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Developing policies for soil carbon management in tropical regions [1]

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Abstract

It is argued in this paper that two fundamental economic processes prevent resource-poor farmers in tropical countries from managing soil carbon in a sustainable manner. The first process is related to the fact that soil carbon and tropical forests are part of the natural capital of these countries and of the world community. As a consequence, the interests of resource-poor farmers in tropical countries, of these countries themselves and of the world community conflict. This implies that levels of adoption of sustainable soil carbon management practices which are optimal from the perspective of resource-poor farmers are sub-optimal from a regional and global perspective.

The second process regards the nature of sustainable soil management practices. These practices are investments in natural capital which bring about net benefits to farmers only after four to six years. Absolute poverty levels in tropical countries make it very difficult for farmers to undertake such investments. It follows that even perfectly informed and rational resource-poor farmers will not voluntarily adopt socially optimal levels of soil carbon management in tropical countries.

Policy interventions are a means of ensuring that soil carbon is managed in such a socially optimal and sustainable fashion in these countries. Two principles are proposed for developing effective, equitable and appropriate policy options. The first is the beneficiary-compensates principle, which requires that society in tropical countries and in industrialized countries should compensate resource-poor farmers in tropical countries for adopting soil carbon management practices. The second principle is that international and national policy options need to be well articulated and that sets of complementary policies should be put in place for greater effectiveness.

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Policies alleviating rural poverty and pressures to deforest are as necessary as policies specifically targeted at soil carbon management.

Finally, research priorities for soil and biological scientists are derived from the analysis. These priorities necessitate the creation of interdisciplinary teams of soil, biological and social scientists. This is perhaps an even greater challenge for the scientific community than the achievement of the research agenda itself.

Keywords: soil carbon management; economic policy

1. Introduction

The carbon cycle, that is, the exchange of carbon dioxide among the biosphere, geosphere (including soils) and the atmosphere, has been affected by human activities over the centuries. One of these activities, landuse, has a direct bearing on soil carbon and soil carbon management. There are specifically two landuse processes in tropical countries which negatively affect the carbon cycle by contributing to CO_2 emissions and global warming. These processes are deforestation, 60% of which occurs through slash-and-burn agriculture (World Bank, 1991, p. 36), and progressive change in soil carbon under cultivation by resource-poor farmers who cannot afford to maintain or manage the carbon content of their soils.

Tropical forests have a large carbon pool in their soils and litter as long as the forest canopy remains intact. This soil carbon pool is estimated at over half the total carbon stored in tropical forests (Dixon et al., 1993). Tropical deforestation affects the carbon cycle directly by burning of branches and also leads to a more gradual loss in this soil carbon pool by oxidation to CO_2. Cultivation of tropical soils results in further losses in soil carbon through erosion and oxidation of surface organic matter, unless carbon management practices are used by farmers as a means of replenishing the soil carbon pool. Tropical deforestation and cultivation in developing countries thus contribute to greenhouse gas emissions and deplete soil carbon. Soil carbon depletion, in turn, leads to a decline in soil quality and, in the long-term, to ecologically unsustainable agriculture. Trends in soil carbon losses in tropical countries, though not well documented on a large scale, are raising concerns about agricultural sustainability in these countries and about global climate change (Bolin, 1977; Brown and Pearce, 1994a). At the same time, various technological solutions which soil and biological scientists have designed for managing soil carbon in a sustainable manner (Table 1) are rarely adopted by farmers in tropical countries. This is a manifestation of the fact that sustainable soil carbon management (like other sustainable land management practices) is, in the words of Agenda 21 and the Rio Declaration, "the responsibility of governments" (Earth Summit, 1993, p. 1). That is to say, in the absence of government intervention and of policies for promoting adoption, most farmers will not voluntarily adopt these practices. Soil erosion control

