J. ENVIRONMENTAL SYSTEMS, Vol. 22(3) 199-210, 1992-93

LAND-USE MANAGEMENT AND CARBON SEQUESTERING IN SUB-SAHARAN AFRICA

R. D. PERLACK

R. L. GRAHAM

A. M. G. PRASAD

Oak Ridge National Laboratory, Tennessee

ABSTRACT

We estimate the magnitude of carbon emissions and the potential for sequestering carbon from alternative land-use management options in Sub-Saharan Africa. Our results indicate that current land-based emissions are of the order of 152 million tons each year. Reducing forestation by 50 percent could lower emissions to twenty-one million tons. With regard to specific land use policies, we estimate that agroforestry, if adopted at a rate of 2 to 4 percent annually, could reduce annual carbon emissions by about thirty-eight to sixty-six million tons. Offsetting industrial roundwood removals or converting 0.1 percent of high and medium productivity land back to forest each year could result in the sequestration of about eleven to eighteen million tons annually. The direct costs of carbon sequestration are estimated at $3 to $22 per ton depending on the land use policy.

INTRODUCTION

Carbon emissions from land use change in Sub-Saharan Africa are dominated by deforestation, primarily in the humid and sub-humid forests of West and Central Africa. By contrast emissions from fossil fuel consumption are about five times less [1]. The principal cause of much of this deforestation and source of land-based carbon emissions is a burgeoning population and its need for agricultural land. This agriculturally induced deforestation is predominant at the forest/savanna boundary and along riparian and transport corridors where forest is gradually incorporated into unsustainable bush-fallow or shifting cultivation. This

doi: 10.2190/552Y-AD1T-NMXQ-N536
http://baywood.com

trend is exacerbated by poverty, inequitable land distribution, low agricultural productivity, inappropriate land-use policies (e.g., resettlement programs), and weak institutions as detailed in [2-9]. The Food and Agriculture Organization estimates that nearly 50 percent of forest clearing in the tropics is attributable to shifting cultivation [2].

Deforestation is also a result of logging. At present, logging is largely limited to West Africa. Gillis reports that four West African countries (Gabon, Ghana, Ivory Coast, and Liberia) account for nearly all timber exports from the continent [10]. Logging changes land use permanently and creates access corridors that accelerate the conversion of adjacent lands to bush-fallow cultivation. The demand for fuelwood (firewood and charcoal) also contributes to land-based carbon emissions. Fuelwood-related deforestation tends to be concentrated around major urban areas.

Although deforestation is widespread, Sub-Saharan Africa still contains the world's third largest closed tropical forest region, primarily in Central Africa (Cameroon, Congo, Gabon, and Zaire). Most of the forests of these countries are sparsely population, and, even though shifting cultivation takes place at the forest boundary, fallow cycles are still long enough to allow adequate forest regeneration [11]. Because populations and economic pressures are increasing, these forests may become similar to those of West Africa—fragmented and in various states of degradation. In West Africa, forests no longer occur in broad continuous belts but only in isolated patches, on mountain slopes, along some coastal belts, or where the physical landscape limits access.

In this article, we estimate the magnitude of carbon emissions and the potential for sequestering carbon from alternative land-use management options. The following section presents a model we developed to estimate carbon emissions and inventories assuming no change in current deforestation rates [1]. Subsequent sections describe modifications we made to the model and estimate the change in carbon emissions that would result from reducing deforestation rates and implementing land-use management strategies (i.e., agroforestry and reforestation). The final sections of this article discuss land-use policy and carbon sequestration costs.

