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Technical Note 3.1 – Impacts of Soil Quality Differences on Deforestation, Use of Cleared Land, and Farm Income[1]

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Abstract

It is often suggested that soils in the western Brazilian Amazon are, on average, too poor to support sustained agricultural production at levels sufficient to meet the basic needs of small-scale agriculturalists. Moreover, the region's poorest quality soils are thought to be especially unsuited for agriculture, and consequently areas containing these soils are often set aside as forest reserve areas in state-level land use zoning exercises. However, while there is general agreement that continued annual crop production cannot be sustained on most Amazonian soils without the use of fertilizers, the same may not be true if the product mix is expanded to include other agricultural products, which may be quite effective in sustaining the livelihoods of smallholder families. This Technical Note uses a farm-level bioeconomic model to assess the impacts on deforestation, use of cleared land and smallholder income of differences in soil quality. Results suggest that deforestation rates are only slightly lower on farms endowed with good-quality (versus poor-quality) soils, due primarily to increased labor requirements on farms with good soils. Use of cleared land also varies: farms with poor-quality soils dedicate proportionately less land to annual crops and secondary fallow, and more to pasture. The biggest impact of soil quality, however, is on smallholder income: farms with good-quality soils earn about 35% more than those tilling poor-quality soils, although the level of income provided to these disadvantaged smallholders is still more than sufficient to meet their food security and other needs.

This Technical Note is prepared as input into the OED's review of the World Bank's forestry policy, particularly the Brazil case study. This note is not for quotation or circulation, and its content does not necessarily reflect the views or opinions of the World Bank.

Introduction

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[1] This is a numbered Technical Note series, with the potential for particular numbers in the series to have several versions; e.g., Note 3.1 may be followed by an updated discussion of the impacts of soil quality on small-scale agriculturalists in the western Brazilian Amazon, which would be labeled Note 3.2.

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Responses by resource users to technology and policy changes will determine the impacts on forests and rural inhabitants of such changes. This is true for forestry and other policies that seek to influence deforestation and land use. This series of Technical Notes takes as axiomatic the need to focus on the whole farm, rather than on particular economic activities (in untouched forests, in forests with extractive activities, or on cleared land). This series also focuses on small-scale agriculturalists at the forest margins, in part because of their sometimes impoverished state (which itself merits policy action), but more importantly because of their critical current and future roles in deforestation. These smallholders are pivotal to slowing deforestation in Brazil; failure to identify new combinations of forestry and other policies, technologies and institutional arrangements that effectively brake smallholder forest clearing will doom the Amazon.

This Technical Note presents the results of a specific experiment linked to the underlying agricultural potential of different lands in the Amazon, with immediate implications for zoning. Several issues arise from this experiment that are relevant for the forestry (and other) policy review. First, will farmers endowed with good-quality soils have deforestation patterns different than their counterparts with poor-quality soils?[3] Second, if deforestation patterns are different, why is that so -- e.g., do the more sustainable crop and livestock production systems that good-quality soils can support have a braking effect on deforestation, perhaps due to greater absorption of labor, or, rather, does the extra cash generated by agricultural activities on good-quality soils fuel deforestation? Third, what are the implications of soil quality for the product mix, e.g., do livestock production systems still dominate the landscape on farms with good-quality soils? Fourth, does soil quality influence technology choice -- for instance, are farmers with poor-quality soils more likely to use chemical fertilizers than farmers with (say) medium-quality soils? Relatedly, what role might chemical fertilizers have (if any) in reducing the differences in incomes and in deforestation patterns due to soil quality differences? Next, what are the implications of soil quality for farm income more generally – are smallholders with good-quality soils better off as regards consumption? Finally, what might the implications of the answers to these questions be for policy, especially land use zoning?

A farm-level bioeconomic linear programming (LP) model, as described in detail in Technical Note 1.1, is used to answer these and other questions.[4] This model contains a 25-year decision time horizon, explicitly accounts for on-farm competition among alternative agricultural and extractive activities for labor, capital and land, and can assess the impacts of policy and/or technological changes on deforestation, land use, and smallholder incomes. The model (for which baseline land use and income results are included in this Note) was built for the western Brazilian Amazon, calibrated for those agronomic and economic conditions, and subject to extensive sensitivity analyses. We feel the model can predict the impacts of policy and technology changes on deforestation and land use by small-scale agriculturists in the western Amazon, and also

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[3] We leave aside the issue of the potential endogeneity of soil quality, i.e., the possibility that farmers with a particular set of characteristics (say, high levels of capitalization) seek out better soils, as this lies beyond the scope of the LP model at present.