Table 1
Strategies for soil carbon management

Management strategy–technology	Principal goals
Management of organic residues:	
In situ use of crop residues or transfer of crop residues within the farm, including composting	Increase soil organic matter and soil carbon
Cultivation of plant and trees for use as green manures, mulches	Increase yields through increased soil fertility
Purchase of residues	Control erosion
Management of placement of residues (pre-planting or post planting): (i) on soil surface (including low tillage) and (ii) incorporated into the soil	
Management of water and nutrients:	
Application of purchased chemical fertilizers (nitrogen and phosphorus) to supplement on-farm organic materials	Increase yields through increased water avail ability and soil fertility
Improvement of water management through the use of water harvesting, weed control, and improved water infiltration	Increase organic matter residues through increased yield
Agroforestry technologies:	
Improved fallows	Increase yields
Hedgerow intercropping	Slow down deforestation (alternatives to slash-and-burn agriculture)
Multistrata systems	
Tree planting on watersheds, on terraces	Increase soil carbon, soil fertility and agricultural sustainability

measures, for example, have been adopted by farmers in the United States on a significant scale only after soil conservation policies were introduced (Miranda, 1992).

The objectives in this paper are to address three (rather narrow) questions. First, why are sustainable soil carbon management practices not adopted on a large scale in tropical countries and why are policy interventions a prerequisite to socially optimal adoption? Second, what are viable and effective policy interventions in tropical countries for ensuring optimal adoption? And third, what are the implications of these policy needs for the research agenda of scientists concerned about soil carbon management? To better focus the argument, this paper addresses these issues with respect to tropical deforestation from slash-and-burn practices and small-scale cultivation in tropical countries. In most countries these two kinds of agricultural systems overlap.

2. Economic processes preventing optimal adoption and need for policy interventions

When the stock of a natural resource has a direct use value and when, in addition, it generates various service flows at different spatial scales, this natural resource is part of the natural capital of a country. Soil carbon is one such component of the natural capital of a tropical country. That is, it generates both local and national benefits. It benefits individual farmers since it contributes to soil fertility and agricultural yields. It also benefits society at large within a country as it contributes to agricultural sustainability and food self-sufficiency.

Tropical forests are also part of the natural capital of tropical countries as well as part of the world natural capital. Individual farmers benefit from their use (e.g., timber extraction), so do national communities (e.g., from biodiversity, tourism) and the world community (e.g., from CO_2 absorption benefits, biodiversity). [2]

Sustainable soil carbon management, or the control of deforestation and soil carbon losses in tropical countries, thus has local, national and global benefits which occur over different periods of time ranging from the medium-term (e.g., increased yields) to the long-term (e.g., biodiversity). These sustainable management practices fall into three categories (Table 1). The first is the management of organic residues by farmers, through the use of crop residues in situ, the purchase of such residues, and the use of green manures and mulches. A second kind of practice consists of improved water and nutrient management through the application of purchased inorganic fertilizers and water harvesting and weed control by farmers. The third category is made up of a number of agroforestry practices, such as managed fallows, alley cropping, multistrata systems and tree planting on terraces. The costs of implementation of all these on-farm management practices are entirely borne by the farmers who decide to adopt them and are therefore strictly local, as well as short-term.

Sustainable soil carbon management practices create two types of benefits: on-farm benefits (e.g., increased yields) and largely off-farm social benefits, such as maintenance of the resource base of agriculture for future generations or control of CO_2 emissions. These benefits, as mentioned above, are perceived

[2] This section does not address the issue of the causes of tropical deforestation which are complex and multidimensional (see Brown and Pearce, 1994b). Rather, it focuses on the reasons why farmers' interests and social interests in soil carbon management in slash-and-burn agriculture do not converge.

