A COMPARATIVE ANALYSIS OF AFFORESTATION AND AGROFORESTRY OPTIONS FOR THE REDUCTION OF CARBON IN NIGERIA

*D.A. Pelemo[1], W.O. Siyanbola[1], F.O. Johnson-Fatokun[1], F.A. Adesina[2], A.O. Adegbulugbe[1], and S. Oluwalana[3]

*[1] Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Nigeria. [2] Department of Geography, Obafemi Awolowo University, Ile-Ife, Nigeria. [3] Federal University of Agriculture, Abeokuta, Nigeria. *Corresponding author. email: dpelemo@yahoo.com*

Accepted in January 2004.

Abstract

This paper examines the relative efficiency of afforestation and agroforestry options in carbon sequestration using the COMAP model. The end use scenario which considers the wood needs of the country is adopted. The wood needs projected to year 2030 were used to estimate the land area required to prosecute the projects. The capability for carbon sequestration and the various costs and benefits of executing the two options were estimated. Items monetized include land, labour, seedling, product unit and tonnes of carbon. Except for sawlog plantation, the carbon pool (sequestered) under afforestation is consistently higher than for agroforestry programmes in the model runs. The results showed that afforestation programmes can pool about 175.2 tC/ha compared to 131.4 tC/ha in agroforestry. The total carbon stored in afforestation was about twice that of agroforestry. The figures are 638.6 and 316.6 MtC for afforestation and agroforestry, respectively. The study concludes that based on carbon flow pattern only, afforestation would be more rewarding if equal land area is used for both forestry programmes. However, because of the other benefits derivable from agroforestry projects such as improved soil fertility and the fact that greater opportunity for running agroforestry projects exist in practical terms in the country, a mix of the options is recommended for implantation depending on wood products targeted as well as the ecological zone for which the project is being planned.

Keywords: agroforestry, afforestation, carbon, climate change, mitigation

[1] Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Nigeria.
[2] Department of Geography, Obafemi Awolowo University, Ile-Ife, Nigeria.
[3] Federal University of Agriculture, Abeokuta, Nigeria.

Introduction

Scientists are strongly anticipating significant changes in global climates. These are linked in part, to the increasing concentration of greenhouse gases (GHGs) such as CH_4, CFCs, SO_2 and particularly CO_2 in the atmosphere. The increasing concentration of these gases in the environment is traceable largely to the burning of fossil fuels and biomass (Watson *et al.* 1990). The gases lock in heat within the earth-atmosphere system forcing the temperatures of the various parts of the earth's surface to rise significantly higher than previous levels, and as a result bring about marked alterations in the established climatic and weather characteristics of the different areas.

The projected changes in climates are already beginning to manifest in some parts of the globe (e.g., Adejuwon *et al.* 1990) and are expected to impact widely on the earth's biophysical systems. This will in turn, impact appreciably on socio-economic activities of the various communities (IPCC 2001). The latter impact may range from a forcing of changes in agricultural regimes in areas with mild climatic shifts to extensive loss of life and property in others that may experience extreme weather conditions as a result of the changes. The global community is increasingly concerned about these changes and their associated impacts, and research effort is being directed at them particularly through the activities of the Inter-Governmental Panel on Climate Change (IPCC). Two main categories of interrelated research and action paths are being pursued in addressing the climate change issues:

i. Development of coping and adaptation strategies for the anticipated change. This is intended to help communities live with the changes which are expected to be permanent when they become established.

ii. Control of the process of change and reversing of the observed trends. The goal of these efforts is to hold back the processes of change by restraining anthropogenic emissions of greenhouse gases and strengthening the natural greenhouse gases "cleaning" processes.

This paper focuses on the latter. The objective of the paper is to assess the relative cost-effectiveness of afforestation and agroforestry techniques in reducing atmospheric carbon in Nigeria.

Forestry Management in Nigeria

The dominant forestry management practices in Nigeria fall into three main groups: agroforestry, reforestation and forest protection (e.g., Adesina et al 1999). In this paper the afforestation and agroforestry options have been selected for consideration. Afforestation has a long history in Nigeria dating as far back as the colonial era and is still widely used by the Nigeria's Forestry Department for economic and environmental purposes. Afforestation involves the planting of trees with desirable characteristics such as fast growth rates and high fodder and timber yielding usually in large estates. The sites could be marginal locations such as degraded lands that cannot be used for food crop production. They could also be areas of good soils acquired by the government for the purpose of afforestation. Some of the common afforestation species include *Tectona grandis, Gmelina aborea, Entandrophragma cylindricum,* and *Terminalia superba*. In terms of products, afforestation may be geared towards fuelwood production as is common in the Sudan savanna belt or could be pursued for timber. In the semi arid areas of Northern Nigeria, the goal could be primarily ecological to curtail the southward expansion of the Sahara desert.

