ELSEVIER

Agricultural Economics 19 (1998) 159–174

AGRICULTURAL ECONOMICS

Agricultural development with rainforest conservation: methods for seeking best bet alternatives to slash-and-burn, with applications to Brazil and Indonesia

Thomas P. Tomich[a,*], Meine van Noordwijk[a], Stephen A. Vosti[b], Julie Witcover[b]

[a]*International Centre for Research in Agroforestry, Southeast Asian Regional Research Programme (ICRAF SE Asia), P.O. Box 161, Bogor 16001, Indonesia*

[b]*International Food Policy Research Institute, 1200 Seventeenth Street, NW, Washington, DC 20036, USA*

Abstract

Forests continue to fall for agricultural purposes throughout the humid tropics, with immediate and potentially large consequences for climate change and biodiversity loss—issues of key interest to the international community. Some of the actors directly responsible for forest conversion fell trees to meet food security needs and alleviate poverty—issues of urgent interest to them and also to national policymakers. This multiplicity of groups with differing (often conflicting) interests in the multifarious goods and services produced by tropical forests complicates the search for alternative agricultural activities for forest margins since these alternatives must satisfy such divergent objectives. This paper sets out a conceptual framework for comparing the impacts of different land use systems and agricultural practices at the margins of tropical rainforests in terms of the concerns and objectives of two key interest groups: small-scale farmers seeking livelihoods at the forest margins and the 'international' interests in the global public goods and services supplied by tropical rainforests. This framework should be useful to a third key group, the national and regional policymakers who must consider these and other policy objectives and then decide on courses of action. The paper identifies data needs and analytical methods capable of supplying an empirical base for this conceptual framework, based on quantifiable indicators. It then presents preliminary results of the application of this conceptual framework in Indonesia and Brazil in association with a global, collaborative, multidisciplinary research program. Even using preliminary order-of-magnitude estimates (to be replaced by more precise measurements as they become available), this conceptual framework presents results in ways that allow researchers and policymakers to select clear 'best bets' for development, when they exist, and to assess tradeoffs and options for complementary policy action and research efforts, when they do not.

Keywords: Rainforests; Upland farming systems; Agricultural development; Agronomic sustainability; Climate change; Biodiversity; Amazon; Brazil; Sumatra; Indonesia

1. Introduction—many interest groups, many forest products, and many policy objectives

It seems that everybody wants something from tropical rainforests, and these desires vary consider-

*Corresponding author. E-mail: t.tomich@cgnet.com

0169-5150/98/$19.00
PII S0169-5150(98)00032-2

ably by interest group. The 'international community' (concentrated in high-income countries, but including some members of the urban elite of developing countries) puts priority on *public* goods provided by the forest: preserving forest-based biodiversity, and maintaining its critical role in global climate regulation (by maintaining or increasing the carbon stored in these forests, plus reducing emissions of greenhouse gases). At the other end of the spectrum, local users of these forests see them via a filter of *private* interest: as the means to earn a living either directly by extracting forest products, or indirectly by clearing forests for agriculture then burning forest biomass to create an initial (usually the only) injection of nutrients into soils that often are fragile and deficient in key nutrients.

As forests recede or the values of extracted products decline, the 'direct' method of earning a living from the forest via extraction becomes less tenable; some forest-dwelling groups formerly dependent on extractive activities for their livelihoods find themselves turning towards agriculture for survival. But among the local users, it is the small-scale farmers at the margins of these forests, currently deriving their livelihoods from converting forest to agriculture and with the fewest options for doing otherwise, who stand out as pivotal for not only those interested in saving the forests, but also those concerned with alleviating poverty.[1] Any conceptual framework (and subsequent empirical work linked to it) that does not give their perspective a central role will miss the mark, since small-scale farmers base their decisions—including the decision to deforest—on the *private* costs and benefits of their alternatives, especially over the short term (Reardon and Vosti, 1995; Vosti and Witcover, 1996). For example, even if various groups in the international community could successfully pressure (through trade embargoes and arm twisting) national policymakers to impose a ban intended to silence chainsaws immediately in tropical forests, the consequences (if any) would be transient; in the absence of alternatives, small-scale farmers will continue to seek forest to clear to plant crops in order to survive. This paper focuses on these small-scale farmers and considers the dilemmas associated with their use of slash-and-burn from two viewpoints: the rural household and the international community.

The conceptual framework presented in this analysis seeks to juxtapose the concerns of these two groups (rural household and international community) in the evaluation of specific land use alternatives in order to identify important tradeoffs between local private interest and global public interest in the supply of forest goods and services. The framework could accommodate other groups deriving livelihoods from felled forest—those involved primarily in logging, treecrop estates, and other large-scale activities involving forest conversion—but such applications lie beyond the scope of this paper. The paper aims to show how use of the conceptual framework can inform another key group—regional and national policymakers.

Regional and national policymakers are important potential users of this conceptual framework and its outputs, not only because they are subject to pressures from both international and local user groups, but also because they are uniquely positioned to act on information about *best bet* land uses. These policymakers increasingly are obliged to consider three (sometimes competing, sometimes complementary) sets of policy objectives: environmental sustainability, economic growth, and poverty alleviation. Furthermore, they must consider these goals *simultaneously* when making policy choices (including decisions about agricultural research and development priorities), even though the links or tradeoffs among the objectives are often not well understood (Vosti and Reardon, 1997). The output from the conceptual framework presented here will shed light on how to move towards

[1]Of course, it is inaccurate to equate all forms of 'slash-and-burn' with permanent forest conversion and unsustainable land use. Traditional shifting cultivation of foodcrops, as practiced for generations by local people in the tropics, was sustainable as long as population densities were low enough to allow long fallow rotations. Although traditional shifting cultivation is disappearing as rural population densities increase, slash-and-burn as a technique of land clearing is used by virtually all actors (public and private, large and small-scale) contributing to forest conversion, sometimes in systems that are unsustainable. Nearly all tropical deforestation uses 'slash-and-burn' techniques for land clearing. There is considerable confusion in the literature, however, on how much of this is part of a long-fallow rotational system ('shifting cultivation') and how much is intended forest conversion.

achieving environmental sustainability and poverty alleviation.[2]

Is there hope of slowing deforestation while alleviating poverty among small-scale farmers? To date no integrated conceptual framework exists to aid in the search for *best bet* land uses and agricultural activities that either meet the needs and objectives of the diverse interest groups under study here, or minimize trade-offs in substituting for rainforests' functions as suppliers of private and public goods and services. Nor has comparable empirical evidence on biophysical and socioeconomic indicators of these objectives been collected for these alternatives.

