 60:123-130.

Thirtle, C., D. Hadley, and R. Townsend. 1995. A multilateral mamlquist productivity index approach to explaining agriculture growth in sub-saharan Africa. Development Polecy Review.13:323 – 348.

Varian, H.R. 1992. Microeconomic analysis. WW Norton. New York.