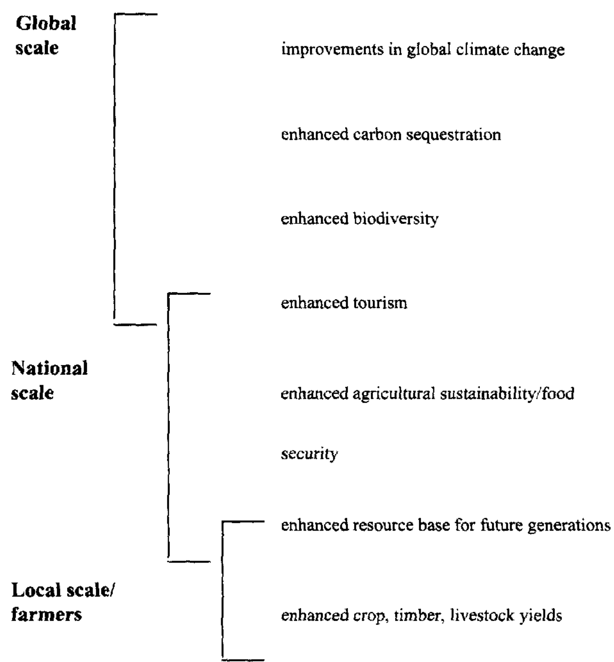

Fig. 1. Principal benefits of sustainable soil carbon management at various spatial scales.

and valued differently by different groups in society since they occur at different spatial scales. Fig. 1 shows some of these benefits and the scale at which they accrue (and it illustrates some of the overlaps which can exist among scales of occurrence). Farmers in tropical countries will take into consideration mainly on-farm benefits when deciding whether to adopt the technologies in Table 1 and will generally ignore off-farm social benefits (Izac, 1994). The discrepancy between the private and social benefits of soil carbon management is however likely to be significant. For example, a recent study estimates that the global benefits of controlling deforestation due to slash-and-burn agriculture in the Amazon region of Brazil are three to four times higher than any on-farm private benefits gained from the same practices. This study compares land prices to these global benefits; land prices can indeed be taken as a proxy in economics for the private on-farm benefits of deforestation control (Brown and Pearce, 1994b). This dichotomy between the interests of resource-poor farmers, tropical countries and the world concerning soil carbon management is illustrated in Fig. 2 where the individual, regional and global marginal benefits of adoption are compared with the individual marginal costs of adoption. Marginal costs and benefits are defined as the first derivative of total cost and total benefit. Because adoption costs are local (borne by individual farmers) whereas benefits are local, regional and global, the level of adoption Qi (where individual marginal costs and benefits intersect) is optimal from the perspective of individual farmers in

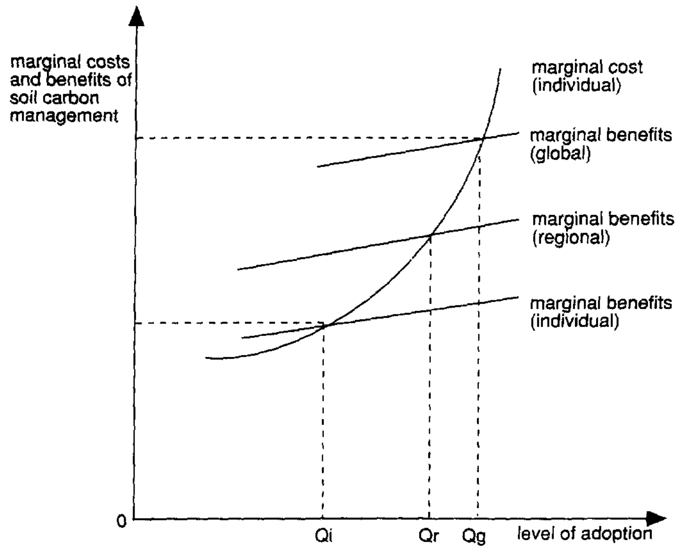

Fig. 2. Gap between individual, regional and global benefits.

tropical countries, whereas Qr (intersection of marginal costs and regional marginal benefits) is optimal from a country's viewpoint and Qg (marginal benefits globally) is optimal from the global viewpoint. (Net returns are always maximized at the point where marginal cost and marginal benefit curves intersect and this point defines optimality in economics; see Hirshleifer, 1980). In the absence of policy interventions, it will be rational for individual farmers in tropical countries to manage their soil carbon at socially sub-optimal levels since soil carbon is part of the national and world natural capital.