APPROACH

A carbon balance model was developed to estimate the impact of various land-use management options on carbon inventories and emissions [1]. The model estimates carbon inventories and emissions at approximately 9000 regularly spaced point locations across the continent. The large number of point locations is necessary to capture the vast geographical differences. At each of these point locations, the model traces carbon inventories and emissions for three land-use categories (forest, forest-fallow agriculture, and nonforest). Emissions are calculated as yearly differences in carbon inventories. All carbon transfers (from the land to the atmosphere or vice versa) resulting from land-use change were assumed to accrue in the year of land-use conversion. The real multiyear process of carbon storage due to plant growth or carbon release due to decomposition was not modeled. This simplification allows the comparison of land-use options with varying carbon conservation time scales. The carbon inventory for each land-use category is specific to a point location. Carbon inventories are estimated by algorithms relating carbon storage to vegetation type, soil fertility, annual rainfall, fallow and cropping periods, and other factors.

To associate the point carbon emissions with a geographic area more environmentally significant than country, most African countries are divided into zones on the basis of likely within-country variations in overall carbon inventory. For example, Zaire is divided into two zones—a zone for the closed forest and a zone for the woodland area bounding the closed forest. Smaller countries without significant vegetational heterogeneity are treated as a single zone. Thus, each point location has a country identity and a zonal identity. The point values of carbon inventories and emissions are converted to zonal estimates by averaging the point values within a zone of a country and multiplying by zonal area. Country and regional emissions and inventories are calculated by summing the zonal values within a country or the country values within the region.

Data on deforestation rates, current land use, site degradation status, soil fertility, annual rainfall and vegetation relationships, potential site carbon density, potential site biomass productivity and likelihood of degradation are derived from FAO maps and published statistics. The specific maps and statistics used for this study were taken from Brown and Lugo, FAO, FAO/UNEP, FAO/UNESCO, Lavenu, Olson et al., Rand-McNally, and White [12-20]. To synthesize the many data sources spatially, a geographic information system (GIS) is used to extract data from digitalized maps at 0.4° latitude and longitude intervals. The extracted values are then used to create the 9000-record data base, each record of which provides soil fertility, annual rainfall, vegetation class, zone, and country occurring at specific point locations. This data base is processed, outside of the GIS, to estimate carbon inventory and emission dynamics at each point and to aggregate the point estimates into zone, country, and region totals.

LAND-USE BASED CARBON EMISSIONS

The estimates of carbon emissions are summarized in Table 1 for the years 1991 through 2001. The results show that three countries (Cote D'Ivoire, Zaire, and Nigeria) are the most significant contributors of carbon emissions. These three countries contributed about 50 percent of carbon emissions for all of Sub-Saharan Africa (excluding South Africa) in 1991. However, by 2001 emissions from these three countries are estimated to fall under 45 percent of total Sub-Saharan African land-use change emissions. Cote D'Ivoire's and Nigeria's initial high values are not sustained because their current annual rate of deforestation (7 and 3%,

Table 1. Estimates of Carbon Emissions from 1991 to 2001 in the Ten Largest Carbon-Emitting Countries of Sub-Saharan Africa

	Carbon Emissions (million tons C)						
Country	1991	1993	1995	1997	1999	2001	Mean
Zaire	32.9	32.8	32.6	32.5	32.3	32.2	32.6
Cote D'Ivoire	31.7	27.4	23.7	20.5	17.7	15.3	22.7
Nigeria	20.2	18.9	17.8	16.7	15.6	14.7	17.3
Madagascar	8.7	8.5	8.3	8.1	7.9	7.7	8.2
Cameroon	7.1	7.1	7.0	6.9	6.9	6.8	7.0
Guinea	6.2	6.1	6.0	5.9	5.8	5.7	6.0
Ethiopia	5.7	5.7	5.7	5.6	5.6	5.6	5.6
Tanzania	5.6	5.6	5.5	5.5	5.5	5.4	5.,5
Malawi	5.8	5.4	4.9	4.5	4.1	3.8	4.8
Sudan	3.3	2.6	2.1	1.7	1.4	1.1	2.1
Sum of top ten countries	127.2	120.0	113.6	107.9	102.9	98.3	111.6
Sum of all countries	169.1	161.2	154.1	147.7	142.0	136.9	151.8