Research to measure and analyze these phenomena is underway at seven sites in the humid tropics under the auspices of the global Alternatives to Slash-and-Burn (ASB) Programme. ASB is designed to undertake a global search for new ways to address natural resource management policy issues involving large global externalities stemming from tropical deforestation. As one basic step in that search process, this paper presents a conceptual framework for assessing some of the key private and social costs and benefits of current and alternative agricultural activities at the margins of tropical rainforests. Section 2 lays out the conceptual framework, including the criteria important for judging *best bets* within this framework, and describes some 'generic' *best bets* for tropical forest margins. Section 3 discusses the measurement issues associated with this framework. Section 4 presents illustrative examples of the use of this framework based on preliminary evidence from ongoing research at two contrasting sites. This evidence, which has not yet reached the point of the precise measurements suggested in Section 3, nevertheless demonstrates that even assessments based on rough orders of magnitude and directions of change can shed light on alternatives. The Indonesian example emphasizes certain land use alternatives that already predominate in the landscape, including some developed by smallholders. The smallholder systems are especially promising points of departure, in terms of both their economic and ecological characteristics. In the example from the western Amazon of Brazil, farmer and 'international' objectives seem less compatible. As occupation of the forest margin there is more recent, current land use patterns are less stable and alternatives are still being sought on farmer's fields and by agricultural research. Section 5 raises some additional caveats, underscores the messages of this work for regional and national policymakers, and charts priorities for future research.

Ultimately, *best bets* probably will *not* refer to a single land use system or technology, since the most attractive way to achieve the various objectives is likely to come from combinations of complementary land use practices in a given spatial context. This whole farm and landscape-level analysis is not feasible now. The activity specific analysis presented in this paper is a necessary precursor to that work.

2. A conceptual framework for identifying *best bet* alternatives—in whose eyes, using what criteria?

The two groups identified above as foci of this paper (small-scale farmers among local forest users, and the international community) have objectives regarding forests that diverge dramatically (though the optimal end use of the forest as seen from these different perspectives need not); they can be seen as 'polar' cases along a spectrum of groups of users of natural forest goods and services.

On the one hand, small-scale farmers focus on the *private* goods and services of rainforest use (which often involves deforestation). On the other hand, the international community focuses on global *public* goods and services from forests—more biodiversity conservation and less global climate change. This does not mean that local users do not have an interest in global public goods and services of forests, but their concentrated private interest typically swamps their more diffuse stake in global public benefits. Furthermore, with existing policy instruments and institutional arrangements, it is difficult (if not impossible) to compensate them for supplying these global environmental benefits. It also does not mean that some parts of the international community do not express a strong interest in local users' welfare, merely that their primary interests lie elsewhere. The approach taken

[2] The framework does not deal systematically with economic growth, or any other phenomena beyond the household, but below the global environmental level. These issues do, however, enter the discussion of how to apply the conceptual framework and interpret its outputs.

here is to lay out the differences inherent in these two polar cases to clarify what *best bet* might mean to each group, and translate these characteristics into descriptions of 'generic' *best bets* candidates based on land uses present in the humid tropical forest margins. In subsequent sections, we move to description and preliminary assessment of candidate *best bet* systems identified for the two case study countries, and derive implications for the policymakers 'in between'.

What do we mean by *best bet*? Overall, a *best bet* is a way to manage tropical rainforests or a forest-derived land use that, when supported by necessary technological and institutional innovation and policy reform, somehow takes into consideration the local private and global public goods and services that tropical rainforests supply. This implies a significant contribution to the objectives of both polar groups: smallholders and the international community. A first step in establishing a framework for assessing this 'balance' between private and public costs and benefits is a clearer idea of what a *best bet* might mean to each of these groups.

For each user group, a list of specific concerns is identified. The reader should note that the following are *lists*, and not *rankings*, of concerns. Establishing *rankings* lies outside the scope of this paper, and would require more detailed consultations with members of each group, and a mechanism for identifying and making use of different views. In principle, such a consultative process could ultimately produce estimates of the relative weights each group applies to their own concerns. Another set of weights, and perhaps other consultative processes (also outside this paper's scope) might ultimately be necessary to rank concerns across these groups. (For a review of scoring mechanisms for rating of technologies by farmers, extension agents, and researchers, see Jaenicke et al., 1995).

2.1. Local private concerns of the small-scale farmer

Since many of the small-scale farmers practicing slash-and-burn appear to do so because they lack feasible livelihood options that do not involve forest conversion, understanding farmer objectives and the social, economic, and biophysical constraints they face is critical. Which land use systems (and technological innovations needed to elevate them to *best bet* candidate status) have the best chance of attaining farmers' multiple economic, agronomic and environmental objectives? What are the tradeoffs from farmers' perspectives?

Fundamentally, for a land use or technological alternative to be a *best bet* candidate, it must be feasible for small-scale farmers to adopt, perhaps on only a portion of their land. A minimum set of four issues, consistent with the literature on smallholder decisionmaking and with ASB field research to date, spans the selection criteria for *best bets* at the farm level: a technology that fails to 'score' positively across all four cannot be expected to be desirable or feasible for the smallholder. For each of the four, the resource situation of the household (human capital, financial and other assets, and natural resource base) will condition the 'weight' that household places on that issue as well as the relevant time frame.

First, *best bets* must be profitable, and more profitable than alternative activities on or off farm. The time frame within which *best bets* would need to turn a profit depends on the financial situation of the household. Among small-scale farmers with few financial assets and little or no access to credit, this time frame could be quite short. Second, *best bets* must improve the food security situation of the farm household (not always synonymous with improved prospects for future profitability), the more so the closer the household lies to, or risks falling below, the threshold for minimum daily requirements. Third, these alternative activities must be compatible with labor constraints at the farm level, limited either by the human resource endowment of the farm household itself or by the rural labor market. (In its strictest form, this would require that the cash needed to hire necessary labor is generated by the *best bets*). Finally, since farmers are not myopic, *best bets* need to be agronomically sustainable; that is to say, alternative production systems must not degrade the underlying natural resource base in ways that undermine productivity and, as a result, destroy the profitability of these systems over time.

Some factors affecting attractiveness of investments in productive assets and for sustainable resource management also operate beyond the household level. These include security of rights of access to and use of the natural resource base. For example, formal and informal land and tree tenure institutions, often operating at the community level, appear to be key deter-

Table 1
Matrix of *best bet* criteria: indicators of private and public concerns/objectives

	Land use systems			
	Current practice 1	Current practice 2	*Best bet* 1	*Best bet* 2
Private (farmers') concerns/objectives				
Profitability	?	?	?	?
Food security	?	?	?	?
Labor use	?	?	?	?
Agronomic sustainability	?	?	?	?
Public (international community) concerns/objectives				
Climate change	?	?	?	?
Biodiversity	?	?	?	?

minants of incentives (and disincentives) for investment in productive assets and for sustainable resource management, at least in Indonesia. These issues affect *best bet* adoption even if the four primary concerns listed above are successfully addressed. These criteria, then, must be taken into consideration in the search for specific *best bets*. Although it is beyond the scope of this paper, subsequent analyses will include qualitative assessment of institutional endowments such as how well markets function for land, labor, capital, inputs and outputs as well as availability of information on production technology (see Vosti et al., 1997).