The second reason for the sub-optimality of adoption rates by small-scale farmers is that sustainable soil carbon management practices are investments in natural capital which these farmers can ill-afford. Studies of small-scale farmers' decision processes in developing countries have shown that these farmers generally use very high discount rates and have short planning horizons (e.g., Izac, 1994). Their primary goal is to produce enough to ensure family food subsistence and since they live in poverty and agricultural production always entails a climatic risk, it is very difficult for them to plan beyond one cropping season. [3]

The technologies in Table 1 are investments in natural capital since they require that farmers bear monetary costs (labor, materials) from the very first

[3] As a consequence of short planning horizons and high discount rates, future benefits have a much lower value in the present for these farmers. For example, a benefit of increased crop yields of \$ 100 in four years time may be 'worth' as little as \$ 40 today to a small-scale farmer in sub-Saharan Africa who is not sure of being able to feed his/her family in the intervening years.

year of adoption in order to receive benefits at some future time. This gap between the time when costs are incurred and benefits are realized, reflects the long-term and cumulative nature of soil carbon management benefits. Few empirical studies have documented the costs and benefits, for small-scale farmers, of organic matter management and agroforestry practices in tropical countries. These studies nonetheless empirically confirm the existence of this gap. For example, tree planting on terraces and grass strips takes a minimum of five years to become financially profitable for upland farmers in Indonesia (Barbier, 1990, p. 202; Huszar and Cochrane, 1990). In Zambia, adoption of improved fallows as a means of slowing down deforestation in chitemene agroecosystems becomes profitable only in the fifth year following adoption (ICRAF, 1994, pp. 33–36). The socially and globally sub-optimal adoption rates of the technologies in Table 1 are thus also due to the fact that these technologies are investments in natural capital which resource-poor farmers trapped in the 'vicious circle' of poverty [4] generally cannot afford because their period of maturity lies beyond these farmers' short planning horizon.

The foregoing analysis has shown that rational and well-informed small-scale farmers in tropical countries adopt sustainable carbon management practices at individually optimal levels but at socially sub-optimal rates. This is because two economic processes render sustainable practices relatively unattractive to small-scale tropical farmers during the initial four to five years following adoption. Expecting these farmers to adopt socially and globally optimal levels of soil carbon management practices amounts to expecting them to subsidise the rest of society in their respective countries, as well as society in 'the north'. Given that 83% of the poorest people in the world live in rural areas in the developing countries (Leonard et al., 1989), such expectations are not only unrealistic but also unethical. Policy interventions which provide appropriate incentives for adoption to small-scale farmers could however remedy this situation. In a very real sense, soil carbon management research poses as much of a policy as a technical challenge to scientists.

3. Policy guidelines for sustainable soil carbon management

Policy instruments can be used to bridge the gap between the individual goals of small-scale farmers in tropical countries and those of society regarding soil carbon management. These instruments must not only be effective in bridging

[4] It is difficult for these farmers to break out of their poverty as they have poor access to credit facilities and agriculture in tropical countries has a low absolute and relative profitability (see Reardon et al., 1993).

this gap, but also be equitable in the sharing of the costs and benefits they embody and be economically and institutionally feasible, given the specific context of small-scale farming in developing countries. An overriding requirement in tropical countries is that these sustainable soil carbon management policies have positive effects on food security and rural poverty. This is indeed a very tall order. Sustainable soil carbon management policies must reconcile, on the one hand, conflicts of interest between resource-poor farmers, national society in tropical countries and society at large in the context of global warming. On the other hand, these policies must also reconcile the often conflicting national objectives of resource conservation and the growth of agricultural output.

Two principles can be used for developing such policy options, the beneficiary-compensates principle and that of complementary national–international policy formulation.

3.1. Beneficiary-compensates principle

Most of the existing environmental and conservation policies have been devised for addressing conservation problems in industrialized societies (e.g., Bohm and Russell, 1985) and are thereby seldom appropriate to the institutional and economic structure of developing countries. For example, policies based on the use of legal incentives, such as regulations and legislation, are unlikely to be effective instruments for promoting sustainable soil carbon management practices because they normally necessitate a complex and costly administrative apparatus for implementation and enforcement. An example is the Brazilian regulation which stipulates that farmers in Amazon colonisation areas can only clear 50% of their land and must thus conserve 50% of their land as forest. This regulation is not respected by farmers and is impossible to enforce by the government (Brown and Pearce, 1994b).