respectively) is so high that it depletes the forest inventory and there is much less forest to deforest in later years. By 2001 their annual carbon emissions fall from 31.7 to 15.3 and from 20.2 to 14.7 million tons, respectively. Emissions from other countries, such as Malawi, Sudan, and Liberia, also drop sharply. Zaire differs from the Cote D'Ivoire and Nigeria in that it has a fairly low relative rate of deforestation but a very large inventory; consequently, emissions decline very little between 1991 and 2001 (from 32.9 to 32.3 million tons). Thus, Zaire may take on a more important role in regional carbon emissions. The Central African Republic, Congo, and Gabon are also similar to Zaire, having low emission rates with sizable forest areas. For all of the Sub-Saharan countries examined, total annual carbon emissions from deforestation are estimated to average 152 million tons between 1991 and 2001. By 2001, total annual carbon emissions are estimated to be about 137 million tons, if no changes in current deforestation rates occur.

To suggest what levels of carbon can be sequestered and stored we estimate scenarios in which current deforestation rates are reduced and/or degraded forest is protected and allowed to recover biomass or stored carbon. That is, the carbon of degraded forests is gradually increased each year until it equals that of undegraded forest. The rate of increase is defined by the potential productivity of the site [1]. Four additional model runs are made—setting deforestation rates to either 0 percent or 50 percent of the current rate and allowing the existing degraded forest to recover or not recover lost biomass. (Table 1 assumes 100 percent of the current deforestation rate with no biomass recovery.) For each of the applicable scenarios, the maximum rate of recovery (i.e., the annual increase in carbon storage) is assumed to be 5 tons per hectare under conditions of good soils and rainfall of 3000 mm/yr. This maximum is then reduced for less rainfall or less than ideal soils.

Reducing country deforestation rates to zero and allowing biomass recovery would result in an average annual sequestering of approximately sixty-two million tons between 1991 and 2001 (Figure 1). This compares with mean annual carbon emissions between 1991 and 2001 of about 152 million tons under the current situation as summarized in Table 1. The net annual change in carbon emissions is about 210 million tons, if the degraded forests are allowed to recover their carbon inventories (152 million tons without recovery). If we assume that land does not revert back to forest then emissions are zero tons. Reducing deforestation rates by 50 percent results in mean annual emissions of twenty-one million tons with biomass recovery and eighty-three million tons if no biomass recovery is allowed (Figure 1). The change in carbon emissions relative to the current situation (Table 1) is 131 million tons with biomass recovery and seventy million tons without biomass recovery. If we continued the analysis beyond 2001, the magnitude of the sink would become smaller and approach zero. The degraded forests would reach their maximum biomass and would no longer increase in size and store carbon.