2.2. *Global public concerns of the international community*

The issue of primary interest to the international community, on the other hand, is taken to be the supply of global public forest goods and services, more specifically preserving biodiversity and limiting climate change. Although natural forests dominate all alternative land uses regarding these global objectives, alternatives at the forest margins do differ significantly in their ability to substitute for these global environmental services of forests. Thus, although the international community seems primarily concerned with preserving natural forest, it should also care about the resulting land uses if forest is felled.

A matrix of criteria for evaluating land use alternatives (Table 1) emerges from consideration of the perspectives of the two polar interest groups. The current land use options and the *best bet* alternatives are its columns, and biophysical and socioeconomic indicators for each concern/objective of both user groups constitute its rows. The question marks indicate matrix 'cells' to be filled with quantitative data so that each land use system can be judged regarding each criterion.

But where should the search for *best bet* candidates begin? Table 2 provides some reasonable points of

Table 2
Generic *best bet* candidates

Land uses	Descriptions	Innovation to create *best bet*
Production forests	Extraction of timber and non-timber products	Enrichment planting
Agroforests	Complex, multistrata agroforestry systems[a]	Improved germplasm
Treecrops	Monoculture or simple multistrata agroforestry systems	Improved germplasm
Foodcrops	Monoculture or multiple cropping	Integrated soil fertility management[b]
Grasslands	Livestock-based systems	Improved pastures

[a]Agroforests in Indonesia begin with intercropping of upland foodcrops, but the primary objective is establishment of treecrops like rubber and various fruit and timber species. Although created by local people, the management system accommodates natural regeneration. As a result, agroforests replicate certain elements of forest structure and ecology (for example, see Michon and de Foresta, 1995).
[b]This includes improved crop management practices involving integration of organic inputs (for example, improved fallows) and inorganic inputs (fertilizers) along with measures to control weeds, pests and diseases.

departure based on descriptions of land use systems currently present in the tropical forest margins, and some types of innovations needed to move these land uses closer to being *best bets* (here focusing explicitly on how to increase profitability via improved productivity). These are reasonable points of departure because, in most cases, some versions of these systems are already in use by at least some farmers in the study areas—indicating that variations on these *best bet* candidates have a reasonable prospect of passing the most fundamental 'test', adoption by small-scale farmers. Thus, wherever possible, existing systems are the starting point for the process of identifying *best bets* for development. This is an easier task, however, on Sumatra in Indonesia—where smallholders have centuries of experience in refining their land use systems—than it is in new settlements in Brazil's western Amazon.

2.3. Evaluation of best bets

And what are the standards for judging *best bets*? Obviously, to be classed a *best bet*, an alternative would have to surpass—in virtually every respect—unsustainable shifting cultivation, which is one possible point of comparison. Agronomically degraded systems—such as grasslands and degraded pastures—provide another set of minimum standards to beat. But because deforestation is among the primary concerns of this research, natural forests are the main point of reference for identifying the environmental and ecological characteristics of *best bet* alternatives. In the analysis in Section 4, measurements for each alternative are expressed as a difference from the natural forest baseline.[3] Systems that make better use of, and enrich, forests should be considered candidates for *best bets*. Likewise, agroforestry and treecrop systems that improve productivity while conserving some biodiversity and sequestering carbon also would be good candidates. Finally, improvements to existing foodcrop and livestock production systems that boost productivity and extend the productive life of soils should also be considered since they *may* reduce demand for additional forest conversion under certain conditions (but see the concluding caveats).

Since changes in land uses will usually affect the supplies of both private and public goods and services, all *best bet* alternatives must be measured against both sets of criteria: household objectives and global environmental objectives. And, if a land use system cannot better the benchmark for household concerns or provide a reasonable substitute for the benchmark on environmental concerns, it probably does not belong among *best bet* candidates.

From the foregoing, two points stand out: (a) the process of identifying *best bet* candidates for a specific setting is a complex one; and (b) the evaluation of *best bet* land use systems cannot be captured in a single, summary measure. Even the parsimonious approach outlined above took as its starting point for candidates a restricted list of land use alternatives (proposing several others as interesting points of comparison), and six concerns to be considered.

The difficulties with coming up with summary measures for given land uses across concerns have already been touched upon. While economic valuation can provide a suitable weighting scheme for some of the objectives and concerns, it is problematic for others (for example, biodiversity). A useful point of departure for assessing tradeoffs among private costs and benefits is the resource allocation method used by small-scale farmers, who deal with such tradeoffs on a daily basis. No similar analytical point of departure, however, exists for assessing tradeoffs among the various global public goods and services provided by forests (although, as will be noted later, some methods for considering greenhouse gas emissions in a common measuring framework do exist), or for assessing wholesale or component-specific tradeoffs among public and private goods and services. But even in this more limited framework, where measurements reveal many tradeoffs, either a multidimensional decision scheme or some system of weighing competing objectives must then be used to evaluate a *best bet* candidate (or combinations of candidates).

3. Measurement issues

Once the evaluation criteria for *best bet* candidates are clear, it is necessary to address the difficult tasks of

[3]Note that the framework can handle assessment of any land use system; since Section 4 presents orders of magnitude estimates rather than precise measurements, an explicit benchmark is required.

finding specific measurable indicators that cover those criteria well (an iterative process that may involve refining the criteria), and then collecting and analyzing data needed to assess the various land use alternatives.

Definitions for the general criteria identified above abound, and each definition carries with it measurement and sample selection issues that loom large in and vary substantially across each of the 'cells' of the *best bet* evaluation matrix. In the face of this complexity, analytical methods selected must yield indicators that are: clear, measurable and, above all, allow for comparisons across alternatives.

This section lays out specific indicators for each of the farmers' (private) and international community (public) concerns, in turn. In no case does a single indicator suffice for assessment; rather, all indicators, plus a minimum set of qualifying information, are necessary for evaluation.

3.1. Measuring smallholder (private) concerns

For the smallholder concerns, the indicators are derived from the literature on household decisionmaking processes. The suitability of this list of indicators, like the concerns themselves, should be validated with farmers. For a more in-depth account of research protocol for each private concern, see Vosti et al. (1997). The following list summarizes indicators selected.

