Environment and Development Economics 2 (1997): 119–143

Theory and Applications

Soil degradation and economic development in Ghana*

KNUT H. ALFSEN, TORSTEIN BYE, SOLVEIG GLOMSRØD and HENRIK WIIG

Research Department, Statistics Norway, PO Box 8131 Dep., N-0033 Oslo, Norway

ABSTRACT. Soil erosion and soil mining are important environmental problems in many developing countries and may represent a considerable drag on economic development. The cost of soil degradation depends, however, not only on the productivity effects it has on agricultural growth, but also on how the agricultural sectors are linked to the rest of the economy. This article describes an integrated economy–soil-productivity model for Ghana, and through several simulated scenarios we calculate the drag on the Ghanaian economy of soil mining and erosion, and illustrate the effects of different policies aiming at a reduction in these environmental problems.

Introduction

A decade of economic reform has lifted Ghana to an average annual economic growth of 5 per cent. This is encouraging, but still the average poor person will remain below the poverty line for another twenty years if this growth rate continues (World Bank, 1992). Hence, current policies aim at an acceleration of economic growth.

Ghana is richly endowed with natural resources such as minerals and forests, and economic growth is to a large extent linked to the utilization of these resources. However, current production technologies contain the potential for conflict with conditions for sustainable development. The most serious environmental problems in Ghana today are soil degradation, deforestation and pollution from mining industries (see Hansen *et al*, 1995). Accelerated growth could seriously challenge the resource base unless emphasis is laid on technological improvement.

The agricultural sector generates some 40 per cent of GDP and 60 per cent of export earnings. Approximately 70 per cent of employment in Ghana is in the agricultural sector (World Bank, 1992). Even if mining and

* This study has been partially funded by the Environment Department of The World Bank, which, however, is in no way responsible for the results and opinions offered here. We are grateful for comments from two referees.

manufacturing industry grow considerably, a take-off for the whole economy will still have to rely heavily on achievement in the agricultural sector. Agriculture in Ghana is characterized by small farm units relying almost solely on land and labour as input factors. As a consequence, nutrients are mined and the productivity of soil is reduced, which in turn increases the land area necessary for subsistence cultivation or to meet external demand. The agricultural frontier moves into forested areas and reduces forest capital representing possible sources of future income for Ghana. A particular concern, therefore, is migration to the Western region of Ghana where the forest reserves are located on soils vulnerable to farming. Hence, the nutrients account of current soil management is crucial to development in several respects.

How does the loss of land productivity affect the prospects for economic growth in Ghana? and how can the productivity loss be combated in an economically efficient way? These are the two main questions addressed in this paper. We approach the subject by way of an integrated economy–soil-productivity model for Ghana. The integrated model takes the form of a computable general equilibrium (CGE) model enhanced with relations between current agricultural practice (mainly amount harvested and type of crop) and soil productivity. An integrated soil–economy approach is particularly useful when we want to highlight the environmental effects of agriculture, the predominant economic activity in Ghana. On the one hand, the impact on agricultural productivity of soil mining and degradation will necessarily lead to repercussions in the rest of the economy. On the other hand, the structure of the economy will determine the price and reallocation effects of changes in agricultural productivity. For instance, the functioning of the labour market has been shown to have a potentially strong influence on the cost and distributional consequences of soil degradation (Alfsen *et al.*, 1996). Of course, not all environmental impacts and policies require a general equilibrium approach for analysis. Many developing countries are, however, heavily reliant on natural resources, and their economies are clearly candidates for economy-wide approaches in the analysis of problems concerning the role of their natural wealth.

The use of integrated economy-wide modelling tools in empirical studies of development issues is clearly on the increase. Recent examples are Munasinghe and Cruz (1995), Persson (1995), and Persson and Munasinghe (1995). A previous general equilibrium study of the cost of soil erosion in Nicaragua (Alfsen *et al.*, 1996) was based on local expert assessment of the productivity loss associated with soil erosion. The present study is similar in approach, but somewhat extended in that we determine the productivity loss from soil degradation by use of a formal model of the nutrient cycles and their impact on soil productivity. This differs from the more traditional approach (see, e.g. Bojö, 1996), in that the full general equilibrium impacts are taken into account in the valuation of soil degradation. However, we consider only costs of on-site effects.

Our economic core model is a fairly straightforward CGE model, though with some 'structuralist' elements in the modelling of the capital market. It is supplemented by an integrated tropical soil productivity module (see Aune and Lal, 1995) which traces the impact of cultivation and management on the productivity of soil in the agricultural sectors. The soil module returns a soil productivity indicator in the production functions of the respective crops in the CGE model based on output and fertilizer use in previous years. The demand for agricultural land corresponding to the production level and soil productivity is calculated, indicating the pressure on the forest reserves. The model treats activities in the Western region of Ghana as separate sectors in order to deal with the crucial concern of deforestation in the growth process.

A key element in our approach is fertilizer use, which has significant potential for raising yields in the short run and to some extent also in future years. The long-run impact is linked to improved vegetation cover which reduces erosion by protecting the soil against heavy rain, and leaves more plant residues for recycling in the ground. Such an indirect approach to soil conservation is worth considering, since lack of incentives to use more direct mechanical measures is widespread. Thus, within a market framework, enhancement of fertilizer demand may serve as a beneficial second-best policy. Since the initial consumption of fertilizer is very low, there is little risk of excessive use and water pollution.

The article is organized as follows. Section 2 presents the overall structure of the CGE model with special emphasis on the features of the agricultural sector and the module that links cultivation practice to soil productivity, which in turn feeds back into the general economy. Section 3 contains some remarks on migration between the Western region and the rest of the country. Section 4 gives a brief description of the Ghanaian economy in the base year 1992. Section 5 contains some results from the use of the soil model and the economic core model as separate entities, before we consider simulation results based on the full integrated model. Section 6 concludes. Two appendices describe the simulation results and the model in more detail: Appendix A shows the sectoral gross production growth rates obtained from the various simulations, while the model equations together with the variables and parameters of the model are presented in Appendix B.