The widespread use of agroforestry as a tested scientific approach in Nigeria is fairly recent. However, its fundamental principles are not completely new to local farmers (Adesina 1991). In the face of a rapidly growing population that makes it impossible to continue with the use of rotational bush fallowing, agroforestry is becoming more acceptable to many farmers as a land management technique. The technique involves purposeful retention or introduction of trees or other woody perennials in food crop or animal production fields to benefit from the resultant ecological and economic interactions (MacDikicken and Vergara 1990; Schroeder 1993; Adesina 1990).

Four varieties of agroforestry practices are common in Nigeria. These are (i) the taungya system in which food crop cultivation is encouraged in sites planted to trees. Cropping continues until the canopy of the trees and or their increasing root volumes which may come near the surface make crop growth difficult; (ii) the alley cropping which involves growing of food crops in alleys between rows of leguminous trees (Wilson and Kang 1981); (iii) enriched short fallows involving the planting of fallows with fast-growing species to speed up the process of soil restoration during the fallow period and (iv) forest floor farming in which certain crops such as *Discorea* spp. and

Xanthosoma spp. are raised under natural or planted forests (Adesina, 1988).

Nigeria, with a land area of about 924,000 km^2 and a projected population of 115 million in year 2000 (NPC 1991), is a dominant eco-political unit in Africa. By virtue of its huge population that is about one fifth of the continent's, and the high propensity of its people to consume biomass and fossil fuel, Nigeria is a major driver of environmental change in the continent. Substantial release of green house gases also comes from gas flaring in the nation's oil fields in the Niger delta.

The country spans five main ecological zones - the Mangrove, Rainforest, Guinea savanna, Sudan savanna and Sahel savanna - from the Gulf of Guinea in the south to the southern limit of the Sahara desert in the north. These ecological zones are differentiated mainly by the volumes of precipitation they receive on an annual basis, and therefore, the richness of the flora they support. They provide varying opportunities for forestry activities in the country.

Method

The Comprehensive Mitigation Assessment Process Model (COMAP), developed at the Lawrence Berkeley Laboratory, USA (Sathaye *et al.,* 1993) was employed in the analysis presented here. The model is designed to comprehensively assess the potentials of the forestry sector of a country in climate change mitigation. Various considerations of land requirement and wood products demand are included in the model. The demand-driven, end-use approach, which takes into consideration the requirements for land and wood products in a given country, is adopted. It is assumed that suitable lands are available for the tree planting program, the availability of such lands being driven by the wood products needs of the country over a planned or projected period. The extent of the land requirement for such period was calculated outside the model but used as input in the model (Nigeria Country Study Program, 1996, Siyanbola *et al.* 2002). The end-use approach recognizes the fact that most developing countries like Nigeria are still deforesting because of their dependence on wood products.

Two scenarios were developed and evaluated. These are described as baseline and mitigation scenarios. The baseline or "business as usual scenario" assumes a situation where deforestation is allowed to proceed in the usual manner without any deliberate effort to reduce carbon emission. On the other hand, the mitigation scenario conceptualizes a situation in which there is a planned effort to reduce deforestation and enhance carbon sequestration.

In running the model, the land requirements for 40 years (1990 to 2030) for the afforestation and agroforestry programmes based on the projected demand and supply of the various wood products are estimated. The projections adopted are those provided by Ojo (1994). The land areas that will be available for the projects are located in the various ecological zones but are more extensive in the savanna areas of the middle-belt and northern parts of the country. Five wood products are considered to adequately represent the wood needs of the country. These are fuelwood, poles, pulpwood, sawlogs and veneer. The cost-effectiveness indicators were evaluated from the cost of running each of the afforestation and agroforestry options and the expected benefits from the programmes.

Cost of land in Nigeria ranges from as low as $25/ha in the hinterland (with very low population densities (NPC, 1991)) to more than $15,000/ha in metropolitan towns like Lagos, Abuja and Port Harcourt. The cost of the wasteland in the northern savanna belt which would be used for fuelwood plantation was estimated to be about $100/ha. The cost of wastelands in the forest/woodland regions which would be used to produce the other four wood products is estimated at $125/ha. The required land area for each wood product based on the demand and supply projection is shown in Fig. 1. The same location of wasteland is taken for both afforestation and agroforestry.

The tree species considered for the projects are those which have desirable characteristics such as fast growth rate, good wood quality and ability to supply the various wood products. The third parameter is particularly important as a tree may have high wood quality, for example, but may not be suitable for a product like veneer.