- Private *profitability*: the appropriate measure of private profitability is the expected net present value (NPV) of revenues less costs of purchased inputs and of domestic factors of production, all valued at market prices. In addition, the time to reach positive cash flow (at a level sufficient to make a substantial contribution to sustaining a farm household), is critical, as is the existence of any subsequent period of negative cash flow. A common time horizon must be applied to all NPV calculations, and selected so as to be compatible with the longest production cycle among candidates. For example, since many of the *best bet* candidates involve perennials or livestock, the time horizon must be approximately twenty years to be appropriate to these systems. Each land use system will have an explicit, although not necessarily common, geographic scale for evaluation. To be comparable, results will be reported on a per hectare basis. Market prices will be adjusted for long-term trends and seasonal fluctuations. Social profitability, calculated at economic (shadow) prices, will be used to assess the impact of policy distortions on incentives for adoption and investment (Monke and Pearson, 1989).
- Household *food security*: the appropriate food security indicator must incorporate both direct consumption of home-produced food as well as trade for food. This is especially important for land use systems that do not involve foodcrops, but applies to food-producing systems as well. The measure used will be based on the concept of risk of food entitlement failure by Sen (1982), which encompasses trade-based and production-based entitlements to food as well as security of property rights over productive assets (inheritance and transfer entitlements).
- Household *labor use*: a measure of labor requirements (person-days per year) of particular systems will be averaged over the land use cycle. This will be supplemented by a measure of cash flow to meet hired labor needs should family labor be insufficient, calibrated so as to capture discrete periods of peak labor demand in the system itself (taking into consideration labor demand in other household activities). It also is necessary to measure division of labor by gender and age for operations where those distinctions matter.
- *Agronomic sustainability*: this term as used here refers to the long-term production capacity of a land use system; like the 'indicators' above, it is itself multidimensional. Soil scientists and agronomists working in ASB have identified a minimum set of seven components of agronomic sustainability, including adequate soil organic matter and nutrient balances. For the purposes of evaluating *best bet* candidates, the overall indicator of agronomic sustainability follows the law of the minimum: it will take a value of 1 (indicating the system is agronomically sustainable) if *all* components are above the minimum *threshold* for sustainable production, but 0 (unsustainable) if *any* component is below its threshold value at any time (note that, in this case, a scientist's assessment of agronomic

sustainability indicators and thresholds may diverge from that of the farmer).

3.2. Measuring international community (global public) concerns

Three indicators of the global environmental consequences of deforestation are available. Two of these indicators are linked to global climate change: *net absorption/emission of greenhouse gases* (carbon dioxide, methane, and nitrous oxide) and *carbon stocks*. These indicators vary with land use systems and other factors, and have aboveground and belowground components: growing perennials use carbon dioxide and thereby (temporarily) sequester a portion of this carbon as biomass; soils under forest cover and also under certain other land uses appear to absorb and oxidize significant amounts of methane (van Noordwijk et al., 1995a); on the other hand, nitrogen fertilizer applied in some land use systems contributes to nitrous oxide emissions.

Protocols for the measurements briefly described below can be found in Murdiyarso et al. (1995). Carbon stocks are measured as tons of carbon per hectare, averaged over the life cycle of a land use system. There are net carbon dioxide fluxes from land use *changes*, but not for land use types per se. For methane and nitrous oxide, each land use will have a net flux. Fluxes of methane and nitrous oxide are measured directly. Estimates of annual flux per hectare of the greenhouse gases are aggregated on the basis of net radiative forcing (IPCC, 1990), with their 'greenhouse effect' in the atmosphere expressed in carbon dioxide equivalents.

Measurement of *biodiversity* richness of the alternative land use systems for major groups of organisms above and belowground is a particularly complex challenge (Giller et al., 1997). In this research program, aboveground measurements are done for plant functional groups as well as using the more conventional taxonomic approach (Gillison and Carpenter, 1997). Gillison's 'plant functional attributes' (PFA) approach provides an overall indicator of biodiversity richness that is suitable for cross-continent comparisons. Belowground assessments focus on organisms that influence agronomic sustainability. Two of the hypotheses to be tested in the ongoing biodiversity component of this research are: (a) that PFAs are highly correlated with plant species richness as well as other aboveground taxa; and (b) that aboveground biodiversity is highly correlated with belowground biodiversity. At this stage, the first hypothesis rests on a firmer body of evidence than the second.

Still, this research overcomes only some of the methodological difficulties associated with biodiversity assessment, and cannot alone answer the question of how much biodiversity will be lost for each hectare of forest converted to another land use. The main methodological gaps concern scaling over space and over time. As one samples biodiversity over larger and larger areas of a particular ecosystem, the number of additional species observed will increase, but at a decreasing rate. This complementarity across space means that one cannot simply 'add' indicators of biodiversity richness across plots. Nor can the number of species seen on a small study area tell us how much land is needed to conserve those species. These species' long-term survival prospects depend on the extent of their habitat, but this is influenced by the pattern of land cover in the landscape. For example, although the plots of Sumatran rubber agroforests studied so far may harbor half to two-thirds of the biodiversity of an equivalent area of natural forest (Michon and de Foresta, 1995), it is not known whether the same is true if one were to compare a million hectares of rubber agroforests to an equal amount of natural forest. Even less is known about what happens if these million hectares occur in a mosaic with undisturbed forest patches.

3.3. Toward improved lists of indicators

This list of indicators for evaluating land use alternatives across these farmer (private) and international community (public) objectives is not definitive. In the absence of any prior effort at comprehensive comparison of specific land use alternatives across these concerns, dimensionality of this problem—that is, the minimum number of indicators necessary for comprehensive assessment—is still an open question. But an exercise now underway—to replicate measurements so as to fill out *best bet* evaluation matrices for particular study areas—should shed light on the dimensionality question. Section 4 presents and discusses estimates based on measurements taken thus far for study sites in the Sumatran peneplains and Brazil's western Amazon.

4. Preliminary results from Indonesia and Brazil—information for selecting *best bets*

Selection criteria discussed in Section 2 were used to derive locally relevant *best bet* candidates for the Sumatran and Brazilian sites corresponding to (but more specifically defined than) the generic land use systems described in Table 2. Data available from ongoing field research fall short of filling in precise quantitative measurements for the indicators described in Section 3, but do allow some preliminary assessment regarding directions of change and their orders of magnitude vis-a-vis the natural forest benchmark. This exercise has already proven useful in comparing site-specific *best bet* candidates, and providing insights as to promising *best bet* technologies at each site. A comparison of the framework's application across the two sites provides clues to its flexibility in dealing with diverse contexts. A look at similarities and differences in the cells of the matrix points to areas where comparative cross-site analysis may yield broadly generalizable findings.

Table 3 presents preliminary *best bet* matrices for Sumatra in Indonesia (Part 1 of the table) and Brazil's western Amazon (Part 2). The column headings for each matrix reflect major land uses and certain alternatives for each site. The measurements in each column of both matrices are based on the authors' estimates of orders of magnitudes of differences, compared with natural forests. It is the cross-row comparisons of land use alternatives, however, that will reveal the most about which of the systems are *best* (and worst) *bets*—with respect to smallholders' objectives and supply of global public goods. The ability to make cross-row comparisons with confidence will grow as orders of magnitude estimates are replaced by more precise measurements in each matrix.