2. The economic core model

Our starting-point is a fairly standard quasi-static CGE model similar to models presented in, for instance, Dervis *et al.* (1982) and Robinson (1989). Concerning the static nature of the model, it tracks year-by-year development by assuming a constant private saving rate and a residually determined public saving rate. The composition of investments is determined by base-year share coefficients. Thus, no optimization over time is performed in the model. It is of course true that resource management is dynamic in nature. However, social constraints may limit the extent to which intertemporal decision-making is a real option. It is a concern that small farmers in developing countries are excluded from intertemporal decisions, being unable to save (because of poverty) and unable to liquidate inherited stocks of assets (e.g. because it is tribal land). According to Braverman and Guasch (1993), only 5 per cent of farms in Africa have access to credit, and 5 per cent of the borrowers receive 80 per cent of the credit. Although the share of economic activity unaffected by credit constraints may well be higher than 5 per cent, agriculture in Africa does seem to be carried out with a fairly short planning horizon. This is also suggested by empirical assessments of time preferences among rural people in Zambia and Ethiopia (Holden *et al.*, 1994).

Agriculture in Ghana is dominated by small-scale farming, even in production of an export crop like cocoa. Although empirical evidence is not readily available, we assume that the farmers' behaviour is rather insensitive to changes in the economy over the eight-year period we are considering. Otherwise, we assume rational economic behaviour in a smoothly functioning market economy, i.e. producers maximize profit and consumers maximize utility. Economic reforms in developing countries during the last decade have strengthened markets considerably and removed structural obstacles to some extent, making this analytical approach more appropriate. However, several non-market features still affect the behaviour of smallholders, such as availability of rural credits, access to roads and the efficiency of distribution networks. Evidence suggests that removal of these structural bottlenecks, which have been a focus of the development debate for decades, is a slow process. Hence, we disregard the potential shifts in technology associated with a fundamental reorganization of the rural economy, and instead stick to the assumption that current technology is binding over a medium-term time horizon.

In the model, production takes place in 19 sectors (see Table 1). The production technology is assumed to be Cobb–Douglas with constant return to scale (Equations (16) and (17) in Appendix B). In all except the four agricultural sectors, input factors are labour and capital, while intermediates and energy are treated as proportional shadow factors (Equation (16)). While labour demand is modelled, labour supply is supposed to follow the demand within the framework of constant nominal wage rates. This is clearly a simplistic representation of the labour market in Ghana, and may form a topic for further study. Capital is determined by investments during the previous period and sectoral depreciation rates. Total investment is determined by savings and transfers from abroad, and distributed according to fixed base-year coefficients (Equations (28) and (29)). We assume one type of labour, while capital goods are divided into construction and other capital goods. Calculated cost shares in the base year 1992 form the elasticities in the production functions. The model includes a complete input/output matrix of the Ghanaian economy as documented in Alfsen *et al.* (1995).

In the agricultural sectors the production functions include input of labour, fertilizer and land (Equation (17)). No real capital is included since mechanization generally is not yet on the agenda of the smallholders who dominate agriculture in Ghana. The land variable represents the shadow cost of land as a scarce factor. The land rent is assumed to be one-third of the profit and to accrue to the village or tribe owning the land. The rest of the profit is compensation to smallholders for clearing of land and other investments in land improvements. It is reasonable to assume that land rent is low when there is no serious shortage of land as in Ghana. However, firm data are in short supply on the issue of land rent, and the above assumption can only be taken as an informed guess on the order of magnitude.

Table 1. *Sector list*

Code	*Sector*	*Code*	*Sector*
cocw	Cocoa, Western region	wood	Production of furniture
cocr	Cocoa, other regions	meta	Production of metals
agrw	Other agriculture, Western region	manu	Other manufacturing
agrr	Other agriculture, other regions	cons	Construction
forw	Forestry, Western region	elec	Electricity production
forr	Forestry, other regions	wate	Water
fish	Fishing	serv	Private services
minw	Mining, Western region	gove	Government services
minr	Mining, other regions	tran	Transport, communications
food	Production of food		

The model follows the Armington hypothesis allocating sectoral domestic output in a profit-maximizing manner to domestic demand and exports according to constant elasticity of substitution (CES) functions (Equations (4), (8) and (10)). Similarly, domestic demand is divided between domestic production and imports, subject to changes in relative import and domestic prices (Equations (6), (11) and (14)).

Private income is composed of wage earnings and private sector profits (Equation (23)). A constant share of private income is saved (Equation (24)). Total tax revenue plus transfers from abroad and profit in public sectors less (exogenous) public expenditures constitutes public saving (Equations (26) and (27)). Total savings (private plus public) determine the level of gross investments (Equation (28)). Gross capital formation is allocated to manufacturing sectors and services by fixed base-year coefficients (Equation (29)). Investments and sector-specific depreciation rates determine the sectoral capital stock.

The macro aggregates for the model are based upon the national accounts for the year 1992 as published in *Quarterly Digest of Statistics* (June 1993). No updated input/output matrix was available for Ghana (a matrix from 1972 exists), hence the input structure has been constructed from various data sources. The production technology and input/output matrix is extrapolated from the Ghana Industrial Census 1987 to correspond with the national account (NA) figures of GDP for 1992. The industrial census covers the manufacturing, electricity and water industries. Gross production in Mining and Cocoa is calibrated to match total exports in the trade statistics. The main source for calculating the size of the service industries and Construction is the national accounts. Separate data-gathering has been conducted to characterize other sectors. Sources of information are the Ghana Statistical Service, the Ministry of Forestry and several printed sources. For the agricultural sectors, data originate from the Ministry of Agriculture and COCOBOD, the cocoa marketing board.[1] Data on private consumption are calculated on the basis of the Ghana Living Standard Survey II as presented in Boateng *et al.* (n.d.).

[1] In our model, agricultural marketing is included in agricultural production activities, except for agricultural transport services which are covered by the transport sector.

The established social accounting matrix for Ghana is quite similar to data published by Powell (1996). However, it is important to bear in mind that some of the elements in the matrix are weak. For instance, the business unit register for the industrial census is not updated, and data on private services are fairly uncertain. Nevertheless, within the accounting framework we have roughly tested the consistency of information from several sources in a systematic way. For further discussion of data sources, see Alfsen *et al.* (1995).

2.1. Agriculture

Agriculture is represented by two model activities, Cocoa and Other agriculture, both taking place in the two model regions, Western region and Other regions. Smallholders dominate within both food and export crops, as is often the case when land is available and there is no landless rural labour class. There is general security of land tenure owing to the right to agricultural land associated with membership of a tribe (Asenso-Okyere *et al.*, 1993). The exception is stranger farmers who are not members of the local tribe and face limited access and uncertain tenures.