Determination of Carbon Pool and Cost Effectiveness Indicators

In the model, the stored carbon is obtained from equation (1):

Carbon stored/ha/year = Land carbon + Product carbon (1)

Where

Land carbon = Vegetation carbon + Soil Carbon + Decomposing matter carbon (2)

$$= C_v*T/2 + C_s*T + C_d*t/2$$

and

Product carbon $= \Sigma Cp_i * n_i /2$ (3)

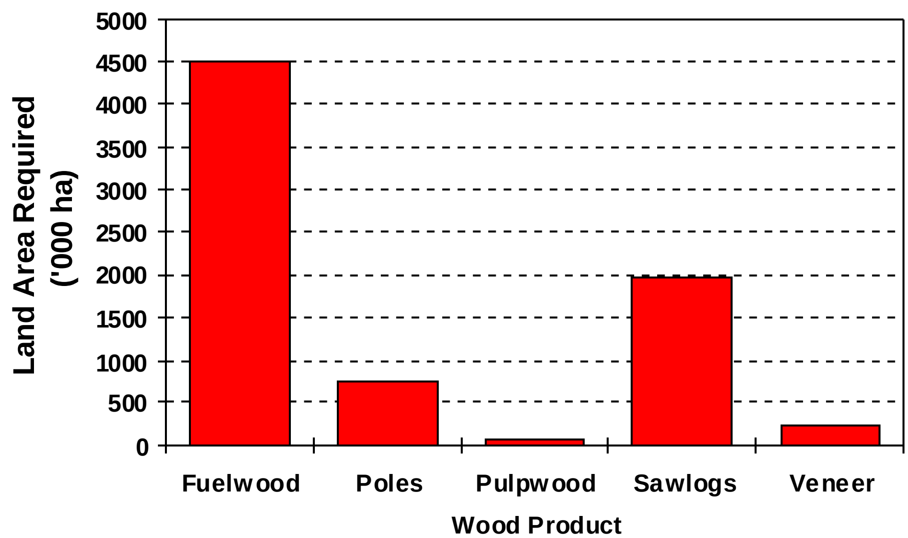

Fig. 1. Land area required to meet wood product needs in Nigeria (1990-2030).

where C_v is the average annual net carbon sequestered per ha C_s is the increase in soil carbon, C_d, the average annual carbon left to decompose, Cp_i is the amount of carbon stored in product; T, rotation period; t, decomposition period and n_i life of product. The total carbon stored (tC/ha) is the sum of land carbon and product carbon, and thus the carbon pool is determined from the product of carbon density (tC/ha) and land area (ha). The determination of product carbon is based on 35% of the carbon stored on land and it is included in the calculation to prevent an overestimation of the unit costs (Dixon *et al.* 1991). The cost effectiveness of conserving carbon is expressed in the net present value of benefits (NPV) and Benefit of Reducing Atmospheric Carbon (BRAC). The BRAC indicator is embedded in the spreadsheet model and its values are determined by the discount rates.

Results and Discussion

Initial cost of establishment

The initial costs of tree establishment are presented in Table 1. Figures on tree establishment were derived from data provided by States Ministries of Agriculture and the Federal Department of Forestry. The initial costs of land include costs of land and land preparation, and purchase and planting of seedlings. Although the density of trees in afforestation is about twice the ones in agroforestry, the costs of establishment are not too different. To establish a sawlog farm under afforestation with a density of 1700 stands per hectare, $395 will be needed whereas to establish the same type of farm under agroforestry at a density of 425 stands per hectare, $335 is needed.

Table 1. Carbon pool and total benefits for the different wood products for the two mitigation options

	Fuelwood		**Poles**		**Pulp**		**Sawlog**		**Veneer**	
	Afforestation	Agroforest	Afforestation	Agroforest	Afforestation	Agroforest	Afforestation	Agroforest	Afforestation	Agroforest
Carbon Pool (tC/ha)										
Baseline	67.2	67.2	98.0	98.0	133.0	133.0	133.0	133.0	133.0	133.0
Mitigation	93.1	79.6	187.3	128.0	172.2	149.6	331.0	224.4	399.6	344.3
Costs ($/ha)										
Initial Cost	495.0	344.0	520.0	335.0	513.0	335.0	520.0	335.0	455.0	335.0
Total Cost	655.0	504.0	680.0	623.0	673.0	628.0	680.0	623.0	615.0	620.0
Benefits ($/ha)										
Baseline	150.0	150.0	200.0	150.0	200.0	200.0	200.0	200.0	200.0	200.0
Mitigation	652.0	2191	667	1589	2069	2211.0	468	3428	479.0	1511

Carbon pool, initial costs and benefits

Table 2 shows the carbon pool for the different wood products as well as the total costs and benefits under each mitigation program. In the baseline scenario the values under the afforestation and the agroforestry programs are the same for each wood product whereas under the mitigation scenarios the wood products in afforestation consistently stored larger amount of carbon than in agroforestry. For example, fuelwood has a carbon pool of 93.1 and 79.6 tC/ha in afforestation and agroforestry practices, respectively. The highest pool of carbon was recorded with respect to sawlogs but as in the case of fuelwood, afforestation stored more carbon (399.6 tC/ha) than agroforestry (344.3 tC/ha)