The Indonesian case is treated in detail; the discussion of the Brazilian case follows, highlighting the flexibility of the framework, and pointing out differences and similarities across sites.

4.1. *Balancing profitability and biodiversity in Indonesia*

While conversion of natural forest has a major effect on the supply of forest functions, the subsequent land uses also matter a great deal for agronomic sustainability and the supply of global environmental benefits. Part 1 of Table 3 presents very preliminary estimates of the orders of magnitude of these differences for seven systems that represent the major land uses in Sumatra's peneplains, the low-elevation, undulating areas of poor soils that comprise the island's largest agroecological zone (see van Noordwijk et al., 1995a for details).

All the tree-based systems in Part 1 of Table 3 (smallholder agroforests and monoculture, as well as large-scale plantation monoculture) are agronomically sustainable. On the other hand, shortening of fallow rotations (from 10–20 years or more to less than five years) with rising land scarcity is undermining sustainability of shifting cultivation, which has been disappearing anyway as population pressure increases in Sumatra (van Noordwijk et al., 1995a). Continuous cultivation of cassava does not appear sustainable on this land because of depletion of nutrients and of soil organic matter. (On these soils, marginal revenues from fertilizer applications to cassava do not cover fertilizer costs at current prices, which are near the world market price for most nutrients except nitrogen, which is subsidized in Indonesia). There also do not appear to be big differences among forest extraction and the other tree-based systems regarding carbon stocks and greenhouse gases. Thus, as far as agronomic sustainability and climate change issues are concerned, tree-based systems dominate among the alternatives.

There are significant differences among the tree-based systems and between these systems and the natural forest baseline regarding aboveground biodiversity.[4] Agroforests are much richer in species than the other tree-based systems, but it must be emphasized that agroforests are not perfect substitutes for biodiversity conservation in natural forests. Indeed, conversion of natural forests to agroforests involves a

[4]Work on belowground biodiversity measurements is ongoing at both sites, but has not progressed sufficiently for inclusion in these preliminary assessments.

Table 3
Preliminary estimates of the impacts of selected land use systems
Part I – Application to Sumatra, Indonesia – peneplains

Private and global concerns/objectives	Land use system large-scale forest extraction	Rubber agroforest	Rubber monoculture	Large-scale oil palm or industrial timber monoculture	Shifting cultivation of upland rice and other foodcrops	Continuous cultivation of cassava	Imperata cylinderical grasslands
Private (Farmers') concerns							
Profitability	++ (+++?)[1]	++	++ (+++?)	++(+++?)[1]	+	+(++?)	–
Food security	–	++	++	–	+	+	–
Labor use	ε(–?)	+	+	+	+	+	–
Agronomic sustainability	N/A	1	1	1	0/1	0	N/A
Public (Global) environmental concerns							
Carbon stocks	–	–	–	–	– –/–	– –	– –
Greenhouse gas absorption	ε	ε	–	–	–	– –	– –
Biodiversity (aboveground)	–	–	– –	– –	– –/–	– –	– –

Part 2 – Application to western Amazon of Brazil[2]

Private and global public concerns	Land use system					
	Managed forests	Agroforestry systems	Treecrops	Managed fallows	Annual crops with legumes	Improved pastures
Private (Farmers') concerns						
Profitability	+	+(++?)	++(+++?)	ε(?)	+	++(+++?)
Food security	+	+(?)	+(?)	ε(?)	++	++
Labor use	+	+(++)?	+	+(?)	+	–(– –?)
Agronomic sustainbility	1	1(?)	1	1	1(?)	1(?)
Public (Global environmental) concerns[3]						
Carbon stocks	ε	–	–	–	– –	– –(–?)
Greenhouse gas absorption	ε(?)	–	–	–	–(– –?)	–(– –?)
Biodiversity (aboveground)	ε	– –	– –	–	– –	– –

[1]Profitability estimates are from the perspective of the operator, which for this land use system is a large-scale company instead of a smallholder household.
[2]*Best-bet* candidates for measurement and evaluation have a considerably narrower definitions than these column headings: for example, improved fallows are annual crop with kudzu or annual/tree crop rotation with nitrogen-fixing tree; and simple agroforestry systems such as coffee/bandarra, coffee/rubber, and/or coffee/peach palm. Current practices are also to be measured: including degraded pasture, perennial stands, and unimproved fallow areas. Still, the ''scores'' presented here for broader land use system categories illustrate the uncertainties surrounding measurement of the diversity of land uses and management practices in the Brazil sites.
[3]Field data to support this analysis in Brazil are still quite preliminary. Early access to, and a careful interpretation of, these data were provided by Divonzil Gonçalves Cordeiro.
(N.B. Estimated changes are all site-specific and expressed in terms of order of magnitude vis-a-vis the natural forest.)
2 orders of magnitude less: – –
0–1 order of magnitude less: –
no significant difference: ε
0–1 order of magnitude greater: +
2 orders of magnitude greater: ++
3 orders of magnitude greater: +++
agronomic sustainability: 0=unsustainable, 1=sustainable.

significant reduction in species richness. For assessments of higher plants made along 100 m line transects in Sumatra, over 350 species were found in primary forests while the number dropped to about 250 species for rubber agroforests. However, the richness remaining in agroforests still is much higher than the five or so species of higher plants found in rubber monoculture (Michon and de Foresta, 1995).

Raising productivity of rubber agroforests, which span millions of hectares, offers a promising pathway in Sumatra. There is potential for raising profitability of these systems through adaptation of existing higher-yielding germplasm within existing smallholder systems (Barlow and Jayasuriya, 1984; Tomich, 1991), which also could contribute to national policy objectives such as enhancing food security and increasing labor absorption. These potential economic benefits may be combined with significant aboveground biodiversity conservation—albeit less than natural forest—because the mix of planted species is augmented by natural regeneration of forest species (Michon and de Foresta, 1995; van Noordwijk et al., 1995b). Indeed, these agroforests may approximate a number of forest functions, thereby providing the technical foundation for some institutional arrangements such as sustainable community-based forest and watershed management.

A key unresolved question is whether the potential for development of smallholder rubber agroforests (with most operating units of 1–10 ha) can compete with the private and social profitability of large-scale alternatives (10,000–300,000 ha), including logging concessions, oil palm plantations and industrial timber estates. The latter schemes are viewed as *best bets* for economic development by many policymakers and donors, in large part because of conventional wisdom of economies of scale in plantation development. *If* it turns out that large-scale development alternatives are more profitable—as indicated in the parentheses of Part 1 of Table 3—three important policy tradeoffs will have to be faced: (a) tradeoffs with food security, since such projects often involve displacement of local smallholders with little or no compensation; (b) in the case of large-scale logging, a tradeoff with labor absorption; and (c) for large-scale plantation monocultures (for example, oil palm and industrial timber), an important tradeoff with biodiversity conservation.