The most important export crop is cocoa, which generated 20 per cent of total export earnings in 1992. Although world prices have been declining, farm-gate prices in local currency have increased due to currency depreciations, and production of cocoa has increased. Reduced marketing costs have benefited cocoa producers, who, at least until 1993/4, have received an increasing share of the export prices. Cocoa is traditionally grown in the Central, Ashanti and Brong-Ahafo regions, but in the past two decades the Western region has taken over as the leading producer region. In food crops, volume has increased in spite of lower average prices. Among food crops, tubers are the most important, accounting for roughly 50 per cent of gross production.

2.1.1. The soil model: Figure 1 shows the main elements in the nitrogen cycle of an agricultural production system (and indicates the connection with soil erosion and acidification). There are four sources of mineralized soil nitrogen. Recycled nitrogen from roots and plant residues (2 and 3 in Figure 1) enters the soil mineral stock in two different ways. One part is immediately mineralized (2), while the rest is stored as organic nitrogen and released (mineralized) two to four years later (3). Thus, there is a considerable time lag in the recycling of nitrogen. The characteristics of the crop and management procedures determine the share of plant nitrogen which is recycled.

The soil organic nitrogen is exposed to water and wind, and some is lost through erosion (4 in Figure 1) on the way to becoming mineralized and available for plant uptake. A high yield (output per hectare) provides a better vegetation cover which shelters the ground against heavy rainfall and reduces soil losses. Thus, there is an important link between productivity and soil erosion.

Chemical fertilizer is mineralized nitrogen which is ready for immediate uptake by plants (5 in Figure 1). The model assumes full efficiency in chemical fertilizer uptake. Generally, efficiency depends on the timing of

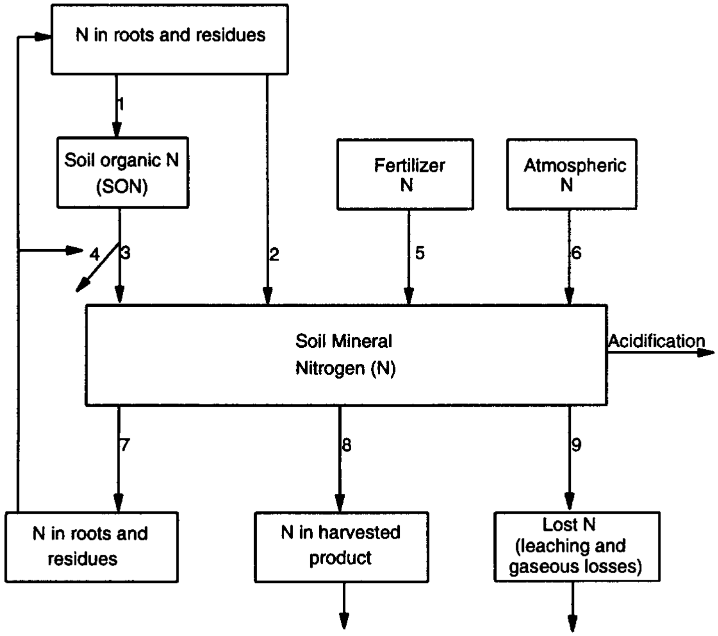

Figure 1. *The nitrogen cycle.*

fertilizer application. When, as in Ghana, the level of fertilizer use is low and the farmer carries the full fertilizer cost, there is reason to believe that the timing of fertilizer application is reasonably good.

The atmosphere also provides nitrogen to plants (6 in Figure 1). Some plants absorb nitrogen directly from the air, while the wet and dry deposition of nitrogen on the ground benefits all crops.

The stock of soil mineral nitrogen is depleted by harvesting products (8 in Figure 1). Some nitrogen is fed back into the nitrogen cycle through roots and stover (7 in Figure 1). There is also a loss through leaching through water and gaseous emissions to air (9 in Figure 1). There is also a link between nitrogen fertilizer and acidification, when nitrogen is converted to nitrate. If nitrate fertilizer is applied, this effect is avoided.

The nitrogen cycle model in Figure 1 has been formalized and calibrated by Aune and Lal (1995),[2] and, in a slightly simplified version, implemented in the general model (see Appendix B, Equations (33)–(39)).

[2] Data for the conversion of plant residues into soil organic nitrogen are based on findings from both tropical and temperate regions (Ladd and Amato, 1985; Uhlen, 1991). The parameter of nitrogen mineralization is in accordance with observations from Nigeria (Jenkinson and Ayanabana, 1977), and estimates of rates of decomposition of soil organic matter are provided by Nye and Greenland (1960) and Young (1989). Soil erosion is quantified by the UN Food and Agriculture Organization's version of the universal soil loss equation (USLE; FAO, 1979), where the role of the vegetation cover for different crops is given by the cover factors in Roose (1977). The effect of nitrogen limitation on relative yields is based on fertilizer experiments from Tanzania (Mowo *et al.*, 1994).

Various crops affect the soil in different ways, with regard to both nutrient withdrawal and the protection offered against soil erosion due to tropical rainfall. Nutrient mining in Ghanaian agriculture may be considerable, since hardly any nutrients in crop removal are replaced by chemical fertilizer. Nitrogen is the limiting factor for most food crops. For cocoa, however, phosphorus is the limiting factor. In the model, the availability of phosphorus is limited by natural decay and soil erosion (Equations (38) and (39)).

3. Regional development and migration

Spatially differentiated development must be expected in a dynamic growth process. One important aspect is related to the regional differences in natural resource endowments and infrastructure development. In Ghana, there is particular concern about the capacity of the Western region to absorb the pressure on forests and land expected from accelerated economic growth.

In the model, we have specified four main economic activities in the Western region: mining, forestry, cocoa and other agriculture. These activities produce outputs which are imperfect substitutes for their counterparts produced in the rest of Ghana. They apply the same production technologies, except for mining.

The model describes the sectoral demand of labour, and assumes identical wage levels across sectors and regions. Simulation results concerning labour demand certainly must be judged against this background. Nevertheless, the simulated regional demand for labour gives an indication of the migration pressure on the Western region.

4. The Ghanaian economy in 1992

The Ghanaian economy was in deep crisis in 1983, but has been growing since the introduction of the Economic Recovery Programme in 1983 and its renewal in 1987. In particular, the mining industry is growing rapidly. As already mentioned, agriculture is the dominant activity in the Ghanaian economy (see Figure 2). Untypically for a developing country though, over 8 per cent of GDP is generated by manufacturing industry, mostly by the production of food and metals (aluminium).