Policies based on the use of financial penalties, such as taxes for farmers who deforest or do not use soil carbon management practices would also be ineffective, for the same reason, viz., prohibitive cost of enforcement. In addition, they would be highly inequitable since they would put the entire financial burden of adoption on farmers and would drive many of them into further poverty.

Policies based on the manipulation of relevant prices to provide indirect financial incentives for farmers to adopt soil carbon management practices would be a possible course of action. For example, it has been argued that increases in the prices of imported fruits in Java through the use of import taxes would encourage local farmers to adopt fruit-based agroforestry (Barbier, 1990). The use of price manipulation policies must however be based on realistic macroeconomic models which permit the assessment of the domino type of changes which will be triggered by the manipulation of just one or two prices in the economy. Price manipulation policies can be equitable and relatively inexpensive to implement, as long as they are based on reliable national macroeconomic models. Such models are essential to analyze all the domino effects and economic, social and environmental consequences of the policies.

Policies based on the beneficiary-compensates principle and on compensations paid to farmers would be equitable. Given the global public benefit nature of soil carbon management, it is indeed 'fair' to put in place policy instruments which require that society, as a beneficiary of this management, should compensate small-scale farmers for the financial burden they will incur during the first years of adoption. [5] Furthermore such policies are likely to be the most effective: they would provide farmers with a direct positive incentive to adopt, and some of them would not require a highly complex enforcement infrastructure.

3.2. Complementary sets of policies with a national and international dimension

The second principle is that complementary sets of policies must be designed, and that these policies must have both national and international dimensions. There are complex linkages between different types of policies in any one country; one type of policy, per se, is unlikely to be successful in alleviating soil carbon losses in tropical countries. Complementary sets of policies, by comparison, have a higher likelihood of being successful. Furthermore, as mentioned above, it is essential that sustainable soil carbon management policies be compatible with increased food production in tropical countries where food security is generally the highest agricultural policy priority. Complementary sets of national and international policies can address this requirement.

Since one of the more direct causes of low levels of adoption of sustainable soil carbon management practices is the absolute poverty of most farmers in tropical countries, national policies for alleviating rural poverty constitute a fundamental base for complementary intervention. These policies are well-known and have been advocated by a number of authors (e.g., Lele and Jain, 1991; World Bank, 1991). They include the provision of better transport, school, marketing, extension, research and credit infrastructure (Table 2). Such policy interventions would have the advantage of decreasing rural poverty through facilitating increases in agricultural production by providing farmers with better access to knowledge, information, health and markets. These policies will

[5] Corruption can distort most policy instruments, in both industrialized and tropical countries. Corruption is, however, not a function of the policies used in a given country but is a function of a whole set of social and economic factors which characterize the country. It would, thus, be naive and unrealistic to claim that policy interventions can be designed in ways which rule out corruption.

Table 2
Complementary national policy options

1. Policies for alleviating rural poverty: better transport, schools, credit, medical facilities, agricultural research and extension, marketing infrastructure
2. Policies for alleviating deforestation pressure tax or prohibit exports of unprocessed tropical timber, raise stumpage fees, enforce 'best practice' logging methods
promote intensification of agriculture instead of forest conversion for extensification: remove tax on intact forests, tax extensive landuses in forest margins, secure land title
promote eco-tourism: national parks, outdoor sports
3. Policies for sustainable soil carbon management: repeal all incentives for unsustainable carbon management: financial incentives for cattle ranching in forest margins, for clearing tropical forest, legal incentives to clear tropical forests (e.g. to prove ownership, to obtain credit)
provide incentives for adoption: free seeds and seedlings; tax deductions for tree and green manure planting; free use of degraded government lands for cropping conditional to agroforestry adoption; loans at zero interest for farmers groups which adopt soil carbon management
promote markets for agroforestry products: tax imports of substitute products; invest in marketing research for processed tree products
publicize soil carbon management to NGOs so that they directly fund projects

however need to be implemented in conjunction with two other national policy options.