Despite the conventional wisdom, the prevailing faith in economies of scale in production of so-called 'plantation' commodities receives no support from the agricultural economics literature (Hayami and Kawagoe, 1993; Tomich et al., 1995). This is, nevertheless, an empirical question that will be addressed in the next phase of research. Unlike production, though, marketing and processing of primary products often are characterized by increasing returns to scale. This is the case for three of the most important land use alternatives—rubber, pulp and oil palm—in Sumatra. The natural rubber industry in Southeast Asia provides an excellent example of the efficiency with which markets can integrate low-cost production by smallholders with processing in factories that achieve economies of scale; similar marketing arrangements should work for pulp. Oil palm conventionally has been viewed as an estate crop in Southeast Asia (but not in Africa) because of its perishability. Even in this case, however, oil palm production on independent plots as small as one hectare began to emerge in Sumatra in the 1980s. Outgrower schemes, contract farming and other institutional arrangements all can help reduce transactions costs in linking efficient smallholder producers with efficient large-scale processors.

Even if analysis shows that the large-scale schemes hold no advantages in terms of private and social profitability compared to smallholder schemes, a potential tradeoff between profitability and biodiversity conservation remains to be addressed concerning smallholder systems (van Noordwijk et al., 1995b). Farmer management aimed at increasing productivity of systems often decreases biodiversity. Whether or not this apparent tradeoff between productivity and biodiversity is inescapable is the subject of debate—and further research. Even modest productivity gains can cause great loss of biodiversity in some cases. For other systems and using different production techniques, biodiversity loss may be relatively slow for *initial* increases in productivity. In the latter case, raising productivity to an intermediate level may involve a modest tradeoff with biodiversity. Thus, two of the most important research questions regarding the selection of *best bets* in Sumatra are: what is the shape of this tradeoff function, and what factors influence the biodiversity of these complex, multistrata systems as productivity of their components increases?

4.2. Seeking a different balance in Brazil

The patterns and pace of occupation of forest margins areas in the Brazilian Amazon have differed substantially from those in Indonesia, resulting in part from different endowments of land, labor, natural resources and capital between the two countries, their differences in access to major commercial centers, and also because of the distinct policy environments that served to attract migrants and guide their land use decisions upon arrival (for Brazil, see Mahar, 1989).

Brazil's western Amazon still is a new frontier for agriculture; most farmers are relatively recent settlers (bringing with them knowledge of other, non-rainforest ecosystems), and markets still are developing. 'Small-scale' operational holding here refers to an area of approximately 80 ha, dramatically larger than the 5 ha holdings characterizing smallholders in Sumatra. A range of management practices may be found within any given land use, with fairly rapid shifts in technique. Land use mixes also exhibit great variety, and soil types vary in more patchwork fashion than in Sumatra.

The shifts and variety in Brazil probably reflect changes in markets and infrastructure that accompany the transition from frontier to a settled area. Ongoing adjustment also means that issues of scale, tenure and the potential role of public institutions are in a state of flux, particularly as new roads link what have been isolated local markets to national and international markets for the first time. Thus, systems that predominate in the landscape now may disappear soon and systems important in the future may not yet be evident (Vosti et al., forthcoming).

Not surprisingly, then, land use systems found at the forest margins of Brazil's western Amazon differ substantially from the myriad tree-based systems of land use found at the forest margins of the Sumatran peneplains. In the western Brazilian Amazon, a large (and increasing) amount of land is dedicated to extensive livestock production systems (Witcover et al., 1996), and some farmers are beginning to intensify livestock production using the improved pastures identified as a *best bet* candidate. Trends in land use also were used to select *best bet* candidates: farmers are only now making initial, tentative forays into agroforestry systems including timber as a component. Promising technologies (at least in environmental terms) identified by agricultural research and undergoing refinement through interaction with farmers, but not currently important on the landscape, also made the list as likely candidates. But few current land use patterns appear among *best bet* candidates. Thus, column headings in Part 2 of Table 3 often have no direct analogue in the matrix for Indonesia.

This discussion suggests that the diversity of land use mixes and management techniques, the unfamiliarity of many agriculturalists with the natural resource base, plus the prospect for continued rapid change that characterize the Brazil site, have implications for the definition and testing of *best bet* practices. Because indigenous knowledge is not well established, getting a list of potential *best bet* candidates—even more than in other areas—must involve an interplay between agricultural research and farmer-based trial.

The differences between these sites give rise to several questions. Can the same conceptual framework applied to the Indonesian case allow for the identification of *best bet* candidates in Brazil? As in the Indonesian case, the preliminary results of field research are summarized for each *best bet* candidate in Part 2 of Table 3, using the seven criteria set out above (four related to farmers' objectives, and three related to the objectives of the 'international community'). The ambiguities in column headings and some cell contents in the matrix highlight the adaptations described above that must be made to make the conceptual framework flexible in its application, but the usefulness of its multiple-user, multiple-objective approach still holds.

If the *best bets* differ from those in Sumatra, or similar *best bets* have extremely different 'cells' as regards the global and farmer objectives listed, why is that so? Unlike the Indonesian case, where the framework revealed some land uses that provide an attractive mix of household benefits and global public goods, the tradeoffs appear starker for Brazil. For example, the financial profitability of improved pasture systems is superior to all of the more environmentally benign alternatives such as managed forests, suggesting a wide gap between the private and public costs and benefits of deforestation. At least for now, the realizable contribution to household incomes of managed forests, improved fallows, and complex agroforestry systems cannot match that of improved pasture systems, although the situation for treecrops might be more promising.[5] This situation may change if increased supplies of beef and milk reduce market prices, if demand for products from managed forests and agroforestry systems increases, or if the policy and other institutional impediments to tapping existing markets for these products are removed. Local market development may open at least some niches for profitable land uses that score higher in terms of biodiversity and carbon stocks (for more on this with regard to agroforestry, see Vosti et al., forthcoming). However, livestock in Brazil's western Amazon is likely to retain this advantage as long as demand for alternative products is weak and/or uncertain, and product supply links are interrupted by seasonal flooding.

As regards food security, the environmentally benign options such as managed forests, fallows, treecrops, and agroforestry systems appear once again to be inferior to improved pasture or legume-based annual cropping systems, especially in this context of seasonally unreliable and imperfect markets.

Future work will quantify these tradeoffs, suggest mechanisms for dealing with them, and test the responses of farmers to likely shifts in relative prices if markets improve.