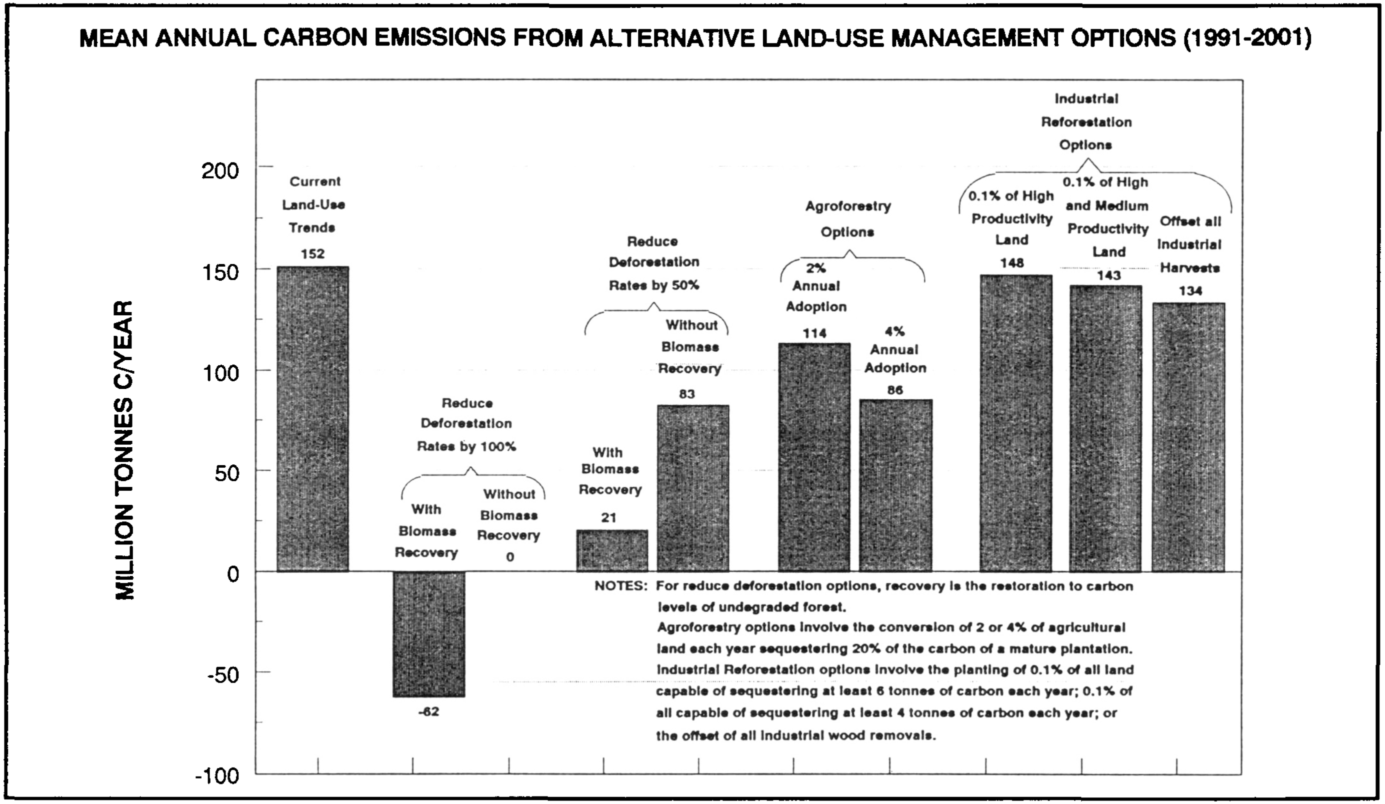
Carbon emissions from Sub-Saharan land-use change represent less than 3 percent of current world carbon emissions from fossil fuel use or about 15 percent of the annual flux from land use change. The carbon-sequestering potential of completely halting deforestation in Sub-Saharan Africa would be equivalent to about 5 percent of current annual fossil fuel carbon emissions from the United States alone or well under 2 percent of current global emissions. Moreover, the sequestering potential of these recovered forests is short-lived. Once the trees are fully mature, they will no longer continue to sequester carbon, serving only to store carbon.

THE POTENTIAL OF LAND USE MANAGEMENT TO SEQUESTER CARBON

In this section, we evaluate the potential of two land-use management strategies, agroforestry/fuelwood and industrial wood plantations, which can help control land use change and sequester carbon.

Agroforestry/Fuelwood

Alley cropping and other spatial tree crop arrangements have the potential to sequester carbon and/or slow the rate of agriculturally induced deforestation. The



NOTES: For reduce deforestation options, recovery is the restoration to carbon levels of undegraded forest.
Agroforestry options involve the conversion of 2 or 4% of agricultural land each year sequestering 20% of the carbon of a mature plantation.
Industrial Reforestation options involve the planting of 0.1% of all land capable of sequestering at least 6 tonnes of carbon each year; 0.1% of all capable of sequestering at least 4 tonnes of carbon each year; or the offset of all industrial wood removals.