The cocoa and mining industries are the cornerstones on the export side (55 per cent of total exports), but imports of petroleum and of most manufactured products still leave an external deficit of about 10 per cent of GDP. While Ghana is one of the leading cocoa exporters in the world, exports of other agricultural products are minor. Exports of manufactured goods are high, with a considerable metal component (gold).

5. Simulation results

We consider five simulation scenarios (0–4) based on the model outlined above. The baseline scenario (1), which includes the effects of soil mining and erosion on the economy, is first compared to a scenario where the model is simulated without taking the soil module into account (scenario 0). This is done in order to illustrate the effects of soil degradation on economic development. Next we illustrate how changes in policy can affect

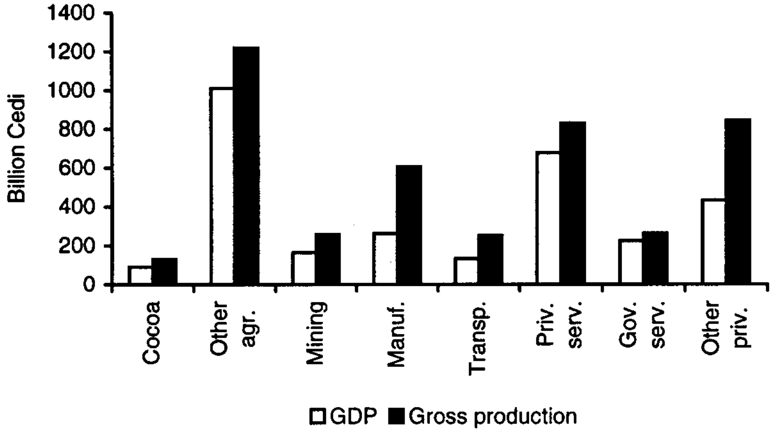

Figure 2. *GDP and gross production in 1992.*

economic growth, the use of land and the regional distribution of labour demand. Scenario 2 explores the consequences of promoting agricultural growth in the Western region. The policy analysed is one of increased farm-gate prices of crops other than cocoa (Other agricultural products) in this region. Cocoa is assumed to be unaffected by these 'reforms', reflecting a possible delay in cocoa marketing reforms.

The loss of soil productivity may be combated to some extent by providing incentives for increased use of fertilizers and pesticides. Scenarios 3 and 4 illustrate some effects on the macro economy of subsidizing fertilizer use in the agricultural sectors. Input of pesticides in cocoa production is given a similar subsidy, not because of any beneficial environmental effects, but as a means of raising the low productivity of this sector. We show that different methods of financing these subsidies may have different impacts on the economy. Table 2 summarizes the main characteristics of the scenarios.

5.1. Partially accounting for soil degradation

Before outlining the results from the model simulations, we shall briefly refer to a partial calculation of the cost of soil degradation. With factor use in the agricultural sectors kept constant over time, the soil module alone

Table 2. *Scenario definitions*

No.	*Description*
0	As scenario 1 (baseline scenario), but without feedback from the soil model
1	Baseline scenario: including feedback from the soil model
2	10% increase in farm-gate prices in the Western region; tsub(agrw) = 0.1
3	50% fertilizer/pesticide subsidy; tf(agr) = 0.5
4	As scenario 3, but with a sales tax on domestically produced agricultural products; rf(agr) = 0.5, td(agr) = 0.075

predicts productivity losses of 2.1 per cent per year in Cocoa production, and 2.9 per cent per year in Other agriculture. These results indicate a considerable negative effect on agricultural growth rates, leading to a lowering of overall economic growth by roughly 1 percentage point. The purpose of our integrated approach is to dig deeper and check such partial reasoning. The following two subsections deal with economic behaviour and adaptation to soil degradation. As a benchmark illustration, we sketch the baseline scenario (1) where the economic effects of lower soil productivity are taken into account, and compare this to a more conventional scenario (0) where this two-way link between the economy and soil productivity is disregarded. Section 5.4 then reports on some alternative policy scenarios based on the fully integrated model.

5.2. The baseline scenario (1)

The simulation period is 1992–2000. As a baseline scenario, we chose a development path characterized by the environmental feedback being in effect while base-year policies are maintained. Thus, the baseline scenario prolongs a fairly high base-year investment rate and leaves other exogenous inputs constant, including the private sector's saving rate and government consumption. Taking into account the negative productivity effects from the soil model, to be discussed below, real GDP in the baseline scenario increases at an average annual rate of 7.1 per cent, although annual growth is lowered to 4.3 per cent towards the end of the period when the soil model is having full effect (see Figure 3). Private consumption increases at an annual rate of 7.5 per cent, while investment measured in constant prices grows at around 6 per cent per year on average. The government sector saving is residually determined and slightly decreasing in the baseline scenario. Total (private plus public) savings measured as a percentage of GDP are, however, almost constant at 12.7 per cent over the time horizon of the simulation.

The average annual inflation rate is 3.9 per cent, and the real wage rate is thus reduced by approximately 35 per cent over the simulated period (the sectoral nominal wage rates are kept constant). This contributes to a significant growth in demand for labour, calculated to be almost 10 per cent per year. Annual growth in the demand for labour in the Western region is 1.4 percentage points higher than in the rest of the country, indicating incentives for migration to the Western region. This follows from a higher initial growth in mining activities and agriculture than in other industries. Growth in gross production in the Western region is 3.5 percentage points above the growth rate in the rest of the country.

As mentioned previously, labour supply is not dealt with explicitly in the model. On this background, it is reasonable to question the realism of a scenario with substantial falling real wages. However, declining real wages can be consistent with a population growth beyond the growth in demand for labour in the economy as a whole. With virgin land available for agriculture it is nevertheless unreasonable to expect real wages to fall below the rural income level which constitutes a wage floor in the economy. This floor is, however, likely to fall over time due to soil degradation and lower productivity of soil at the margin. In these circumstances it may be reasonable to assume that labour supply can meet labour demand even if real wages are declining.

Mining, Water, Other agricultural production and Transport are all sectors growing faster than total production (see Table A1). At the low-growth end we find Production of metals, Cocoa, Forestry and Fishing. This is mainly a reflection of the investment/depreciation pattern of the model, which allows for high net investment rates in the mineral and water sectors, while investment in Forestry, Fishing and Production of metals is quite low.

In the baseline scenario, land use increases by almost 11 per cent per year in the agricultural sector and close to 4.5 per cent in Cocoa production. This rapid growth in demand for land must be expected to exert considerable pressure on forests.