Other types of complementary national policies are those which alleviate deforestation pressures, increase the economic value of intact forests and promote agricultural intensification on existing farmlands (Table 2). Policies which render deforestation less attractive while making agricultural intensification on existing farmland more attractive to small-scale farmers should result in increased agricultural production and decreased deforestation rates. Deforestation can for example be slowed down by raising stumpage fees and the price of timber concessions. Incentives to deforest, such as insecure land titles over intact forests, need to be removed. Incentives which increase the economic value of forests, such as eco-tourism or the development of markets for traditional non-timber forest products (e.g., medicines, Brazil nuts) are also necessary in such a three-pronged approach (Goodland et al., 1991; World Bank, 1991).

Finally, the last type of national policies are specifically targeted at removing existing incentives to unsustainable soil carbon management and are aimed at creating positive incentives (Table 2). Current financial incentives for unsustainable soil carbon management, such as the need to clear tropical forests to

Table 3
International policy options

Promote debt for nature swaps for protecting pristine rainforests
Transfer funds directly from industrialized countries to farmer' groups in tropical countries (e.g., through private voluntary organizations)
Create a multilateral fund for supporting tropical countries which have a national implementation plan for soil carbon management

demonstrate 'land improvements' and decrease land taxes in some countries, need to be repealed. Positive incentives (compensations) for adopting are also needed. For example, loans at zero interest and free seeds and tree seedlings can be made available to farmers groups which manage soil carbon sustainably at the local community level. Governmental lands which are not forested can be made available to resource-poor farmers for cropping (free of charge), conditional to their adopting sustainable soil carbon management practices on their own lands, and on these government lands. In addition, markets for the new products which farmers can produce when adopting soil carbon management practices (e.g., tree products) should be promoted.

It is important that these complementary sets of national policies be articulated with appropriate international policies, since sustainable soil carbon management has global as well as local and national impacts. The beneficiary-compensates principle indicates that industrialized countries need to pay financial compensations to tropical countries for the benefits they will accrue from the implementation of sustainable soil carbon practices in tropical countries. These funds can then be used by tropical countries to meet the enforcement costs of the national policies just discussed. Examples of such international policies are provided in Table 3.

International efforts to mitigate net greenhouse gas emissions will continue to focus on increasing energy use efficiency and reducing the consumption of fossil fuels. This is because fossil fuels are the major source of increasing greenhouse gases, over three times the annual flux attributed to landuse changes (IPCC, 1992). However, under the Framework Convention on Climate Change (FCCC), OECD countries have committed themselves to funding mitigation measures in developing countries through the Global Environment Facility (GEF). In addition, private sector funds may be available through the mechanism of Joint Implementation (JI) or international carbon offsets.

The Joint Implementation is a mechanism by which countries or entities within countries can invest in greenhouse gas emission reduction projects in other countries and share in the emission reduction credit. Since the costs of mitigation projects may be lower in developing countries and JI potentially provides additional transfers of capital and technologies, this is an attractive option. While criteria for acceptance of JI projects under the FCCC (e.g., emission reductions that are additional, verifiable and accountable) have yet to be developed, some projects are already underway. Tropical reforestation, agroforestry and forestry projects are being sponsored by a number of U.S. and Dutch companies in tropical countries, as well as by GEF (Anderson, 1989; Adger and Brown, 1994, pp. 219–227).

Debt-for-nature swaps are another way of implementing international compensations for tropical countries. These swaps consist of official debt relief tied to the protection/conservation of pristine rainforests in a tropical country. A number of such swaps has taken place since the first one occurred in 1987 in Bolivia (see Hansen, 1989). Table 3 provides other examples of such international policies.