Figure 1. Sub-Saharan carbon emissions from alternative land-use management options.

main tenet of these agroforestry systems is sustainability—improving soil structure and fertility, creating a more favorable microclimate, reducing the rate of decline in soil productivity, and providing a renewable source of fuelwood and fodder. It can be argued that increasing or at least maintaining agricultural productivity of a given land area would have a land-stabilizing presence and lessen the need to deforest land for cultivation.

There is a potential for sequestering carbon in direct proportion to the spatial arrangement of the trees. Although there are many possible spatial arrangements for trees and crops, a typical arrangement is to have a closer in-row spacing and a wider between-row spacing to allow for crops. We assume an average seedling spacing of 4 m between rows, a 1-m in-row spacing, and a tree row width of 1 m. This spatial arrangement would correspond to a tree-planing density of approximately 1000 trees per hectare.

We assume that land converted to agroforestry would accumulate 20 percent of the carbon of a mature tree plantation. (In highly managed tropical plantations, annual carbon accumulation has been estimated as high as 15 tons/ha [21].) The specific amount of carbon accumulated on a plantation is based on four site classes. If the potential annual carbon accumulation of the site is judged to be greater than eight tons per hectare then the plantation carbon storage at maturity is assumed to be 120 tons. These sites would correspond to locations that had ideal conditions (high moisture and good soils). Sites with less than ideal soils or moisture levels are assumed to accumulate less carbon. The poorest sites for agroforestry are assumed to have eighty-five tons of carbon at maturity. We then identified the land as being capable of supporting agroforestry and assumed that each year either 2 or 4 percent of the capable land is converted to agroforestry. Details of the analysis of identifying land capability can be found in Graham et al. [1].

The increase in Sub-Saharan carbon inventory and the decrease in regional carbon emissions as a consequence of adopting agroforestry is shown in Figure 1. Relative to current land-use trends (i.e., deforestation), agroforestry has the potential to reduce carbon emissions by 25 to 43 percent. Under the low adoption scenario about thirty-eight million tons would be sequestered each year. Under a high adoption scenario, sequestration would increase to sixty-six million tons. Net annual emissions of carbon would be about 114 and eighty-six million tons for the low and high adoption scenarios, respectively. The total amount of land in agroforestry in the year 2001 under the low adoption rate would be about twenty-six million hectares and forty-seven million hectares under the high adoption scenario.

Industrial Reforestation

We examine two plantation scenarios for industrial reforestation. The first scenario is based on offsetting industrial roundwood removals. The rate of conversion is assumed to be a function of annual deforestation rates and World

Resources Institute/International Institute for Environment and Development estimates of total industrial roundwood removals [22]. The specific reforestation amount is the product of the ratio of industrial roundwood production to total wood production (fuelwood and industrial) and the annual rate of deforestation. In effect, this scenario assumes that industrial roundwood removals are offset by reforestation. Plantations could consist of plantings of valuable hardwoods trees or coniferous (long-fiber) trees appropriate for meeting future domestic pulp and paper needs.

The second scenario uses our land-use trend model to determine the total amount of land that is physically suitable for forest plantations and then assumes that 0.1 percent of that land would be planted annually. Suitability is defined as land that had a annual productivity greater than 4 tons of carbon per hectare and is not in "forest" or "forest-fallow" land use.

The average amount of carbon that could be stored by each plantation hectare over a rotation is assumed to be half the amount of carbon that would be stored just prior to harvest. The amount stored at harvest is assumed to be 120 tons per hectare for plantations on sites whose potential annual productivity is greater than 8 tons per hectare (high site class), 100 tons per hectare for plantations on sites with potential annual productivities between eight and six tons per hectare (moderate site class), and 90 tons per hectare for plantations with potential annual productivities between four and six tons per hectare (low but feasible site class).

The results indicate that if all industrial wood removals were offset, approximately eighteen million tons of carbon would be sequestered each year, involving about 371,000 hectares annually (Figure 1). Under the second scenario, yearly sequestration is estimated at nine million tons. This would involve the planting of about 196,000 hectares each year. Carbon emissions under these scenarios would be reduced 6 to 12 percent.