Table 2. The initial density of trees and initial establishment costs

		Afforestation		Agroforestry	
Wood Product	**Rotation Period (yrs)**	**No of trees /ha**	**Initial cost ($)**	**No of trees /ha**	**Initial cost ($)**
Fuelwood	7	1700	495	850	344
Poles	15	1700	395	425	335
Pulp	8	1700	388	850	335
Sawlog	30	1700	395	425	335
Veneer	40	850	330	425	335

The total benefits under baseline and mitigation scenarios are also presented in Table 2. The benefits were derived based on various considerations. For instance, under fuelwood afforestation it was assumed that there would be breakages of branches due to wind storms from the fourth year of planting and that as much as $5 worth of fuelwood per hectare would be realized from this. At the time when the plantation will be clear-felled about $875 worth of benefits would be realized per hectare. The year 2030 coincides with the fifth year of planting, and if the plantation is clear-felled it is estimated that two-thirds of the wood that would normally be obtained at the end of the seven -year rotation period, would be available.

For the pole products under afforestation, it is estimated that as much as $5 would accrue from thinning as from the 4th year. Out of the 1700 tree stands about 50% would be thinned at 10 years as small poles and fuelwood. These are estimated to be capable of giving benefits of $531 and $106 per hectare, respectively. At the end of each rotation of 15 years, it is estimated that about $1750 would be realized from poles. At each clear felling for poles it is assumed that 20% of the harvested trees would end up as fuelwood.

At the end of the rotation period of eight years in the pulpwood plantation about $2250 would be realized with a pole selling for $1.50. An additional benefit worth $510 would come from fuelwood resulting from 20% off-cut from the harvested trees. For the sawlogs, the 1700 tree stands in the plantation will be thinned by 40% at 10 years of planting to give $425 as benefit. Also another thinning by 40% of the remaining tree stands would be done at the 15th year of planting to fetch $225 and at the 20th year about 65% of the remaining stands will be harvested to fetch $250. At the end of the rotation, i.e., at age 30 years, 200 stands would remain following standard forestry practices in Nigeria. This will give a benefit of $5,000 at $7 per cubic meter assuming that each stand produces an average of 3.6 cubic meters of sawlog. As before, during cutting it is assumed that 20% of the tree harvested would be available as fuelwood. This was estimated in cords. Our field observations show that on the average, fuelwood is sold in cords at $0.625 per cord in the country.

Of the 850 trees in the veneer plantation, 625 stands would be removed at age 15 to give poles that would fetch $1375 and fuelwood of about $70 per hectare. Also at age 20, the number of trees that would be removed would be 225. It is estimated that $1313 would accrue from the poles per hectare and fuelwood would fetch $70 per hectare. At the end of the 40-year rotation it is estimated that 200 stands would be left and when there is clear felling it was estimated that $5,000 worth of benefits would come from timber. There is additional benefit from fuelwood (20% contribution from trees on clear felling) estimated at $125 per hectare.

The same estimates as above were made in the agroforestry option. The average returns from a hectare of maize plantation was estimated at $405 using farm-gate price obtained from the Nigerian Agricultural Bank. In our consideration for fuelwood agroforestry, it is assumed that this amount would drop by 25% by the 4th year. Therefore, a figure of $300 was adopted as the value of the benefit coming from the maize planted in the agroforestry fields. Under the poles, pulp, sawlogs and veneer agroforestry, it is assumed that the productivity of maize will decrease to about $205 per hectare as the sizes of the agroforestry trees increase.

Cost and benefit analysis

Assumptions made in calculating the cost and benefit of the options include availability of suitable land to implement the options, the choice of appropriate option for each ecozone and the selection of suitable species of trees to be planted. Figs. 2 and 3 display the NPV of benefits for the afforestation and agroforestry options, respectively. The trends are the same but higher values of NPV of benefits are estimated in agroforestry than in the other option. Three discount values were considered in estimating the costs and are shown in Tables 3 and 4; these are 0%, at 8%, and at 12% discount rates. Twelve percent was the World Bank lending rate and 8% represents a realistic rate between the World Bank lending rate and at no discount at all. At 0% discount rate the values under fuelwood plantation the NPV is $101.9 and $741/tC for the afforestation and agroforestry program, respectively. The respective NPVs per hectare are $2634 and $9225.