[4] The model was laid out in great detail in the technical appendix circulated earlier.

believe that these results (especially the *directions* of farmer responses to policy/technology changes) are relevant for other frontier areas in the Amazon. Moreover, the dynamics of land use change that are driven by profitability and conditioned by factor availability, productivity, and relative prices (the principal drivers in this model) provide lessons that apply over broader geographic areas.

The next section briefly describes what the model does, and how, then presents baseline land uses and the net present value (NPV) of consumption generated by these baseline land uses over a 25-year period. The following section defines precisely what is meant by good-quality, medium-quality (used in the baseline simulation), and poor-quality soils, describes the technical coefficients linking soil quality to productivity, and presents the results of two model simulations, one with good-quality soils and a second with poor-quality soils, with special attention paid to differences that emerge from these simulations as regards deforestation, use of cleared land and household income. The Note ends with a brief discussion of policy implications of these simulations.

Baseline Simulation – Our Benchmark

Model Description – A linear programming (LP) model was developed to explicitly account for the biophysical and economic factors determining farmers' deforestation and land use decisions.[5] The archetypical farmer whose decisions are characterized by the model maximizes the discounted value of his/her family's consumption stream over a 25-year time horizon by producing combinations of products for home consumption and sale, subject to an array of constraints related to technologies for producing agricultural and extractive products, the impact of agricultural activities on soil productivity, and the financial benefits associated with different activities, including the potential to sell household labor off farm and to hire labor on farm for agricultural purposes.

Aside from a set of alternative economic activities (and their associated technical production coefficients), their financial returns, and the biophysical factors that constrain activity choices over time, the model contains a set of initial conditions, that is, an explicit set of farm and

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[5] Note that some potentially important factors influencing deforestation and use of cleared land have ***not*** been incorporated into this version of the model, most notably: the asset values of different types of land; effects of land tenure; farmer’s choice of off-farm investments other than family labor hired out; and production risk due to unexpected weather shocks. Asset values will be the focus of future work. Land tenure and income diversification strategies involving non-agricultural activities are addressed in other work. We expect the explicit treatment of risks (weather, price, policy and other) to reinforce our results — that is, cattle production systems are dominant in virtually all model experiments, and the inclusion of risk would make these systems even more attractive. In future work, we intend to link the bioeconomic model with the Decision Support System for Agrotechnology Transfer (DSSAT) crop growth model, which contains a weather generator capable of simulating weather shocks and long-term climate change.

farm household characteristics that indicate both the model's starting point in terms of land already in use (for example, area in pasture), and farm- and household-specific constraints (for example, family size and distance to market) that can influence the allocation of land, labor, and cash to alternative land uses.[6] The model also limits certain input and product flows onto/off farms to reflect market imperfections, e.g., milk sales are constrained by quotas, and the amount of hired labor that can be acquired in any given month is 15 man-days. Finally, the model explicitly includes some forestry policies, but excludes others, to reflect the policy setting in the western Brazilian Amazon as regards the degree to which forest areas are available for economic activity. For example, in the model, small-scale farmers are not allowed to harvest timber products from their forested land.[7] In addition, the 50% rule mandating that no more than half of any farm be cleared for agricultural purposes is *not* enforced in the model simulations presented here.[8]

Perhaps most important for the set of experiments presented here, the model also explicitly accounts for the restrictions to agricultural productivity and soil recovery caused by inherent problems of soil fertility, and for their correction by the use of external inputs (some problems due to soil physical and chemical characteristics which cannot be addressed by use of external inputs, as will be spelled out in detail below). As noted above, model baseline represents the case of medium-quality soils.[9]

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[6] The model's point of departure was determined from field data collected in 1994. Farm households from the Pedro Peixoto settlement project, Acre, were clustered on the basis of characteristics deemed to be exogenous to farmers' land use decisions as characterized by the model (for example, soil type, distance to market, and age of settlement of land). Several clusters emerged, each of which can be thought to represent a farm type. The average farm and household characteristics for a ***relatively well-situated farm type*** in terms of access to markets were used as the initial conditions to generate the model baseline. This cluster of farms was dominated by soil types of medium quality -- that is, soils with some inherent restrictions to agricultural productivity (fertility problems, and/or mild slope or rockiness). Most model simulations take as a point of departure the characteristics of this typical farm; in the simulations presented in this Note one initial condition (namely, soil quality) is changed, all other initial conditions remain the same.

[7] Although technically permissible by law, the bureaucratic obstacles to obtaining official permission to sustainable harvest timber products in farmers' legal reserves have been in practice insurmountable, and have indeed made any on-farm timber extraction difficult. Such practices are therefore not permitted in the simulations presented here. Recent changes in certification requirements may, in the future, reduce these costs; once these new costs are known, they can be easily incorporated into the model.