As in Indonesia, economies of scale in production systems have yet to be demonstrated, but scale economies in marketing or processing may occur. Empirical evaluation may suggest organizational changes (for example, cooperatives) or institutional changes (for example, farmer contracts with large-scale processors) that allow smallholders to exploit scale economies in production, processing or marketing, if they exist.

[5]For a discussion of the potential of standing forests, see Braz and d'Oliveira (1994) on the production potential of small-scale managed forests in the state of Acre, Witcover and Vosti (1995) on issues of import for market in emerging non-timber tree products, and Guimarães (forthcoming) on the application of these issues as applied to the study area, with a focus on pimenta longa (a native source of the oil saffrole) and peach palm. Oliveira (1997) explores potential profitability of coffee among tree crop systems. See Oliveira and Vosti (1997) for a discussion of productivity and financial profitability of selected agroforestry systems in Rondônia; and Faminow et al. (forthcoming) for exploration of similar issues as regards improved pastures within a whole-farm context.

5. Next steps in research, conclusions, and policy messages

This paper identified a conceptual framework for selecting among alternative land use systems at the margins of tropical rainforests. The framework incorporates multiple users with different objectives regarding the private and public goods and services supplied by forests. Based on this framework, the notion of a *best bet* candidate was introduced and discussed in terms of private and global public benefits. Two 'polar' groups with contrasting objectives regarding private and public aspects of forest goods and services were chosen as foci: small-scale farmers (who focus on private benefits, and who are central to any strategy that targets *both* poverty and forest loss), and the international community (who focus on global public benefits). Concerns of these groups and indicators for assessing land use systems were specified, and the methodological and practical difficulties in measurement of indicators and valuations of *best bet* candidates were discussed. In addition to the difficulties of assessing these complex private concerns and public concerns separately, the overriding challenge is to weigh tradeoffs between the objectives of different interest groups. The potential (and need) for consultative processes and multi-criteria decisionmaking tools should be apparent.

Examples drawn from field research in Indonesia and Brazil suggest that some *best bet* alternatives may exist, but these examples also highlight the potential tradeoffs among local and global concerns. Although the *best bet* candidates differed greatly across sites, it was feasible to adapt the conceptual framework and measurement techniques to these contrasting cases, and draw lessons about cross-site comparability from the exercise.

5.1. Next steps in research

Ongoing research aims to replace the orders-of-magnitude estimates contained in this paper with more precise figures. These data will provide a better basis for assessing the tradeoffs among *best bet* candidates, and the types and amounts of technological change and/or policy reform necessary for their adoption. Looking across types of constraints to land use alternatives, first within specific sites, then across sites, will provide a starting point for more efficient assessment of *best bet* candidates or likely constraints to them, perhaps even prompting some evaluation of potential for transfer of *best bet* candidates from one site to others.

5.2. Panacea or Pandora's box?

However, several overriding caveats regarding technological change must be faced. First, *best bet* technologies alone cannot arrest forest conversion. Many of the forces driving deforestation and natural resource degradation arise at the regional or national level, and can overwhelm the mitigating effects of technological change. For example, an inflow of migrants facilitated by road construction and driven by lack of economic opportunity elsewhere can swamp the effects of *best bet* alternatives at the field level. Second financial profitability is a necessary condition for adoption of *best bets* by smallholders, but is *not* sufficient by itself as a means to slow deforestation. Indeed, because *best bet* alternatives are *profitable*, they can have the perverse effect of accelerating deforestation, either by attracting new migrants to the forest margins or by promoting increased forest conversion by current inhabitants. Third, the relative profitability of forest conversion by smallholders is not determined solely by production technology; it also is tied to institutions and legal frameworks that establish, monitor and enforce property rights; to policies regarding public investment in infrastructure and social services; and to macroeconomic policy. The institutional and policy environments sufficient for *best bet* alternatives to reduce poverty *and* deforestation are not well understood yet; and this is top priority on ongoing research. However, it is a *sure* bet that deforestation will accelerate in developing countries if profitable innovations for rainfed land uses are introduced where there is open access to rainforests and within an economy-wide context of rapid population growth and declining economic opportunities.

Hence, *best bet* candidates examined in this paper are appropriate from the perspective of existing small-scale producers: if the number of small-scale producers were to increase greatly and quickly, or, if small-scale producers were displaced by other types of producers, the *best bet* technology choices coming out of this framework may not function as intended.

Still some trends and changes are more likely than others. A promising way to handle uncertainty would be to re-apply the evaluation under different scenarios. For a description of such an approach applied to agroforestry systems for the western Brazilian Amazon, see Oliveira and Vosti (1997).

5.3. Messages for policymakers 'in between'

While the paper focused primarily on two sets of consumers of forest goods and services, small-scale farmers and the international community, some messages for regional and national policymakers 'in between' these polar cases emerged.

Policymakers' preferences regarding land use systems have so far not been systematically included in this framework, but they can and should be. The triad of policy objectives of environmental sustainability, economic growth and poverty alleviation would be one place to start. As part of this effort, the factors affecting economic growth would be placed more squarely on the table than they were here. One approach might be the addition of one or more 'rows' in the matrix to quantitatively capture these macroeconomic concerns. Policymaker objectives might inform the feasibility of achieving wide adoption of *best bet* alternatives. For instance, realistic assessments of the costs of technology development and dissemination of information are missing from this framework, but must be included in future work. More generally, though, this paper presents the policymaker with a framework for identifying tradeoffs regarding objectives of smallholders and the international community. A next step for researchers and policymakers might be an examination of tools at their disposal for minimizing these tradeoffs.

Acknowledgements

This research is part of the Alternatives to Slash-and-Burn (ASB) project. ASB was established with assistance from the United Nations Development Programme (UNDP) with initial funding from the Global Environmental Facility (GEF) and additional support from the Danish International Development Agency (DANIDA), the Government of Japan and other donors, as well as from core budgets of the collaborating institutions. This research also benefitted from support from the Inter-American Development Bank and the Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA). The authors have benefitted from discussions with and research undertaken by scores of ASB collaborators. Among these, conversations with Neil Byron, Chantal Line Carpentier, Andrea Cattaneo, Divonzil Gonçalves Cordeiro, Merle Faminow, Hubert de Foresta, Andy Gillison, Tamara Gomes, Angelo Mendes, Daniel Murdiyarso, Samuel Oliveira, Vanda Gorete S. Rodrigues, Marcelo Rossi, Michael Swift and Judson Valentim have been particularly important in the development of the ideas presented in this paper. We also are grateful for comments received from Steve Franzel, Frank Place and Meredith Soule. The authors are solely responsible for any errors in fact or interpretation.

References

Barlow, C., Jayasuriya, S.K., 1984. Problems of investment for technological advance: the case of Indonesian rubber smallholders. J. Agric. Econ. 35, 85–95.