We did not examine reforestation options that are primarily motivated to replenish fuelwood supplies. The evidence is quite clear that individual and government sponsored reforestation programs are not financially viable or provide adequate incentives for farmers to plant trees. For example, see French and Elkan [23, 24].

Carbon Sequestration Costs

We have estimated the likely range in carbon that might be sequestered through alternative land use policies. However, we have not addressed the costs of these land use policies. For example, the costs of improved forest management would include direct management and protection expenses, as well as the costs of programs for addressing the root causes of forest encroachment and destruction. One very broad range of cost estimates for preserving a naturally managed forest ran from $20 to $100/ha, with annual recurring expenses for administration and management of $0.50 to $1.50/ha [25]. Using these estimates, life-cycle costs of preservation for each hectare of land would range between $25 and $115, assuming a 10 percent real discount rate. The cost of each ton of sequestered carbon would lie between $3 and $15. These estimates of the direct expenses for overseeing the managed forest area do not include the costs of concomitant measures to relieve or remove development and encroachment pressures (e.g., development of sustainable agricultural systems, promotion of local forest products industries).

The minimum costs of implementing a program to encourage agroforestry would include the costs of developing nurseries to produce tree seedlings, transportation and distribution expenses to get the seedlings to the farmers, and training and extension services to ensure the seedlings are properly planted and tended. Anderson's review of farm forestry costs for Nigeria gives production costs of $0.13 per seedling and training, extension, and management expenses of $0.12 per seedling [26]. These costs are for a semiarid zone and therefore may not be representative of more favorable growing conditions. Leach and Mearns cite agroforestry project costs of $0.03 to $0.11 per seedling [27]. If we assume a planting density of 1,000 seedlings per hectare and a range in seedling costs (including distribution and extension costs) of $0.05 to $0.15 each, the direct costs for establishing each hectare of agroforestry land would lie between $50 to $150. Any expenses incurred after tree establishment (e.g., weed control and other cultural management activities) would be borne by the individual farmer. Based on the $50 to $150/ha establishment costs and assuming a 10 percent real discount rate, carbon sequestration costs would be $3 to $10 per ton.

The costs for establishing industrial wood plantations are dependent on site-specific factors, such as the previous land use, extent of site preparation, availability of seedlings, silvicultural management, and protection. Leach and Gowen report establishment costs ranging from $200/ha to $2000/ha [28]. In addition to establishment costs, there will be annual costs for maintenance (e.g., weed control), protection, and management. Plantation establishment costs for this study are therefore assumed to range between $250 and $750/ha, with annual recurring costs of $50/ha. Total costs for plantation establishment with recurring maintenance over the 1991-2002 period would be between $560 and $1060/ha, assuming a 10 percent real discount rate. The cost of sequestering carbon for each of these scenarios is about $11 to $22/ton.

The direct costs for each of the land use management options is summarized in Table 2. These data indicate that carbon sequestration costs would be lowest for agroforestry and fuelwood and highest for the industrial plantations. These estimates are consistent with more site-specific estimates provided by Pace, which range from about $4 to $16/ton [29].

DISCUSSION

Sub-Saharan land-based emissions represent a small fraction of total global emissions of carbon. However, they are a significant fraction (about 20%) of emissions from global tropical deforestation. A concerted effort in reducing

Table 2. Estimated Costs of Carbon Sequestration

Land-Use Option	Cost Assumptions	Levelized Costs ($/ha)	Carbon Costs ($/ton C)
Improved forest management	$20 to $100/ha initial expense with $0.50 to $1.50/ha annual maintenance	$25 to $115	$3 to $15
Agroforestry and fuelwood	$0.05 to $0.15/seedling with 1000 seedlings/ha	$50 to $150	$3 to $10
Industrial forest plantations	$250 to $750/ha establishment with $50/ha annual maintenance	$560 to $1060	$11 to $22