[8] Again, legally, farmers in states with ratified land use plans must maintain 50% of their lots as forest reserves; farmers in states with*out* ratified plans should retain 80% of their land in primary forest, though a special waiver has been issued for small-scale farms below 100 hectares. In practice, few do so, and fines are rarely assessed on smallholders. That said, some empirical evidence suggests that the law and the enforcement rhetoric associated with it do have braking effects on deforestation. Future work will focus on estimating this braking effect and introducing it into the model.

[9] For all simulations, it is assumed that a particular soil quality is distributed uniformly across the entire farm, e.g., a farm identified as having poor-quality soils has only these soils. In reality, soil quality is not homogeneous on farms; patches of good soils and bad soils appear frequently on farms, and some

Model Baseline – Figure 1 depicts land uses (including forest, and therefore implicitly deforestation) generated by the model for a 25-year time span for a typical small-scale farm. Several results related to land use emerge from this baseline. First, the amount of forest retained is clearly declining over time, finally disappearing in about year 25, despite the small but positive revenue provided by the extraction of Brazil nuts from forests (an activity currently undertaken by about 50% of sample farms).[10] Second, in terms of area, cattle production is the dominant activity and pasture to support it eventually occupies about 85% of the farm. Third, annual crop production occupies about 8% of the farm throughout the 25-year time horizon. Finally, perennial crops (in this case, manioc, which has a production cycle spanning more than one year) take up about one hectare of land over time, and secondary fallow weaves into and out of the baseline land use scenario, becoming significant as forests disappear completely.[11] Note that the block of pasture land appearing in Figure 1 is not homogeneous; the carrying capacity of each hectare of pasture declines over time. Eventually, it can be taken out of production and placed into an 8-year rehabilitation cycle (called Degraded Pasture in Figure 1) when the financial benefits from doing so outweigh the costs of converting other lands to pasture and/or reducing herd size. In this baseline scenario, no pasture is debilitated to the point of requiring an 8-year fallow, because a productivity-increasing and extending technology is used by farmers.[12] Note also that blocks of land under other uses are not homogeneous, but rather are composed of crops planted at different times using different production technologies, and consequently generate different yields. Details of this heterogenity for annuals crops are discussed below.

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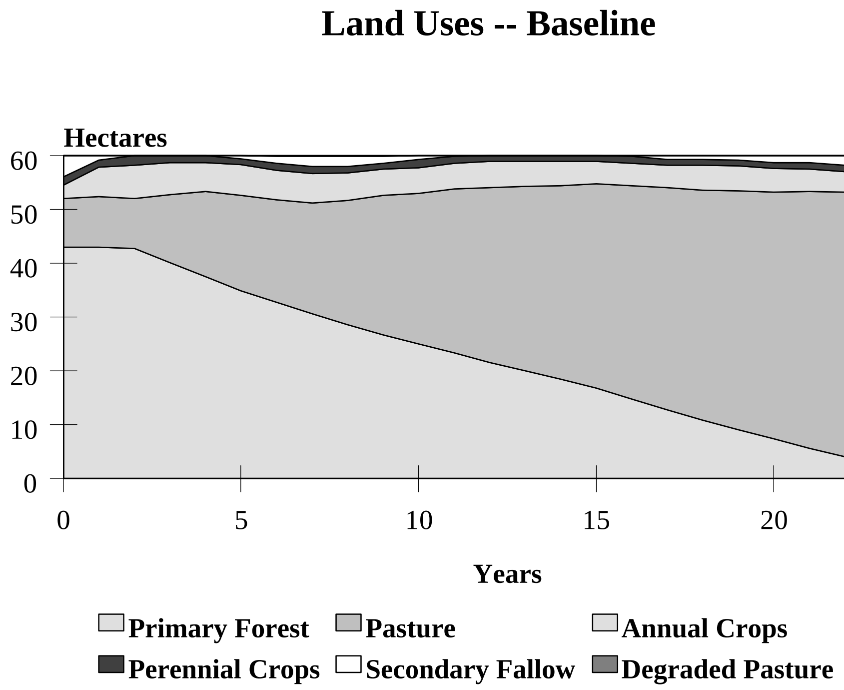
areas (especially waterlogged areas) are not suited for any type of agricultural activity.

[10] The supply of Brazil nuts is directly linked to the amount of forest cover remaining on farms. The same survey data from 1994 used to identify farm types were also used to estimate Brazil nut off-take.

[11] Baseline simulations out to 35 years suggest that the area in secondary fallow continues to increase at approximately .20 ha every two years and plateaus at 5.5 hectares in year 35.