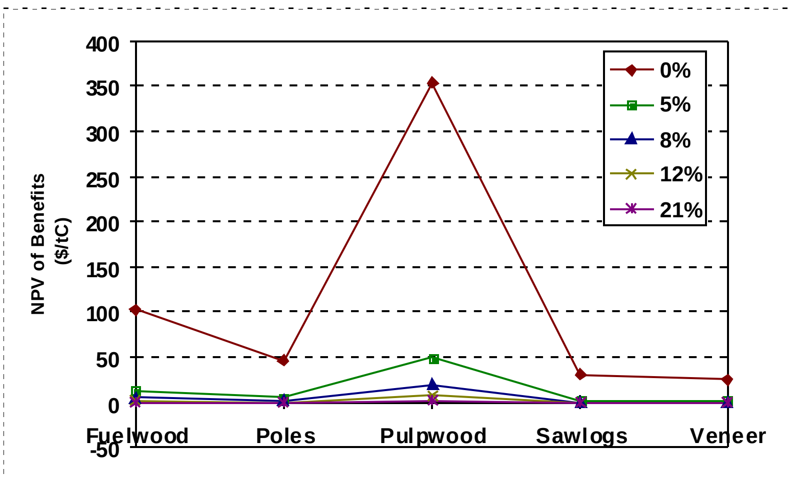

Fig. 2 : NPV of benefits for afforestation option

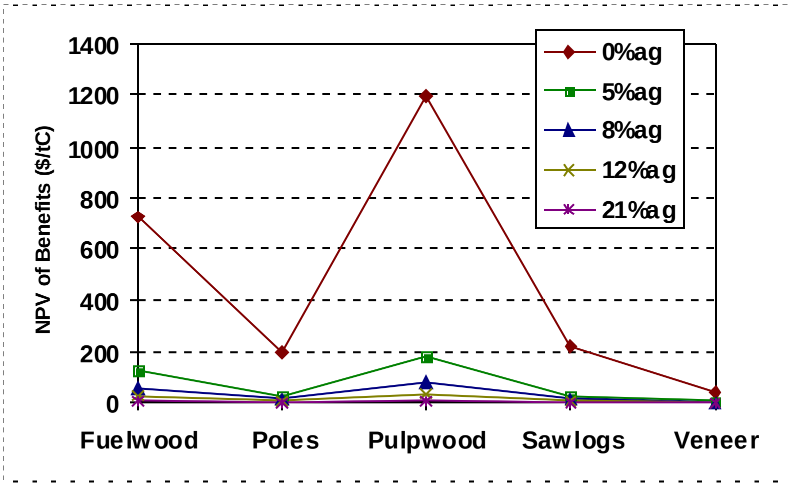

Fig. 3 :NPV of benefits for agroforestry option

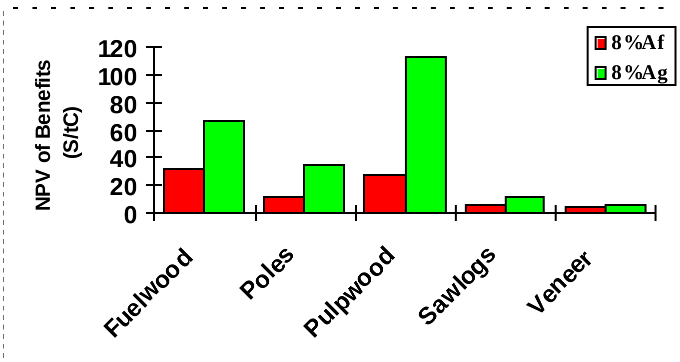

Fig. 4: Endowment ($/tC) at 8% discount rate for afforestation (Af) and groforestry (Ag)

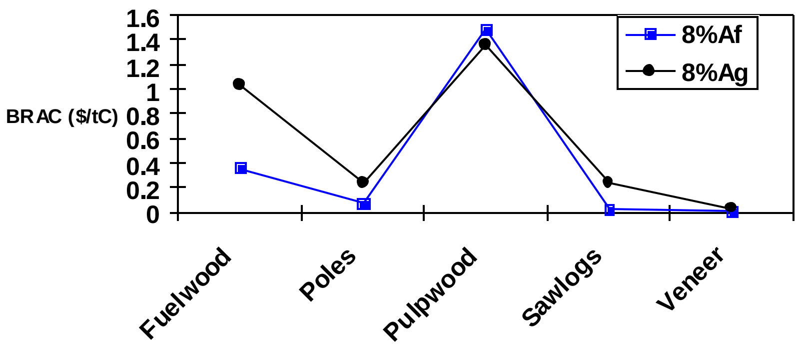

Fig. 5: Benefits of reducing atmospheric carbon (BRAC) for each wood product under afforestation and agroforestry options

Table 3. Cost Effectiveness Indicators for the Afforestation Option at 0, 8 and 12% discount rates

Wood product	Land area reqd. ('000 ha)	Discount rates (%)	NPV of Benefits $/tC	NPV of Benefits $/ha	Present Value of Cost (Endowment) $/tC	Present Value of Cost (Endowment) $/ha	BRAC $/tC-yr
Fuelwood	4,489.5	0	101.9	2634	75	1950	7.64
		8	4.76	123	33	848	0.36
		12	1.58	41	25	641	0.12
Poles	757.2	0	44.76	3995	27	2438	3.36
		8	1.09	98	12	1059	0.08
		12	0.00	0.00	9	801	0.00
Pulpwood	58.1	0	353.5	13863	62	2438	26.52
		8	5	772	27	1059	1.48
		12	19.69	289	20	801	0.55
			7.37				
Sawlogs	1,956.4	0	31.21	6181	12.31	2438	2.34
		8	0.22	45	5.35	1059	0.02
		12	-0.21	-41	4.05	801	-0.02
Veneer	244.5	0	24.96	6566	2.17	2438	1.87
		8	0.17	45	4.03	1059	0.01
		12	-0.15	-39	3.05	801	-0.01