Braz, E.M., d'Oliveira, M.V.N., 1994. Manejo florestal para áreas com populações tradicionais. 3° Simpósio Internacional de Estudos Ambientais sobre Ecossistemas Florestais. Porto Alegre, Brazil. Volume de resumos, p. 39.

Faminow, M.D., Oliveira, S., Sá, C.P., forthcoming. Development of an investment model for the smallholder cattle sector in the western Amazon. Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA)/Acre Documento, Rio Branco, Brazil.

Giller, K.E., Beare, M.H., Lavelle, P., Izac, A.M.N., Swift, M.J., 1997. Agricultural intensification, soil biodiversity and agroecosystem function. Appl. Soil Ecol. 6, 3–16.

Gillison, A.N., Carpenter, G., 1997. A generic plant functional attribute set and grammar for dynamic vegetation description and analysis. Funct. Ecol., in press.

Guimarães, V., forthcoming. Pesquisa de mercado de produtos vegetais não madeireiros (NTTP): pesquisa de mercado estudos de caso, pimenta longa (*Piper hispidinervium*) and pupunha (*Bactris gasipaes* H.B.K.). Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA)/Acre Documento, Rio Branco, Brazil.

Hayami, Y., Kawagoe, T., 1993. Peasant and plantation in Asia. In: Hayami, Y., Kawagoe, T. (Eds.), The Agrarian Origins of Commerce and Industry. St. Martins Press, New York, 202 pp.

IPCC (Intergovernmental Panel on Climate Change), 1990. Climate change: the IPCC scientific assessment. Cambridge Univ. Press, Cambridge, UK.

Jaenicke, H., Franzel, S., Boland, D., 1995. Towards a method to set priorities amongst multipurpose trees for improvement activities: a case study from West Africa. J. Trop. For. Sci. 7(3), 490–506.

Mahar, D.J., 1989. Government policies and deforestation in Brazil's Amazon region. World Bank, World Wildlife Fund, and The Conservation Foundation, Washington, DC.

Michon, G., de Foresta, H., 1995. The Indonesian Agroforest Model. Forest Resource Management and Biodiversity Conservation. In: Halladay, P., Gilmour, D.A. (Eds.), Conserving Biodiversity outside Protected Areas. The Role of Traditional Agro-Ecosystems. The World Conservation Union (IUCN), Gland, Switzerland.

Monke, E., Pearson, S.R., 1989. The Policy Analysis Matrix for Agricultural Development. Cornell Univ. Press, Ithaca, NY, 279 pp.

Murdiyarso, D.M., Hairiah, K., van Noordwijk, M., 1995. Modeling and measuring soil organic matter dynamics and greenhouse gas emissions after forest conversion. Proceedings of Workshop/Training Course, 8–15 August 1994, Bogor/ Muara Tebo, Indonesia in ASB-Indonesia Publication No. 1.

van Noordwijk, M., Tomich, T.P., Winahyu, R., Murdiyarso, D., Partoharjono, S., Fagi, A.M. (Eds.), 1995a. Alternatives to slash-and-burn in Indonesia: summary report of Phase 1. Alternatives to Slash-and-Burn Agriculture (ASB)-Indonesia Report No. 4. ASB-Indonesia Consortium and ICRAF, Bogor, Indonesia.

van Noordwijk, M., van Schaik, C.P., de Foresta, H., Tomich, T.P., 1995b. Segregate or integrate for biodiversity conservation? Paper presented at the Global Biodiversity Forum, 4–5 November, Jakarta, Indonesia.

Oliveira, S., 1997. Custos e lucratividade da cafeicultura em Rolim de Moura, Rondônia. Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), EMBRAPA/Rondônia, Brazil.

Oliveira, S., Vosti, S.A., 1997. Aspectos financeiros de sistemas agroflorestais em Ouro Preto do Este, Rondônia. In Administração rural: Instrumento de sucesso Numa economia estável. Anais do 2° congresso Brasileiro de administração rural: Tema central. Uberaba, MG, Brazil.

Reardon, T., Vosti, S.A., 1995. Links between rural poverty and the environment in developing countries: asset categories and investment poverty. World Dev. 23(9), 1495–1506.

Sen, A., 1982. Poverty and Famines: An Essay on Entitlement and Deprivation. Oxford Univ. Press, New York, 257 pp.

Tomich, T.P., 1991. Smallholder Rubber Development in Indonesia. In: Perkins, D.H., Roemer, M. (Eds.), Reforming Economic Systems in Developing Countries. Harvard Univ. Press, Cambridge, MA, pp. 249–270.

Tomich, T.P., Kilby, P., Johnston, B.F., 1995. Transforming Agrarian Economies: Opportunities Seized, Opportunities Missed, Cornell Univ. Press, Ithaca, NY, 474 pp.

Vosti, S.A., Reardon, T. (Eds.), 1997. Sustainability, Growth, and Poverty Alleviation: A Policy and Agroecological Perspective. Johns Hopkins Univ. Press, Baltimore, MD, 407 pp.

Vosti, S.A., Witcover, J., 1996. Slash-and-burn agriculture: household perspectives. Agric. Ecosyst. Environ. 58, 23–38.

Vosti, S.A., Witcover, J., Gockowski, J., Tomich, T.P., Carpentier, C.L., Faminow, M., Oliviera, S., 1997. Socioeconomic issues linked to *best bets*. Proceedings of a Modellers' Workshop, 18–25 March 1997, Empresa Brasileira de Pesquisa Agropecuária

(EMBRAPA)/Acre Research Station, Rio Branco, Brazil. Mimeo, EMBRAPA/Acre, Rio Branco, Brazil.

Vosti, S.A., Witcover, J., Oliveira, S., Faminow, M.D., forthcoming. Policy issues in agroforestry: Technology adoption and regional integration in the western Brazilian Amazon. Forthcoming in Agroforestry Systems 38.

Witcover, J., Vosti, S.A., 1995. Workshop on non-timber tree product (NTTP) market research. Environment and Production Technology Division (EPTD) Workshop Summary Paper No. 3, International Food Policy Research Institute. Washington, DC.

Witcover, J., Vosti, S.A., de Almeida Barbosa, F.R., Batista, J., Beatriz, V., Böklin, G., de França, S.B., Castilla, C., Fujisaka, S., Figueiredo Gallo, S.L., Garcia, J.H., Cabral, W.G., Hurtado, L. Leite, A., Nogueira Leite, F.M., Souza, D.A., de Souza Marinho, J.T., Rocha, K., Rosa Neto, C., 1996. Alternatives to slash-and-burn agriculture (ASB): A characterization of Brazilian benchmark sites of Pedro Peixoto and Theobroma, August/September 1994. MP-8 Working Paper No. US 96-003, Environment and Production Technology Division, International Food Policy Research Institute (IFPRI). IFPRI, Washington, DC.