[12] For a detailed description of pasture and cattle management technologies, see Intensified Small-Scale Cattle Production Systems in the Western Brazilian Amazon: Will They Be Adopted and Can They Save the Forest?; Chantal Line Carpentier, Judson Valentim, Stephen A. Vosti, Julie Witcover, in *Technological change in agriculture and deforestation,* edited by Arild Angelsen, David Kaimowitz, and Stephen A. Vosti, forthcoming.

Figure 1 – Baseline land uses, by year



The dominance of pasture on the archetypical farm merits special attention; two issues emerge. First, dairy production begins early on in the 25-year scenario, and continues to play an important role throughout — once the milking herd is established (say, by year 10) roughly 77% of income is derived from dairy operations, which occupy an average of 42% of available household labor in every month except May. In May, pasture and animal care combined with other activities require more labor than the household can muster, so 15 man-days (the maximum allowed by the model) must be hired in. Second, beef cattle production emerges as a second cattle activity in year 9, and its contribution to income plateaus in year 18, at which time it represents 25% of household income, but occupies (on average) just 4% of available household labor.

Taken together, financial flows from on-farm agricultural and extractive activities and off-farm sales of adult male labor are substantial. Savings during the first few years allow for subsequent investments that boost production (and consumption) in later years. Large investments (negative savings) are required in years 5, 9, and 11 to expand pasture areas. Farm profits peak at about year 13, at a level of approximately R$9,000 per year, and begin to decline after the end of the 25-year time horizon presented here.[13] The net present value (NPV) of the 25-year stream of household consumption is R$50,635.[14]

Several important results emerge from the baseline scenario that are relevant for soil nutrient management. Farmers with medium-quality soils *do* face soil fertility problems that would cause yields of annual and perennial crops to decline over time. These soil quality problems, though, are addressed by altering cropping patterns and *not* by purchasing chemical fertilizers, although fertilizers are available and farmers have sufficient cash reserves to purchase them. Policy experiments can show whether differences in soil quality (improvements and/or reductions) will cause smallholders to shift from this land-use strategy (adapting land uses to fertility constraints), perhaps to a purchased-input strategy for managing soil nutrients.

Technology Experiment – Major Differences in Soil Quality

Definition of Soil Quality – What is meant by poor-, medium- and good-quality soils? These three categories of soils were selected on the basis of chemical tests done on a subset of soils various types and qualities in the Pedro Peixoto settlement project in Acre.[15] Table 1 summarizes the results of these soils tests. Descriptions and average ranges for some characteristics are as follows: pH refers to the level of acidity (neutral range = 6.6 to 7.3); P refers to levels of available phosphorus in soils (average range = 11 to 30 mg/dm^3); K refers to levels of available potassium in soils (average range = 0.13 to 0.38 cmolc/dm^3); Ca refers to levels of calcium available in soils; Mg refers to levels of magnesium in soils (average range for $Ca + Mg$ = 2.1 to 6.0 cmolc/dm^3); S is the sum of Ca, Mg and K (average range = 2.6 to 5.5 cmolc/dm^3); Al refers to levels of aluminum in soils (toxicity begins at 0.3 cmolc/dm^3); H+Al measures potential acidity; T measures the sum of cation exchange in soils ($T = S + H$+Al, moderate range = 5.1 to 15.0 cmolc/dm^3); V measures base saturation (V=(100xS)/T, average range = 51 to 70); and m measures aluminum saturation (levels above 50% can cause production problems).

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[13] All values are reported in terms of 1996 Brazilian reais; the baseline model and all simulations presented in this Note use a constant set of 1993/94 input and product prices for the entire decision time horizon.

[14] A discount rate of 9% was used to calculate the NPV.

[15] Soil samples were taken from land under different uses (e.g., forest, annual crops, perennial tree crops, pastures), but priority in the analysis of soil samples was given to samples taken from pastures and forests. The soil quality categories presented here were derived on the basis of the results of the analysis of this priority subset.

Table 1 — Three soil quality groups representative of Pedro Peixoto soils[16]

	pH	P	K	Ca	Mg	S	Al	H+Al	T	V	m
		mg/dm^3			cmolc/dm^3					%	%
Poor	4.4	2	0.05	0.2	0.1	0.35	2.3	5.11	5.46	6.4	86.8
Medium	5.1	5	0.36	2.4	1.5	4.26	0.4	3.3	7.56	56.3	8.6
Good	6.6	7	0.67	4.4	1.3	6.37	0.1	1.3	7.67	83.1	1.6

Source: Soil samples were collected and analyzed by Angelo Mansur and Tarcizio. Gomes and Carpentier generated soil quality categories. N=61.