The increase in fertilizer use is slightly less than the increase in demand for land. The increase does not, however, prevent a 2 per cent annual decline in soil productivity in Cocoa and Other agricultural production. The integrated model indicates that loss of soil productivity increases demand for land by 5.4 per cent in the year 2000 compared to a hypothetical development without soil productivity loss.

5.3. Economic consequences of soil degradation

When the soil module is integrated with the economic core model as in our baseline scenario, adaptation to soil degradation takes place. The degree of adaptation can be illustrated by comparing the baseline scenario (1) with a hypothetical scenario (0) which ignores the impacts on, and responses to, soil degradation, and which is thus based on a 'traditional' (i.e. non-integrated) economic model approach.

When farmers are facing the declining soil productivity in scenario 1, inputs like labour and fertilizer are substituted for the less productive land. The annual growth rate of labour input increases by approximately 0.2 percentage points, while fertilizer use increases by 0.8 percentage points relative to the simulation path with no productivity feedback (scenario 0). Through increased fertilizer use, soil fertility loss itself is reduced to an average annual rate of 2 per cent in Other agriculture, while the productivity loss in Cocoa production is only marginally reduced to 2 per cent per year. In terms of overall economic growth, we find that the conventional forecasting approach in scenario 0 indicates an average annual growth rate in real GDP of 7.7 per cent, while the integrated approach yields a growth rate of 7.1 per cent (see Table 3).

Without soil productivity losses the general price level increases by 3.1 per cent annually over the simulation period, 0.7 percentage points lower than in the reference scenario. This means that soil productivity losses add almost 1 percentage point to the general rate of inflation; a clear indicator of the drag on general competitiveness caused by soil degradation.

The decline in agricultural productivity has several indirect effects on the rest of the economy. The agricultural sector's demand for intermediates except fertilizers and pesticides decreases in relative significance, holding back production in sectors producing intermediates as well.

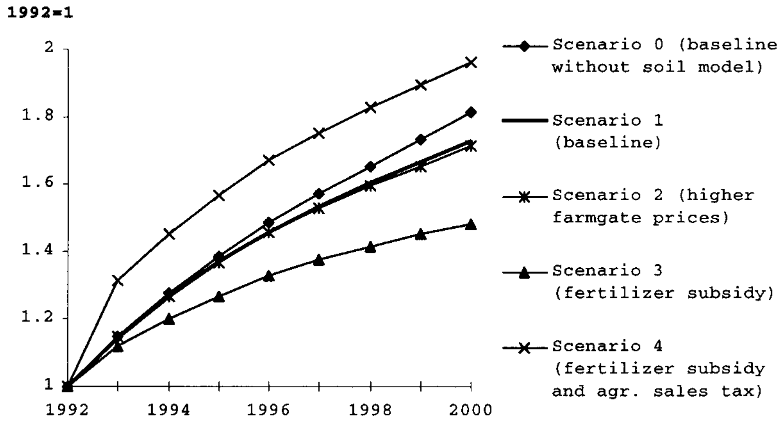

Figure 3. *Real GDP growth.*

Table 3. *Average annual percentage growth over the period 1992–2000 in real GDP, gross production and input factor use in the baseline scenario (1), in a scenario excluding the feedback from the soil productivity module (scenario 0) and in the alternative policy scenarios (2–4)*

	Scenario no.				
	0	*1*	*2*	*3*	*4*
Real GDP	7.7	7.1	7.0	5.0	8.8
Gross production (X)	7.9	7.4	7.3	5.7	6.8
Western region	11.0	10.6	10.8	8.4	9.8
Rest of the country	7.7	7.1	6.9	5.5	6.5
Labour (L)	9.6	9.9	9.7	7.6	8.5
Western region	10.4	11.1	10.9	8.7	9.9
Rest of the country	9.6	9.7	9.6	7.4	8.3
Capital (KF)	5.3	5.2	5.1	3.6	4.9
Fertilizer (F)	8.5	9.2	9.1	16.1	16.3
Western region	7.1	8.1	7.8	14.9	15.3
Rest of the country	8.6	9.4	9.3	16.3	16.4
Land (KL)	9.8	10.5	10.7	7.7	7.9
Western region	9.2	10.2	13.1	7.3	7.5
Rest of the country	9.9	10.6	10.4	7.8	8.0

Together, these reductions generate a decrease in income that partially reduces private consumption and investments.

Reduced supply of agricultural commodities due to loss of productivity increases the prices of these commodities. Through terms-of-trade effects between the agricultural sectors and the rest of the economy, agricultural profit increases and enforces the increase in factor use in these sectors.

In our calculations we find that the sum of the direct productivity loss in the agricultural sector and the indirect input–output, income, investment and terms-of-trade effects reduces the annual GDP growth rate by on average 0.6 percentage points, summing up to a total reduction in (real) GDP of 4.8 per cent in the year 2000 (see Figure 3). This compares to the partial approach referred to in section 5.1, which gave a reduction in annual GDP growth of approximately 1 percentage point. It is thus essential to include the general equilibrium effects when assessing the economic cost of soil degradation. Table 3 shows the effects on gross production and input factor use. We note in particular that the inclusion of the effects of soil productivity loss increases the demand for labour in the Western region more than in other parts of the country. Thus, soil mining tends to encourage migration to the Western region. Finally, growth in real private consumption is reduced from an annual average level of 8.2 per cent to 7.5 per cent due to all the combined effects of the soil model.

5.4. Alternative agricultural policies

Below we focus on how different ways of encouraging agricultural growth will affect the productivity loss of the soil as well as the development potential of the whole of the economy.

5.4.1. Increasing the price of agricultural products from the Western region (scenario 2): Our first alternative scenario (scenario 2) investigates the effects of a 10 per cent increase in farm-gate prices in the Western region. Such a partial price increase might reflect a situation where regional road transport facilities are improved, perhaps in order to facilitate a growth in mining activities in the region.

We assume that the price increase is entirely financed by the government, and that only the sector Other agricultural products in the Western region (agrw) benefits directly from this policy. Total government revenue is reduced by 5.3 per cent in the year 2000 relative to the baseline scenario. The drain on public funds implies a decrease in public savings and thereby a decrease in real capital investments in the rest of the economy. Thus, the capital stock at the end of the period is 1.3 per cent lower than in the baseline scenario, and total gross production declines by 1 per cent. However, agricultural production in the Western region rises to 7.2 per cent above the baseline scenario in 2000. This is achieved by a 25 per cent increase in the use of land, obviously putting more pressure on forested areas in the region. The use of fertilizer declines slightly relative to the baseline level since agricultural production in the rest of the country declines. Reduced use of fertilizers leads to a loss of soil productivity of almost 3 per cent compared to the baseline scenario in 2000. For the Western region, the negative impact on demand for fertilizer is probably overestimated, since better infrastructure (roads and distribution networks) in the region would probably lead to a decline in the cost of fertilizers to the farmers.