Table 4. Cost effectiveness indicators for the agroforestry* option at 0,8 and 12% discount rates

Wood Product	Land Area Reqd. ('000 ha)	Discount Rates (%)	NPV of Benefits $/tC	NPV of Benefits $/ha	Present Value of Cost (Endowment) $/tC	Present Value of Cost (Endowment) $/ha	BRAC $/tC yr
Fuelwood	4,489.5	0	741	9225	157	1950	55.61
		8	61.66	767	68	848	4.62
		12	28.91	360	52	641	2.17
Poles	757.2	0	152	5939	63	2438	11.42
		8	10.52	410	27	1059	0.79
		12	4.87	190	21	801	0.37
Pulpwood	58.1	0	678.1	11263	147	2438	50.85
		8	44.89	746	64	1059	3.37
		12	19.15	318	48	801	1.44
Sawlogs	1,956.4	0	218.1	19930	27	2438	16.36
		8	5	1289	12	1059	1.06
		12	14.11	569	9	801	0.47
			6.23				
Veneer	244.5	0	46.99	9928	12	2438	3.52
		8	2.02	426	5	1059	0.15
		12	0.82	174	4	801	0.06

*** Food crop combination: *Zea mays* (maize).**

The Present Value of Costs (Endowment) is the sum of establishment cost and all the discounted value of all future investment and the recurring costs during the lifetime of the project. For the two options and using a discount rate of 12%, the different endowment requirements were \$641.00/ha for fuelwood plantation and \$801.00/ha for each of poles, sawlogs and veneer wood plantations. This gives a weighted average of \$725/ha. In terms of carbon sequestered, however, the endowment costs range from about \$3/tC for veneer wood plantation to about \$25/tC for fuelwood plantation, with a weighted average of \$15/tC for the plantations based on afforestation option (Table 3). The range in agroforestry option is quite different (Table 4). The values are from \$4/tC for veneer wood to \$157/tC for fuelwood. Fig. 4 shows the endowment at 8% discount rate for the two options.

Benefit of Reducing Atmospheric Carbon (BRAC)

BRAC expresses the NPV of a project per unit of atmospheric carbon reduced. Rather than measuring the reduction of net emissions it captures the atmospheric resident time of carbon. BRAC values are included in Tables 3 and 4. In addition, Fig. 5 shows BRAC estimates for the five wood products and the two forestry options at 8% discount rate. For afforestation, BRAC is highest for pulpwood at \$1.48/tC at 8% discount rate. It is highest for pulpwood under agroforestry \$5.94/tC.

Choosing a mitigation option for Nigeria

In deciding to adopt a particular option for mitigation, a useful exercise is to rank the options in terms of a wide range of parameters. Tables 5 and 6 provide summaries of such parameters that can be used in the ranking and Table 7 shows the outcome of the ranking. The ranking is based on the perceived potentials of the benefits which each option can provide. The whole process takes into consideration national environmental impacts and socio-economic benefits.

Considering carbon flow alone, afforestation is the better option with a carbon pool of 175.20 t C/ha compared to agroforestry with a figure of 131.4 t C/ha. If approximately 7.5 x 10^6 ha of wasteland could be used exclusively for afforestation, Nigeria would meet all her required domestic wood needs as well as reduce significantly the net carbon emission over the 40-year period of projection.

Table 5. Estimated costs and stored carbon under afforestation

Plantation	Land area (`000ha)	Unit Cost ($/ha)	($/tC)	NPV of benefits ($/ha)	BRAC $/tC-yr	Carbon pool (mitigation) (tC/ha)	Annual incremental carbon	Total carbon stored (MtC)
Fuelwood	4,489.5	527.00	20.00	123	0.3	93.1	2.90	116.1
Poles	757.2	516.00	6.00	98	0.0	187.3	1.69	67.6
Pulpwood	58.1	496.00	13.00	772	1.4	172.2	0.06	2.3
Sawlogs	1,956.4	516.00	2.60	45	0.0	33.1	9.68	387.4
Veneer	244.5	476.00	1.80	45	0.0	399.6	1.63	65.2
Total	**7,505.**	**521.10***	**1.34***	**102.6***	**0.19***	**175.2***	**15.96**	**638.6***