Soil characteristics are important for agricultural production because of their nutrient content, but also because of their individual and/or joint effects on the potential for correcting yield-reducing soil nutrient and chemical imbalances. For example, the poor-quality soil above is acidic, but because the sum of the cation exchange (*T*) is 5.46 cmolc/dm^3, applying lime would greatly improve soil productivity. In many cases, soil amendments can correct for inherent soil infertility or other problems; but these amendments cost money to purchase and time to apply. Plus, weeds may benefit from soil corrections as much as crops, implying higher labor costs of controlling weed growth. So, the financial benefits of improving soils (in terms of enhanced crop yields) may be less than the sum of out-of-pocket and labor costs required to purchase and use soil amendments. The model weighs all these financial considerations in determining product mix and production technology (and implicitly the use of purchased inputs).

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[16] This table of soil characteristics should not be viewed as static, or as being independent of land use. Soil characteristics change over time, especially when land is converted from forest to agriculture; hence, the values of the soil characteristics noted here and others (especially those related to soil physical properties) will in part depend on the land use history of sampled plots.

Translating Soil Quality Indicators into Yield Coefficients[17] — Interviews with farmers located on soils where soil testing was done (or located on soils judged by soil scientist to be similar to those where soil testing was done), combined with expert interviews with extension agents and scientists were used to estimate crop- and technology-specific yield coefficients for each of the three qualities of soils prevalent in our sample. Recall that most products can be produced using different types of technologies (v1 being the most rudimentary and using no purchased inputs, v2 being a more advanced technology using some purchased inputs, and v3 being the most advanced and using relatively large amounts of purchased inputs), so yield coefficients needed to be estimated for each product-technology-soil combination. Table 2 reports the results of this participatory assessment of the impact of soil quality on first-year crop yields using different production techniques.[18]

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[17] In what follows, product- and technology-specific yield coefficients are presented for good- , medium- , and poor-quality soils for most of the products produced by small-scale agriculturalists. Two potentially important gaps in this list of products are pasture and secondary fallow, which retain their technology-specific yield coefficients (carrying capacity for pasture, and nutrient regeneration patterns for secondary fallow) identified for medium-quality soils in both the poor- and good-quality simulations. Invariant pasture and secondary fallow productivity across soil qualities may influence deforestation rates and patterns of use of cleared land. Future work will address this issue.

[18] Peak yields for annual crops generally occur during the first year of planting; these first-year estimates are used to compare yield effects across soil quality categories. However, annual crops produced using v1 and v2 technologies experience significant, and different, yield declines over time. This issue is examined in some detail below for annual crops, and it taken up in footnote 24.

Table 2 — First-year crop yields, by technology level and by soil quality

	Monoculture[19]			Intercropped[20]	
	v1	v2[21]	v3[22]	v1	v2
rice (kg/ha.)					
poor	--	1500	3400	620	488
medium	--	2000	3400	799	1300
good	--	2500	3400	992	1642
corn (kg/ha.)					
poor	--	2000	3500	488	800
medium	--	2500	3500	640	900
good	--	3000	3500	800	1000
beans (kg/ha.)					
poor	--	500	1500	–	–
medium	--	800	1500	–	–
good	--	1000	1500	–	–
manioc (tons/ha.)[23]					
poor	17	--	--	–	–
medium	19	--	--	–	–
good	22	--	--	–	–
coffee[24] (kg/ha.)					
poor	500	--	3500	–	--
medium	970	--	3500	–	--
good	1200	--	3500	–	--
bananas (bunches/ha.)					
poor	800	--	1300	–	--
medium	800	--	1300		
good	800	--	1300	–	–

Source: Productivity parameters were generated on the basis of meetings with farmers' groups, extension agents and agricultural researchers. v1 intercropped parameters were first estimated from field data and then verified by meeting participants.

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[19] v1 monoculture technologies are neither practiced by small-scale agriculturalists in the sample area nor selected in the model simulation, and have been omitted from the table.

[20] v3 intercropping technologies are not practiced by small-scale agriculturalists, nor is their development contemplated by agricultural researchers; therefore they do not appear in the table.

[21] v2 monoculture and intercropped technologies make use of some pesticides, primarily insecticides, but do not use chemical fertilizers.