5.4.2. Introducing a subsidy on use of fertilizers and pesticides: The use of fertilizers and pesticides in Ghana is extremely low.[3] Increasing the use of fertilizer in agricultural production, and the use of pesticides in cocoa production will increase productivity and should generally be profitable,

[3] According to our data, the cost share of fertilizers in agriculture is of the order of 0.3 per cent.

except in some remote areas where transport costs are prohibitive. In the central areas there may be several reasons why farmers do not use these products more intensively despite the potential economic gain. They may be unaware of their real productive effect. When the income level is low, the intertemporal calculation rate of 'investments' may be high (i.e. the value of today's consumption is extremely high). Expansion of credit services may bridge the gap in discount rates between very poor farmers and the rest of the economy, but is likely to take a long time. An alternative policy could be to introduce a fertilizer subsidy, in order to harvest the positive external effects on soil productivity, and probably also on social capital, of raising rural income. The fertilizer subsidy, which acts partly as a widespread investment in soil quality, may be paid for in different ways: by reduced investments in the rest of the economy; increased sales tax on consumer goods; increased output tax on forestry, mining or other sectors; increased taxes on fossil fuel uses, etc. We consider just two alternatives: decreasing the price of fertilizers/pesticides by 50 per cent by lowering investments, and introducing a tax on agricultural output (scenarios 3 and 4, respectively).

5.4.2.1. Subsidies financed by lowering investments (scenario 3): A 50 per cent fertilizer/pesticide subsidy increases the use of these input factors in agricultural production by 75 and 62 per cent, respectively, compared to the baseline scenario in 2000. The initial use is, however, rather low, so the increased use enhances soil productivity in the agricultural sector by only 1.7 per cent over an eight-year period. The first-order incremental effect on agricultural production from increased fertilizer use requires increased production of intermediates in other sectors. Altogether this implies an upward trend in total income, total consumption and investments. However, several effects counteract this initial reaction.

Improved agricultural productivity entails a reduced national price level, and fuel and other imported goods are becoming relatively more expensive. This leads to a contractive effect which dominates over the initial effect; thus even agricultural production is reduced.

The fertilizer/pesticide subsidy decreases government revenue by approximately 40 per cent. Since government consumption is kept unchanged, reduced revenue implies reduced government savings. With nearly unchanged private savings and unchanged transfers from abroad, the fertilizer/pesticide subsidy is financed from a substantial decline in investment.

The total effect in this scenario is a slowdown in annual real GDP growth of 2 percentage points. The total real annual investments growth rate is reduced by 4.6 percentage points, while the (real) private consumption growth rate is reduced by 1.8 percentage points.

Cheaper input factors in agricultural production feed through the economy and lead to an overall reduction in the annual inflation rate of 0.8 percentage points (3.1 instead of 3.9 per cent). This is equivalent to a devaluation of the local currency by a similar magnitude, something that initially would help to increase exports. However, the counteractive effects described above more than outweigh this initial terms-of-trade benefit.

Growth in total exports decreases from 12.6 to 10.5 per cent measured as an annual rate. Increased use of fertilizers requires an initial increase in imports. The contraction of exports and the restriction on the trade balance, however, imply that total imports are also reduced.

Annual growth in total demand for labour is reduced by 2.3 percentage points. The labour demand growth rate for the construction sector is almost halved compared to the baseline scenario. Increased productivity in the agriculture sector has, as described above, a counteractive effect both on agricultural production and on factor input. The labour demand growth rate in the agricultural sector declines from a rate of almost 11 per cent in the baseline scenario to almost 8 per cent in the fertilizer subsidy scenario.

Overall, the simulation clearly confirms the unwisdom of financing productivity increases in the agricultural sectors by reduced investment in other sectors. There are, however, alternatives that show more optimistic economic and environmental results.

5.4.2.2. Internally financed subsidy (scenario 4): Internalizing the cost of the fertilizer and pesticide subsidy in the agricultural sectors might create additional distributional benefits, since all farmers face reduced input prices but only those with a marketed surplus will have to pay the additional tax. Although the model is not able to reveal such distributional benefits, we can describe the macroeconomic impacts of such a reorientation of net agricultural taxes in this manner. Thus, in scenario 4 we add a domestic sales tax on domestically produced agricultural products. The soil-related dynamics in this scenario are comparable to the dynamics in the above alternative. However, the income distribution effect on private consumption and investments is quite different. In this ‘internally financed’ scenario, total income in the private sector is lower and total income in the governmental sector higher than in the ‘lowering investments’ scenario. The counteractive effect on production through lowered investments is then much smaller. In addition the impact on individual sectors shows a different pattern (see Table A1). In particular, the negative impact of cuts in investments on the mining sector is eased when the subsidy is financed by taxes. Total production is still decreased compared to the baseline scenario (the growth rate is 0.6 percentage points below that in the baseline scenario). The reduction, however, is largest in the intermediate input-intensive sectors with lower value added. Hence, total GDP in the ‘internally financed’ scenario actually increases and is more than 13 per cent above the baseline level in 2000. Even private consumption increases in the long run due to a higher level of GDP and a small decrease in total investments as a share of GDP.

Taxing agricultural products turns out to increase the pressure on land only slightly, a reflection of the fact that a cut in investments hits the agricultural sectors more than direct taxation. Gross production in the Western region is reduced by 5.6 per cent at the end of the simulation period, compared to a 4.5 per cent reduction in the rest of the country. Still, the Western region fares better compared to the rest of the country when the subsidy is financed by a sales tax than when it is financed by cuts in investments.

6. Conclusion

We conclude by highlighting some of the main points from the simulations described above.