Notes: These cost estimates ($/ton C) are consistent with estimates provided by Pace [29]. For an agroforestry project (Applied Energy System's agroforestry project in Guatemala), Pace reports annualized costs of $1.43 million (10% discount rate) and annual carbon savings of 0.41 million tons/ha. This results in carbon costs of about $3.50/ton. For a reforestation project (Conservation Foundation/World Wildlife Fund report), Pace reports an estimate of $700/ha ($70/ha, annualized at a 10% discount rate) with annual sequestration of 4.5 tons/ha. This is equivalent to about $15.60/ton C.

deforestation, promoting sustainable agricultural systems, and reforesting selected areas in Africa (and elsewhere) could significantly increase carbon sequestration.

Zaire, Gabon, Central Africa Republic, Cameroon, and Congo now contain half (26,000 million tons) the forest carbon of Sub-Saharan Africa. Because of inaccessibility and fairly low population pressures, this inventory is still largely intact. If deforestation accelerated in Central Africa, land-based emissions could become much more significant globally. For example, a tripling of Zaire's annual deforestation rate to 0.6 percent, still far below that of the Cote D'Ivoire or Nigeria, would cause carbon emissions from Sub-Saharan Africa to increase by 30 percent. If Zaire's deforestation rate was the same as that of Cote D'Ivoire, emissions would be 500 million tons of carbon per year, roughly one-tenth of current global fossil fuel emissions. This change would place Zaire's emissions at levels nearly equal to those of Brazil. Such circumstances could develop if timber extraction increases significantly to make up for reduced harvesting in Brazil and Asia and for the depletion of forest reserves in West Africa.

As elsewhere in the tropics, deforestation in Sub-Saharan Africa is driven by agriculture, international wood markets, and fuelwood. It is imperative to design and carry out land-use policies for protecting existing forests and their stores of carbon, along with policies for reducing development pressures on these forests. It is crucially important to emphasize the full package of benefits derived from intact forests, not merely short-term timber and unsustainable agricultural products. Land-use policies are necessary to protect and conserve remaining natural forests, to implement better management techniques for forests being exploited for timber and wood products, to promote sustainable agricultural systems, and, where appropriate, to reforest selected areas.

Our results indicate that there is some potential for sequestering carbon through land use policies. Specifically, we estimate that agroforestry, if adopted at a rate of 2 to 4 percent annually, could reduce emissions by approximately thirty-eight to sixty-six million tons. Industrial reforestation has a smaller potential for reducing current land-based emissions: eleven to eighteen million tons annually. The direct costs of sequestering carbon are estimated at $3 to $22 per ton. Conspicuously missing from our analysis is an assessment of the tractability of implementing any significant land use policy in Sub-Saharan Africa. That issue is well beyond the scope of this article, particularly so in light of the political instability that is rampant across much of Sub-Saharan Africa.

REFERENCES

1. R. L. Graham, R. D. Perlack, A. M. G. Prasad, J. W. Ranney, and D. B. Waddle, *Greenhouse Gas Emissions in Sub-Saharan Africa*, Oak Ridge National Laboratory, ORNL-6640, Oak Ridge, Tennessee, 1990.
2. FAO (Food and Agricultural Organization), *The Tropical Forestry Action Plan*, prepared by FAO in cooperation with the World Bank, United Nations Development Program, and the World Resources Institute, Rome, 1987.
3. E. Boserup, *The Conditions of Agricultural Growth*, Allen and Unwin, London, 1965.
4. FAO (Food and Agriculture Organization), *Changes in Shifting Cultivation in Africa*, Forestry Paper 50, Rome, 1984a.
5. FAO (Food and Agriculture Organization), *Land, Food and People*, Rome, 1984b.
6. FAO (Food and Agriculture Organization), *Institute Aspects of Shifting Cultivation in Africa*, Rome, 1984c.
7. B. N. Okigbo, *Improved Permanent Production Systems as an Alternative to Shifting Cultivation*, Food and Agriculture Organization, FAO Soils Bulletin 53, Rome, 1984.
8. J. B. Raintree, *Agroforestry, Tropical Land Use and Tenure*, International Council for Research in Agroforestry (ICRAF), Background Paper for the International Consultative Workshop on Tenure Issues in Agroforestry, Nairobi, May 1985.
9. J. B. Raintree, Agroforestry Pathways: Land Tenure, Shifting Cultivation and Sustainable Agriculture, *Unasylva, 38*:154, 1986.
10. M. Gillis, West Africa: Resource Management Policies and the Tropical Forest, in *Public Policies and the Misuse of Forest Resources*, R. Repetto and M. Gillis (eds.), Cambridge University Press, Cambridge University Press, Cambridge, 1988.
11. J. P. Lanly, *Tropical Forest Resources*, FAO Forestry Paper 30, Rome, 1982.
12. S. Brown and A. E. Lugo, *Biomass of Tropical Forests: A New Estimate*, 1984.