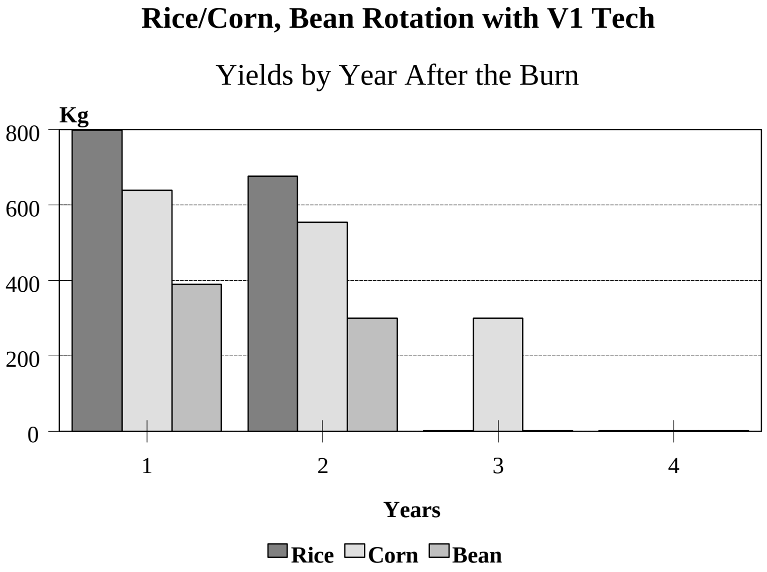
[22] v3 monoculture technologies make use of both pesticides and chemical fertilizers, adjusting use of the latter to compensate for inherent differences in soil quality; hence, v3 technology yields do not vary across soil quality categories.

[23] Manioc yields are identical for v1 and v2 technologies.

[24] Yields for coffee and bananas begin low, increase over time, and then drop off, and the yield drop-offs are much quicker for v1 technologies than for v3 technologies. Yield figures for coffee and bananas represent peak yields achieved for these crops (plateau yields for v3 technologies, over the productive life of the plant); yield peaks/plateaus are achieved for v1 coffee in year 3, for v3 coffee in year 4, for v1 bananas in year 3 and for v3 bananas in year 4.

The first-year yields reported in Table 2 are not constant over time for given plots of land, with the exception of those associated with v3 technologies, which (by design) correct soil chemical imbalances prior to planting and annually replenish soil nutrients depleted during production. The most commonly encountered production technologies in the field (v1 and v2 technologies) all experience yield declines when practiced on the same plots over time. Although v3 technologies, which make intensive use of external inputs, especially chemical fertilizers, do not experience yield declines, these technologies are still somewhat experimental for annual crops. Figure 2 depicts yield declines due to nutrient deficiencies for an intercropped rice/corn, bean rotation using (low-level) v1 production technology. Note that yields for this technology, which does not use external inputs, drop to zero after year 2 for rice and beans, and after year 3 for corn. Similar yield drop-off patterns occur for v2 technologies, but first-year yields are higher for these more intensive cropping systems.[25] [26]

Figure 2 – Yield declines for intercropped annual crops, using v1 technology



Details of the Technology Experiment – Using the sets of technology-specific, first-year yield

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[25] Yield drop-offs rates are the same for all three soil qualities for given technologies; drop-off rates for medium-quality soils are an integral part of the model that generated the baseline scenario depicted in Figure 1.

[26] As noted above, soil nutrient recovery rates, which, in the model, allow fallow to annually recover a fixed proportion of lost nutrients (achieving complete recovery in 5 years), also do not vary across the soil quality categories used here.

coefficients identified above for different soil qualities (and the yield drop-off and soil recovery functions common to all soil qualities), the bioeconomic model was run twice, once for poor-quality soils and a second time for good-quality soils.[27] The decision time horizon (25 years), relative input and output prices, and the remaining initial conditions of the model (distance to market, farm and family size, initial land use pattern and asset base, etc.) were identical, in both runs of the model for these technology experiments, to parameters used in the baseline run. The results for each run are described, then briefly compared.

Results of Model Simulation – The following results emerged from the separate runs of the bioeconomic model, each run using a different set of yield coefficients based on soil quality.

Figure 3 presents aggregate land use categories (and implicitly deforestation patterns) for small-scale farms located on *poor*-quality soils with generally *lower* yields.[28] Compared with the baseline (with its medium-quality soils, and land uses depicted in Figure 1, above) deforestation is only very slightly slower, especially after about year 10, resulting in a small patch (about 1 hectare) of primary forest remaining in year 25 (the baseline had no primary forest at that point). As regards use of cleared land, the farm with poor-quality soils dedicated even more land to pasture, and less to annual crop production and secondary fallow than in the baseline run, and did not resort to application of chemical fertilizer. Finally, and perhaps most important, the net present value (NPV) of consumption over the 25-year simulation time horizon is R$44,132, or about 15% lower than the R$50,635 earned under the medium-quality soil baseline scenario.[29]

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[27] Again, the model assumes that the archetypical farm possess only one quality of soil. In reality, while the quality of the predominant soil on farms does vary across farms, farm-level soil quality is generally heterogeneous. Assuming a single predominant soil quality ignores this heterogeneity, or, that the total amounts of land on farms comprised of non-predominant soil qualities are small relative to the areas comprised of the predominant soil. In the case of medium-quality soils, yield effects of ignoring areas of poor- and good-quality soils are expected to be small due to averaging across soil qualities.