- Comparison of the simulations with and without the feedback from the soil model (scenarios 1 and 0, respectively) clearly shows the importance of soil degradation for economic development in Ghana. A 5 per cent reduction due to soil degradation in real GDP after eight years represents the loss of almost one year's economic growth.
- The simulations also show, however, that one should be careful in formulating policies addressing the soil degradation problem. In particular it is important to shelter capital formation during environmental policy reforms. Scenarios 2 and 3 illustrate this by analysing different ways of supporting agriculture. In scenario 2, subsidies to agricultural activity in the Western region are introduced, marginally increasing the gross production in this region. The result is a substantial increase in the use of land, possibly at the expense of the tropical forest, and a slight decrease in real GDP at the end of the simulation period. Scenario 3 calculates the effects of a direct subsidy to fertilizer usage. Apart from a substantial increase in fertilizer usage, the result is a decrease in the use of land, thus presumably preserving more forested land, but also a large decrease in real GDP, due to a decline in investments in this scenario. These results have the common trait that the subsidies are financed by lowering public savings and hence investments, and hence lowering economic growth.
- In the final scenario (scenario 4), the fertilizer subsidy is financed by a tax on agricultural products, thus protecting the public budget. Again, we find a substitution from the use of land to the use of fertilizer in the agricultural sectors, but in this scenario growth is not inhibited. Instead, real GDP is almost 15 per cent above the baseline level at the end of the simulation period.

The main message from these simulations is quite optimistic, in that there seems to be room for simultaneous economic and environmental improvements when the policy instruments are well chosen, as illustrated in scenario 4. It is also encouraging that it seems feasible to reduce the pressure on the Western region by reducing the inflow of migrators and the demand for agricultural land simultaneously with giving incentives for increased fertilizer use, and hence reducing the problem of reduced soil productivity.

References

Alfsen, K.H., T. Bye, S. Glomsrød and H. Wiig (1995), 'Integrated assessment of soil degradation and economic growth in Ghana', Documents 95/8, Statistics Norway, Oslo.

Alfsen, K.H., M.A. DeFranco, S. Glomsrød and T. Johnsen (1996), 'The cost of soil erosion in Nicaragua', *Ecological Economics* **16**: 129–145.

Asenso-Okyere, W., S.Y. Atsu and I.S. Obeng (1993), 'Communal property resources in Ghana: policies and prospects', Discussion paper No. 27, Institute of Statistical, Social and Economic Research (ISSER), University of Ghana, Legon.

Aune, J.B. and R. Lal (1995), 'The tropical soil productivity calculator—a model for assessing effects of soil management on productivity', *in* R. Lal and B.A. Stewert, eds., *Soil Management: Experimental Basis for Sustainability and Environmental Quality,* III Series: Advances in Soil Science, Boca Raton, FL: CRC Press.

Boateng, E.O., K. Ewusi, R. Kanbur and A. McKay (n.d.), 'A poverty profile for Ghana 1987–1988: social dimensions of adjustment in sub-Saharan Africa', Working Paper No. 5, The World Bank, Washington, DC.

Bojö, J. (1996), 'The cost of land degradation in sub-Saharan Africa', *Ecological Economics* **16**: 161–173.

Braverman, A. and J.L. Guasch (1993), 'Administrative failures in rural credit programs', *in* K. Hoff, A. Braverman and J.E. Stiglitz, eds., *The Economics of Rural Organization. Theory, Practice and Policy,* Oxford University Press.

Dervis, K., J. De Melo and S. Robinson (1982), *General Equilibrium Models for Development Policy,* Cambridge University Press.

Food and Agriculture Organization (FAO) (1979), 'A provisional methodology for soil degradation assessment', FAO, Rome.

Hansen, J.K., S. Hansen, J. Claussen and H. Harboe (1995), 'Integrating environmental concerns into economywide policies in developing countries: the role of multilateral development banks', MS.

Holden S., H. Hvoslef and P.L. Sankhayan (1994), 'Impact of adjustment programs on peasants and the environment in northern Zambia', Ecology and Development paper No. 11, Agricultural University of Norway, Ås.

Jenkinson, D.S. and A. Ayanabana (1977), 'Decomposition of ^{14}C labelled plant material under tropical conditions', *Soil Science Society of America Journal* **41**: 912–915.

Ladd, J.N. and M. Amato (1985), 'Nitrogen cycling in legume–cereal rotations', *in* B.T. Kang and J. van der Heide, eds., *Nitrogen Management in Humid and Subhumid Tropics,* Haren, The Netherlands: Haren Institute of Fertility, 105–128.

Mowo, J.G., J.P. Magoggo, A.E.T. Marandu, E.G. Kaitaba and J. Floor (1994), 'Review of fertilizer recommendations in Tanzania. Part I', in Tanzanian National Soil Service, *Proceedings of the Workshop on the Review of Fertilizer Recommendations, Aruasha, 11–12 November 1991*, National Soil Service, Tanzanian Ministry of Agriculture.

Munasinghe, M. and W. Cruz (1995), 'Economywide policies and the environment. Lessons from experience', Environmental Paper No. 10, World Bank, Washington, DC.

Nye, P.H. and D.J. Greenland (1960), 'The soil under shifting cultivation', Technical Communication No. 51, Commonwealth Bureau of Soils, Commonwealth Agricultural Bureau, Harpenden.

Persson, A. (1995), 'Deforestation in Costa Rica. Investigating the impacts of market failures and unwanted side effects of macro policies using three different modeling approaches', Beijer Discussion Paper Series no. 148, The Beijer International Institute of Ecological Economics, Stockholm.

Persson, A. and M. Munasinghe (1995), 'Natural resource management and economywide policies in Costa Rica: a computable general equilibrium (CGE) modeling approach', *The World Bank Economic Review* **9**: 259–285.

Powell, M. (1996), 'Integrated environmental and economic accounts for Ghana', paper presented at the International Symposium on Integrated Environmental and Economic Accounting in Theory and Practice, Tokyo, 5–8 March 1996.

Robinson, S. (1989), 'Multisectoral models', *in* H. Chenery and T.N. Srinivasan, eds., *Handbook on Development Economics,* vol. 2, Amsterdam: Elsevier Science Publishers BV.

Roose, E.J. (1977), 'Adaption des méthodes de conservation des sols aux conditions écologiques et socio-économiques de l'Afrique de l'ouest', *L'Agronomie tropical* **32**: 132–140.

Uhlen, G. (1991), 'Long-term effects of fertilizers, manure, straw and crop rotation on total-N and total-C in soil', *Acta Agriculture Scandinavia* **41**: 119–127.

World Bank (1992), 'Ghana 2000 and beyond: setting the stage for accelerated growth and poverty reduction', Report No. 11486-GH, Western Africa Department, The World Bank, Washington, DC.

Young, A. (1989), 'Agroforestry of soil conservation', Commonwealth Agricultural Bureau International, UK, Wallingford.