13. FAO (Food and Agriculture Organization), *FAO Maps and Statistical Data on Population and Crops by Administrative Units*, FAO, Rome, 1983a.
14. FAO (Food and Agriculture Organization), *FAO Map of Mean Annual Rainfall and General Climate Zones for P/PET for Africa*, prepared by Todor Boyadgiev, Soil Resources Management and Conservation Service, FAO, Rome, 1983b.
15. FAO/UNEP (Food and Agriculture Organization/United Nations Development Program), *Forest Resources of Tropical Africa*, Tropical Forest Resources Assessment Project, Volume 1 & 2, Rome, 1981.
16. FAO/UNESCO (Food Agriculture Organization/United Nations Educational, Scientific, and Cultural Organization), *Soil Map of the World*, Vol. VI, Africa, 1977.
17. F. Lavenu, Digitized Vegetation Map of Africa—Descriptive Memoir and Map, prepared for the Department of Forestry Resources, FAO, Rome, 1987.
18. S. J. Olson, J. A. Watts, and L. J. Allison, *Major World Ecosystem Complexes Ranked by Carbon in Live Vegetation: A Data Base*, Oak Ridge National Laboratory, Tennessee, 1985.
19. Rand-McNally, *The New International Atlas*, Chicago, 1982.
20. F. White, *The Vegetation of Africa with Accompanying Maps*, Unesco, 1983.
21. A. E. Lugo, S. Brown, and J. Chapman, An Analytical Review of Production Rates and Stemwood Biomass of Tropical Forest Plantations, *Forest Ecological Management, 23*, pp. 179-200, 1988.
22. WRI/IIED (World Resources Institute/The International Institute for Environment and Development), *World Resources 1988-89*, Basic Books, New York, 1988.
23. D. French, Confronting an Unsolvable Problem: Deforestation in Malawi, *World Development, 14*, pp. 531-540, 1985.
24. W. Elkan, Alternatives to Fuelwood in African Towns, *World Development, 16*, pp. 527-533, 1988.
25. A. J. Leslie, A Second Look at the Economics of Natural Management Systems in Tropical Mixed Systems, *Unasylva, 39*, pp. 46-58, 1987.
26. D. Anderson, *The Economics of Afforestation—A Case Study in Africa*, The World Bank—Occasional Paper Number 1/New Series, The Johns Hopkins University Press, Baltimore, 1987.
27. G. Leach and R. Mearns, *Beyond the Woodfuel Crisis: People, Land and Trees in Africa*, Earthscan Publications, London, 1988.
28. G. Leach and M. Gowen, *Household Energy Handbook: An Interim Guide and Reference Manual*, World Bank Technical Paper No. 67, World Bank, Washington, 1987.
29. Pace University Center for Environmental Studies, in *Environmental Costs of Electricity*, N. Robinson, D. Hodas, and S. Babb (eds.), Oceana Publications Inc., New York, 1990.

Direct reprint requests to:

Dr. Robert D. Perlack
Energy Division
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831