[28] Initial runs of the model for poor soils yielded infeasible solutions, probably due to the inability of smallholders to feed their families adequately, which the model requires. Small amounts of additional cash had to be ‘added’ to the initial conditions for the poor-quality soils runs to avoid this problem; possible policy implications of this required ‘fix’ are discussed in the conclusions.

[29] Simulations for poor- and good-quality soils extending beyond the 25-year time horizon reported here have not been run, so, we cannot say what the longer term implications for income will be for either case.

Figure 3 – Land uses with poor-quality soils

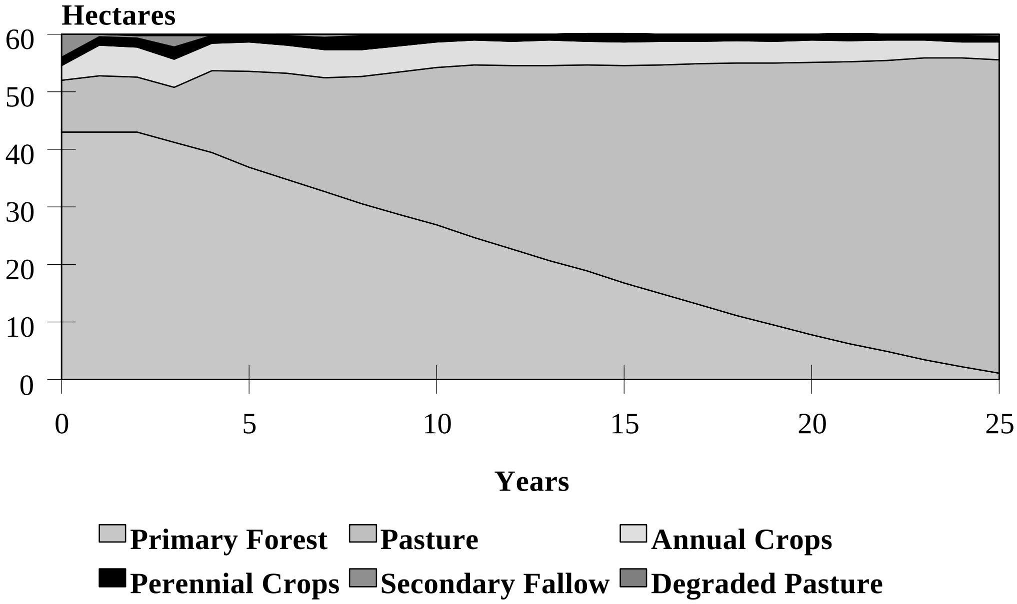
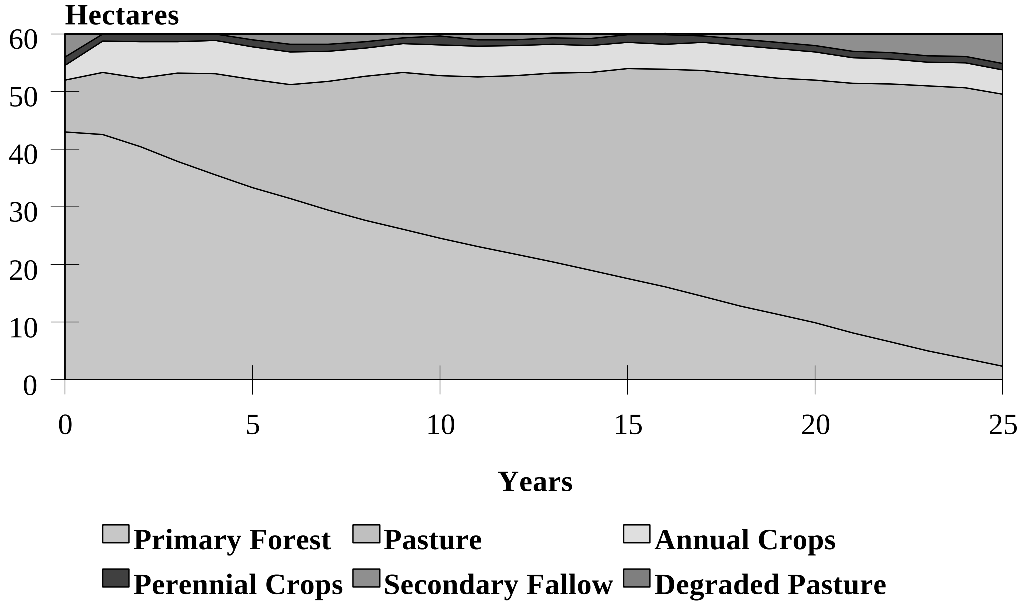