4. Research implications

The last issue which needs to be addressed is: How do scientists develop the scientific information necessary for improving soil carbon management policies? Linkages between scientific knowledge and policies may become tenuous whenever 'knowledge' is not a cut and dried matter, as in the case of global warming and CO_2 emissions:

''Scientists and other experts like to provide 'right' answers, but politicians want 'clear' answers and tend to become confused when scientific debate becomes suffused with political purpose. Scientists do not function well if (i) they are opposed by other scientists who produce different facts and analyses; (ii) the points they wish to argue cannot be proven absolutely; and (iii) the analyses they wish to undertake are infused with controversy as to meaning and political purpose. Consequently, politicians tend to use scientific information in different ways to justify taking or avoiding a decision, interest groups align themselves to scientific advice for political purposes, and the bemused general public is usually by-passed as with other matters of great public interest.'' (O'Riordan, 1985, p. 973)

To successfully implement the two policy principles advocated in this paper and to ensure that the interest of the general public and those of resource-poor farmers are not 'by-passed,' a number of research directions need to be pursued. The participants in the International Soil Carbon Management Workshop, where this paper was presented, considered that for maximum effectiveness and relevance it is essential that soil and biological scientists work in an interdisciplinary fashion with economists and policy scientists towards the fulfilment of each of these research goals.

First, policy-makers must be provided with information which they can understand on current soil carbon status in different tropical countries and on its significance in terms of agricultural sustainability, biodiversity, farmers welfare and global climate change. Whenever feasible, threshold values that represent critical limits for soil carbon should also be identified. Biophysical and socio-economic data bases need to be systematically expanded to provide such baseline data. When developing policy options, data must be aggregated from the local to the regional and international levels. Policy implementation, in turn, will require desegregation back to the local level. The use of geographical information systems (GIS) will be instrumental in these processes of aggregation and desegregation of the baseline data.

Second, on the basis of such data, evaluations of the worth of soil carbon in tropical countries to society and to farmers are needed. Sustainable soil carbon management policies need to be based on a valuation of soil carbon which reflects as best as possible the full range of benefits it generates and the full range of costs associated with its loss. These valuations must therefore take into account monetary, non-monetary, present and future costs and benefits, and must do so at different spatial scales (local, regional, international). Such valuations, called shadow pricing by economists, are complex undertakings. They require that the various ecological, environmental and agricultural functions of soil carbon first be identified. The shadow price, or economic value to society of soil carbon in tropical countries, can then be directly related to the physical, chemical and biological functions of soil carbon in tropical ecosystems.

These various roles or functions can be identified, for example, by thinking about how different agroecosystems correspond to different levels of agricultural intensification, substitute man-made inputs for soil carbon as agricultural intensification increases. This is represented in Fig. 2 where different levels of intensification are shown on the x-axis, from very low intensification, when slash-and-burn practices are used, to extremely high intensification, with hydroponic agriculture. The functions of various inputs, viz., inorganic fertilizers, limes, irrigation water, hydroponic solutions, are substituted for the function of soil carbon, and therefore fulfill the functions of soil carbon, as agricultural intensification increases. It follows that the shadow price of soil carbon is equal to the sum of the prices/costs of these various substitutes:

If P_s = price of substitute s for soil carbon (shown on the y-axis of Fig. 2), and $s = [1,n]$, then

$$P_c = \sum_{s=1}^{n} P_s$$

where P_c = shadow price of soil carbon.

This shadow price is likely to be substantially higher than the figures used in current carbon offset programs, where soil carbon is priced between US$ 2 and 30 per ton (Adger and Brown, 1994, pp. 223). The figures used in such programs do not reflect a shadow price, or the economic value to society (Fig. 3) of the ecological functions of soil carbon. Rather they reflect the respective