* Weighted average values at 8%

Table 6. Estimated costs and stored carbon under Agroforestry

Plantation	Land area (`000ha)	Unit Cost ($/ha)	($/tC)	NPV of benefits ($/ha)	BRAC $/tC-yr	Carbon Pool (mitigation) (tC/ha)	Annual incremental carbon	Total carbon stored (MtC
Fuelwood	4,489.5	333.00	27.00	123	0.3	79.6	1.40	55.80
Poles	757.2	353.00	9.00	98	0.0	128.0	0.57	29.50
Pulpwood	58.1	323.00	19.00	772	1.4	149.6	0.02	0.96
Sawlogs	1,956.4	323.00	4.00	45	0.0	224.4	4.47	178.70
Veneer	244.5	338.00	2.00	45	0.0	344.3	1.29	51.60
Total	**7,505.7**	**332.50***	**18.31***	**102.6***	**0.19***	**131.4***	**7.75**	**316.56***

* Weighted average values at 8%

Table 7. Parameters for ranking the mitigation options

Mitigation Indices	Afforestation	Agroforestry
• GHG saving or storage		
Carbon Pool (tC/ha.)	175.2	131.4
Mean Annual Incremental Carbon		
(MtC/ha-yr)	15.96	7.75
• Initial cost		
$/ha	521.10	332.50
· $/tC	13.4	17.20
Net Present Value of Benefit		
$/ha	102.6	1413.6
· BRAC ($/tC-yr) (weighted average)	0.19	3.13
• Indirect economic impact		
- Jobs creation (#)	Medium	High
- Reduced imports (US$)	High	Medium
• National environmental impacts (net		
change)	Medium	Medium
Biodiversity	High	Medium
Control of Desertification		
Erosion Control	Medium	Medium
- Other environmental impacts		
• Potential ease of implementation	Medium	Medium
• Sustainability of option	Low	High
• Consistency with national goals	High	High
• Uncertainty of data	Low	Medium
• Equity Considerations		
Impact on		
- Low income jobs	High	Medium
- Low-income monthly expenditure	Low	High

Note that the exchange rate as at 1990 was: $1=₦ 8

The incremental carbon of 15.96 MtC/ha/yr in afforestation is about twice the value obtained from agroforestry, which suggests that afforestation has a greater potential for impacting on carbon reduction in the atmosphere than agroforestry especially in the early stages of the project when it carries more biomass than agroforestry. However, in this exercise, the same land areas have been used for both agroforestry and afforestation. If a larger area of land is committed to agroforestry, which is a possibility as many of the current practices can be tuned towards agroforestry (Adesina *et al.* 1999), agroforestry would turn out to be more effective in carbon pooling. Most of the farmland in the country with the exception of swamps and flood plains is suitable for food crop agroforestry. This land area is estimated at about 35 million hectares (FAO, 1992). Even if we assume that only 50% of this will be used for agroforestry, something close to three-folds of the estimate of total carbon stored made in this study can be got from agroforestry. It should be noted that this carbon returns are in addition to the benefits expected from the food crops that will be produced under the agroforestry system. Thus agroforestry appears to be the better land management option available for climate mitigation in Nigeria.

In general, wherever tree establishment is important, agroforestry offers a good opportunity for participation by the small-scale farmers who operate at the grassroot levels, the aggregate impact of whose activities cannot be pushed aside in terms of their implication for the environment. In Nigeria as in many other developing countries, local farmers do not always want to engage in tree planting because its economic return comes in the medium to long term, often considered too long to meet the immediate financial needs of the farmers. Agroforestry techniques however ensure that the farmer can get reasonable benefits from his foodcrop husbandry while he waits for the benefits from the trees (e.g. Adesina 1991). Thus, in the context of climate change mitigation where tree planting is expected to play a dominant role in terms of carbon sequestration, agroforestry offers an attractive option for encouraging local participation by the small-scale farmers.

Recommendations and Conclusions

The analysis of the forestry sector as presented above shows that the sector has a significant role to play in climate change mitigation in Nigeria. Afforestation in particular has a great potential for carbon storage and meeting the wood needs of the country. It is also very relevant for biodiversity preservation. The modeling shows agroforestry to be less efficient in carbon storage given the same area of land but the approach has many other benefits as discussed above. Besides all these, the carbon storage in agroforestry within the country can be increased if the approach is encouraged over a larger area of land.

Although afforestation is more efficient than agroforestry in the volume of carbon stored per unit land area, both approaches are relevant depending on the product that is targeted and the eco-climatic characteristics of the area where the project will be prosecuted. For example, agroforestry will appear more appropriate in the densely settled part of eastern Nigeria where it is difficult to get large areas of land for afforestation. On marginal soils such as in severely eroded lands and overgrazed sites and hill slopes with thin soils, however afforestation would be more appropriate given the environmental constraints of such locations.