Figure 4 presents aggregate land use categories (and deforestation patterns) for small-scale farms located on *good*-quality soils with generally *higher* yields. Compared with the baseline (again, in Figure 1, above) deforestation is still slower, although still almost negligibly so, now with about 3 has. of primary forest remaining in year 25 (versus zero for the baseline at that point). As regards use of cleared land, the farm with good-quality soils has slightly more area dedicated to annual crop production than the baseline, and makes slightly greater use of secondary fallow. The net present value (NPV) of consumption over the 25-year simulation time horizon for the good-quality soils simulation is R$60,478, or about 20% higher than the R$50,635 earned under the baseline scenario.

Figure 4 – Land uses with good-quality soils



Comparing the good- with the poor-quality cases (i.e., setting Figures 3 and 4 alongside one another), several results emerge. First, deforestation patterns are similar, and in all cases the forest disappears within a period of 25 to 30 years from the starting point, with farmers with good-quality soils deforesting only slightly more slowly than those with poor-quality soils. Second, while both scenarios continue to be dominated by pasture, good-quality soils lead to greater amounts of annual crop production and to the use of more secondary fallow than do production systems on poor-quality soils. On neither, though, did farmers opt to purchase and apply chemical fertilizers -- neither the poor-quality soils farmers, with more severe soil fertility problems, nor farmers with relatively good-quality soils, where yields could still benefit from soil amendments. Finally, the income implications of soil quality are substantial; a farm with good-quality soil can generate over 35% more income than one with poor-quality soil.

Conclusions and Implications for Forestry (and Other) Policy

Some conclusions can be derived from these technology scenarios that are relevant for forestry and other policies.

First, farms located on poor-quality soils can still generate substantial income over the model's decision time horizon, approximately R$44,000, which compares positively to incomes earned in some urban and many rural areas of Brazil. This result undermines the argument that it may somehow be easier to protect areas from invasion if they are endowed with poor-quality soils; the demand for farms with good-quality soils will always be greater than for those with poor-quality soils, ceteris paribus, but the latter will still be quite attractive.

Second, the most important and largest impact of soil quality differences are differences in farm income; a farm with good-quality soil generated over 35% more income over the 25-year simulation period than did a farm with poor-quality soil.

Third, comparing simulated deforestation rates for a farm endowed with good-quality soil with a farm having poor-quality soils shows very small differences, and the differences that do exist as regards the amount of primary forest retained on farms after 25 years disappear if the time horizon is extended another five years or so.

That said, when we include the medium-quality soil scenario (the baseline run) in our comparisons, a small ‘U-shaped’ pattern emerges between soil quality and deforestation -- farms with medium-quality soils deforest more quickly than those with poor- *or* good-quality soils, although with only slight effects on forest remaining in year 25, in this case. Despite this small difference, it is worth noting that the factors braking deforestation as we move towards better- or poorer-quality soils seem to be different – farmers with poor-quality soils are too cash/capital constrained to deforest all the land they’d like to, while farmers with good-quality soils have the cash/capital to deforest as much as the farm with medium-quality soils, but choose to deploy household and hired labor in ways that consume less forest. Although this braking effect of improved soil quality on deforestation is not large, it suggests that types of agricultural intensification that make intensive use of labor may reduce deforestation rates somewhat, and that improved soil fertility may be one way to promote such labor-led intensification, presumably on land uses that respond (in yields and in terms of profits) to higher fertility. A closer examination of this U-shaped relationship, and assessments of the potential for improving and exploiting its implied trade-offs via policy and technology changes, will be the foci of future work.

Fourth, even though chemical fertilizers are capable of raising yields on all farms (regardless of soil quality), farmers choose not to use them because it is not profitable to do so under the price scenario used here. Rather, farmers alter product mix and production technology in response to changes in the productive potential of soils, engaging in more annual crop production and secondary fallowing where soils are better. Reductions in fertilizer prices and/or increases in product prices might change this outcome as regards product mix and technology choice, but the implications for deforestation rates will not likely be large.

Fifth, to run the poor-quality soil scenario, the archetypical small-scale farm household had to be endowed with more cash to enable it to meet its food security objective. This suggests that amount and composition of the initial package presented to colonists might need to vary depending on the quality of soil on their farms. Those receiving poor-quality soils will need more cash to purchase food during the first years of settlement to compensate for low agricultural yields.

Finally, and perhaps most important as regards the extrapolation domain for research emanating from this case study of the western Brazilian Amazon, since very large differences in soil quality actually led to very small differences in deforestation rates and patterns of use of cleared land, there might be wide swaths of Amazonian soils for which these research results apply.