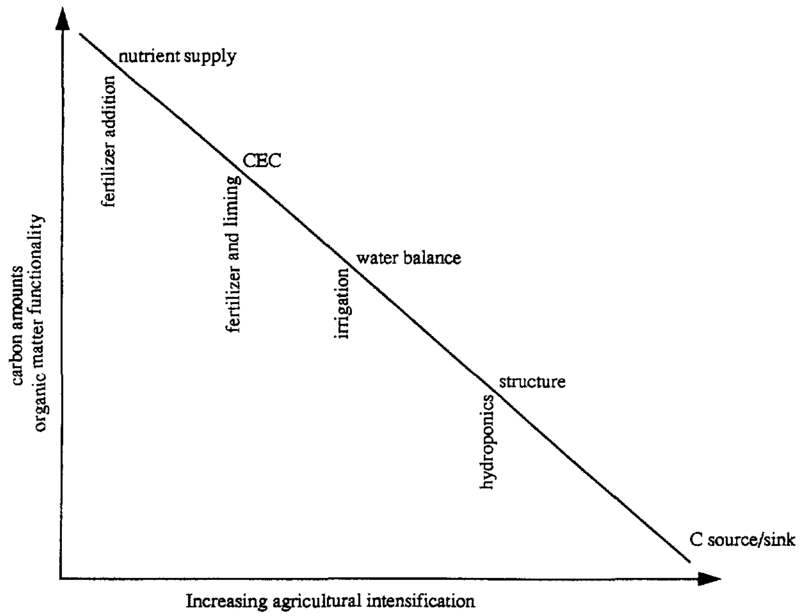

Fig. 3. Principal functions of soil carbon with increasing agricultural intensification. (Source: H. Tiessen and P. Woomer, pers. commun., 1994).

bargaining power of the few existing buyers and sellers of soil carbon in offset programs.

Interdisciplinary research is thus needed to assess the actual shadow price of soil carbon (for farmers and for the global society) in tropical countries as policy-makers are particularly responsive to valuation methods which succinctly express the trade-offs, highly relevant in the policy arena, between sustainable agricultural development and unsustainable agricultural growth. In Europe and North America, for example, there has been a general trend in policy-making over the last decades toward a greater quantification of policy parameters and the use of sophisticated assessment models. These include cost–benefit analysis (U.S., Germany) and multicriteria decision models, such as the Electre model (France) (see Barde and Pearce, 1991). Biological, soil and social scientists thus need to provide policy-makers with soil carbon valuations which can be integrated in such approaches. Such valuations would have the added advantage of providing tropical countries with a strong basis for requesting compensations from industrialized countries.

Third, analyses of policies for sustainable carbon management and of policy linkages across different sets of policies should be undertaken on the basis of assessments such as shadow prices. In other words, these shadow prices should be used to fine tune the policies in Tables 2 and 3 and to adapt them to the specific environmental, ecological, economic and institutional circumstances of different tropical countries.

5. Conclusions

It has been argued in this paper that two fundamental economic processes prevent resource-poor farmers in tropical countries from managing soil carbon in a sustainable manner. The first process is related to the fact that soil carbon and tropical forests are part of the natural capital of these countries and of the world community. As a consequence, the interests of resource-poor farmers in tropical countries, of these countries themselves and of the world community are conflicting. This implies that levels of adoption of sustainable soil carbon management practices which are optimal from the perspective of resource-poor farmers are sub-optimal from a regional and global perspective.

The second process regards the nature of sustainable soil management practices. These practices are investments in natural capital which bring about net benefits to farmers only after four to six years. Absolute poverty levels in tropical countries make it very difficult for farmers to undertake such investments. It follows that even perfectly informed and rational resource-poor farmers will not voluntarily adopt socially optimal levels of soil carbon management in tropical countries.

Policy interventions are a means of ensuring that soil carbon is managed in such a socially optimal and sustainable fashion in these countries. Two principles are proposed for developing effective, equitable and appropriate policy options. The first is the beneficiary-compensates principle, which requires that society in tropical countries and in industrialized countries should compensate resource-poor farmers in tropical countries for adopting soil carbon management practices. The second principle is that international and national policy options need to be well articulated and that sets of complementary policies should be put in place for greater effectiveness. Policies alleviating rural poverty and pressures to deforest are as necessary as policies specifically targeted at soil carbon management.

Finally, research priorities for soil and biological scientists are derived from the analyses presented in this paper. These priorities necessitate the creation of interdisciplinary teams of soil, biological and social scientists. This is perhaps an even greater challenge for the scientific community than the achievement of the research agenda itself.

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