The modeling of the carbon flow in the forestry sector gives some indications of how much forest establishment is needed in order to meet the wood needs of the country. It is estimated that about 7.5 million hectares of land will need to be planted to trees of various types over the forty-year period of the project. This translates to planting about 180,000 hectares of land per year for forty years in the country. Implementing this will require substantial investment in forestry. Clearly, this is an enormous task for the government and is particularly daunting in the face of several development issues calling for attention. A lot can however be achieved if government is willing to address the issue. The first critical task for government is to create an enabling environment for both private individuals and organizations to invest in forestry. This could take many forms such as the provision of seeds and seedlings and other inputs at subsidized costs for the establishment of plantations. Also, the government will need to relax regulations on harvesting of forest products particularly timber, to make harvesting attractive for investors in the sector. The preservation of the existing forests is also important. This can be done through rigorous implementations of the provisions of the environmental protection laws of Nigeria. Related to this is the need to control the spate of urban sprawl that has become a main feature of urban land use in the last decade or so in Nigeria. This will not only protect the existing forested lands but also ensure that those who wish to invest in forestry development have access to land.

Acknowledgments

We gratefully acknowledge the technical support from the team of the US Country Studies Program and the provision of financial assistance under the program by the US government.

References

Adejuwon, J.O., Balogun, E.E. and Adejuwon, S.A. (1990). "On the annual and seasonal variations in sub-Saharan West Africa" *Int. J. Climatol*, 10: 839-848.

Adesina, F. A.(1988). Developing stable agroforestry systems in the tropics: an example of local agroforestry techniques from south western Nigeria, *Discussion papers in Geography*, **37**, 27pp. Department of Geography, University of Salford, UK.

Adesina, F.A. (1990). 'The relevance of agroforestry techniques in conservatory agriculture.' In: Ogunjumo, O, Aloba, O. and Adesina, F.A. (eds.) *Contemporary Research in Geography at Ife*, Chapter 18. Department of Geography, OAU, Ile-Ife

Adesina, F.A. (1991). Soil management with cultivated fallows in the humid and subhumid Africa. *Canad. J. of Soil Science*, 71: 147-154.

Adesina, F.A., Siyanbola, W.O., Oketola, F.A., Pelemo, D.A., Momodu, S.A., Adegbulugbe, A.O. and Ojo, L.O. (1999). Potential of agroforestry techniques in mitigating CO2 emissions in Nigeria: some preliminary estimates, *Global Ecology and Biogeography*, 8:163-173.

Dixon, R., Schroeder, P. and Winjum, J. (1991). *Assessment of promising forest management practices and technologies for enhancing the conservation and sequestration of atmospheric carbon and their costs at site level*, UE EPA/600/3-91/067, p.24.

FAO (1992). *Forest Resources Assessment* 1990 Tropical Countries, FAO Forestry Paper 112.

IPCC (2001). Intergovernmental Panel on Climate Change. In *Climate Change 2001: Impact, Adaptation and Vulnerability*, IPCC Third Assessment Report, Working Group II. http://www.grida.no/climate/ipcc_tar/

MacDicken, K.G. and Vergara, S. (1990). *Agroforestry: Classification and management*, John Wiley and Sons, New York.

NEST (1991) Nigeria's threatened environment- A national profile. Nigerian Environmental Study/Action Team, Ibadan, Nigeria.

Nigeria Country Study Program (1996). Greenhouse gases emission reduction in Nigeria- Least Cost Reduction Strategies and Macroeconomic Impacts. Vol.3B- Forestry Sector (Prepared by: W.O. Siyanbola, F.O. Oketola, D.A. Pelemo, S.A. Momodu, A.O. Adegbulugbe, F.A. Adesina, L.O.Ojo, and S.A. Ijalana). Report Submitted to US Country Studies Program, 140pp..

NPC (1991). National Population Commission, Nigeria Census, Unpublished.

Ojo, L.O. (1994). Update of woods supply and demand data. Report submitted to the Forest Management, Evaluation and Coordinating Unit (FORMECU), Ibadan, Nigeria, p.119-133.

Sathaye, J.R., Norgaard, A. and Makundi, W.R. (1993). *A conceptual framework for the evaluation of cost effectiveness of projects to reduce GHG emissions and sequester carbon*. Lawrence Berkeley Laboratory, University of California, Berkeley, LBL-33859.

Schroeder, P. (1993) Agroforestry Systems. Integrated landuse to store and conserve carbon. In: Sandra H. and Robert, K.D. (eds.) *Climate Research Special*, Vol. 3 Nos. 1 and 2.

Siyanbola, W.O., Oketola, F.O., Pelemo, D.A., Adegbulugbe, A.O., Adesina, F.A. and Ojo, L.O. (2002). *Towards Global Climate Change Mitigation: assessment of afforestation option for Nigeria*. *The Environmentalist*, 22: 83-92.

Watson, R.T., Rodhe, H., Oeschger, H. and Siegenthaler, U (1990). Greenhouse gases and aerosols. In: Houghton, J.T., Jenkins, G.J and Ephraums, J.J. (eds.) *Climate Change: The IPCC Scientific Assessment*, Cambridge University Press, pp.1-40.

Wilson, G.F. and Kang, B.T. (1981). Developing stable and productive biological cropping systems for the tropics. In: Stonehouse, B. (ed.) *Biological Husbandry*, Butterworths, London.