APPENDIX A

Sectoral gross production

Table A1. *Average annual percentage growth of gross production in the baseline scenario over the period 1992–2000, and differences in gross production in 2000 relative to the baseline scenario*

	Average annual growth, 1992–2000	*Deviation from baseline scenario (1) in 2000 for scenario No:*			
Sector	*Baseline (1)*	*0*	*2*	*3*	*4*
agrw	8.4	13.5	7.2	−11.9	−11.8
agrr	8.2	15.8	−1.2	−11.4	−10.4
agr	8.3	15.6	−0.4	−11.5	−10.5
cocw	0.5	16.7	−1.0	−7.3	9.4
cocr	0.5	16.7	−1.0	−7.3	9.4
coc	0.5	16.7	−1.0	−7.3	9.4
forw	1.9	0.2	−1.0	−10.3	−2.4
forr	1.9	0.2	−1.0	−10.3	−2.4
for	1.9	0.2	−1.0	−10.3	−2.4
fish	1.8	0.3	−0.9	−9.3	−2.2
minw	23.2	−0.5	−2.1	−19.8	−3.9
minr	22.9	−1.6	−1.7	−15.7	−2.7
min	22.9	−1.4	−1.8	−16.7	−3.0
food	5.4	10.2	−1.0	−10.0	6.3
wood	6.3	−0.1	−1.5	−13.4	−1.7
meta	−0.5	0.0	−0.6	−3.5	0.5
manu	5.2	0.0	−1.1	−5.5	3.2
cons	6.3	0.5	−2.1	−19.5	−4.1
elec	5.1	−0.1	−1.1	−10.7	−1.9
wate	14.5	0.1	−1.3	−15.4	−3.8
serv	3.1	0.2	−0.8	−8.0	−1.9
gove	3.9	0.3	−0.4	−7.9	−3.2
tran	7.4	5.3	−9.0	−12.0	−4.6
All	7.4	5.5	−1.0	−11.9	−4.6

Note: See Table 1 (p. 123) for explanation of sector codes.

APPENDIX B

Model equations, variables and parameters

Model equations

Regional aggregation:

(1) $P_i X_i = P_i^w X_i^w = P_i^r X_i^r$ $\quad i \in SP$

(2) $X_i = ar_i \left[\varepsilon_i X_i^{w-\rho_{ri}} + (1-\varepsilon_i) X_i^{r-\rho_{ri}} \right]^{\frac{-1}{\rho_{ri}}}$ $\quad i \in SP$

(3) $\dfrac{X_i^w}{X_i^r} = \left[\dfrac{P_i^r}{P_i^w} \; \dfrac{\varepsilon_i}{1-\varepsilon_i} \right]^{\frac{-1}{1+\rho_{r_i}}}$ $\quad i \in SP$

Import and exports:

(4) $P_i \cdot X_i = PD_i \cdot XD_i + pe_i \cdot E_i$ $\quad i \in EX$

(5) $P_i \cdot \mathrm{X}_i = PD_i \, \mathrm{XD}_i$ $\quad i \in GD - EX$

(6) $PC_i \cdot XC_i = PD_i \cdot (1 + td_i) \cdot XD_i + pm_i(1 + tm_i) \cdot M_i$ $\quad i \in IM$

(7) $PC_i \cdot XC_i = PD_i \, (1 + td_i) \cdot XD_i$ $\quad i \in GD - IM$

(8) $X_i = at_i \cdot \left[\gamma_i \cdot E_i^{\rho_{ei}} + (1 - \gamma_i) \cdot XD_i^{\rho_{ei}} \right]^{\frac{1}{\rho_{ei}}}$ $\quad i \in EX$

(9) $X_i = XD_i$ $\quad i \in GD - EX$

(10) $\dfrac{E_i}{XD_i} = \left\langle \dfrac{pe_i}{PD_i} \cdot \dfrac{1 - \gamma_i}{\gamma_i} \right\rangle^{\frac{1}{\rho_{ei}-1}}$ $\quad i \in EX$

(11) $XC_i = ac_i \cdot \left[\delta_i \cdot M_i^{-\rho_{mi}} + (1 - \delta_i) \cdot XD_i^{-\rho_{mi}} \right]^{\frac{-1}{\rho_{mi}}}$ $\quad i \in IM1$

(12) $XC_{fuel} = M_{fuel} \cdot (1 + tm_{fuel})$

(13) $XC_i = XD_i \cdot (1 + td_i)$ $\quad i \in GD - IM$

(14) $$\frac{M_i}{XD_i} = \left\langle \frac{PD_i(1+td_i)}{pm_i(1+tm_i)} \cdot \frac{\delta_i}{1-\delta_i} \right\rangle^{\frac{1}{1+\rho_{mi}}} \qquad i \in IM1$$

(15) $$XD_{fuel} = 0$$

Production functions:

(16) $$X_i^{1-\alpha_i} = ad_i \cdot LC_i^{\alpha}{}_i \cdot kf_i^{\,1-\alpha_i} \qquad i \in NAGR$$

(17) $$X_i = AD_i' \cdot \left[LC_i \cdot X_i\right]^{\alpha_i} \cdot \left(\frac{F_i}{KL_i}\right)^{\beta_i} \cdot KL_i^{1-\alpha_i} \qquad i \in AGR$$

Profit:

(18) $$PRFTi = \left[P_i - \sum_j PC_j \cdot a_{ji} - w_i \cdot LC_i\right] \cdot X_i \qquad i \in NAGR, j \in GD$$

(19) $$PRFT_i = \left[P_i \cdot (1+tsub_i) - \sum_j PC_j \cdot a_{ji} - w_i \cdot LC_i\right] \cdot X_i - PC_{manu} \cdot (1+tf_i) \cdot F_i \qquad i \in AGR, j \in GD$$

Factor demand:

(20) $$pkl0_i \cdot KL_i = \eta \cdot PRFT_i \qquad i \in AGR$$

(21) $$PC_{manu} \cdot (1+tf_i) \cdot F_i = \beta_i \cdot \left[P_i - \sum_j PC_j a_{ji}\right] X_i \qquad i \in AGR, j \in GD$$

(22) $$w_i \cdot LC_i = \alpha_i \cdot \left[P_i - \sum_j PC_j a_{ji}\right] \qquad i \in I1, j \in GD$$

Private income and consumption:

(23) $$Y = \sum_i w_i \cdot LC_i \cdot X_i + er \cdot trxk + \sum_i PRFT_i - PRFT_{gove} + yx \qquad i \in I1$$

(24) $$EXPEND = (1-s) \cdot (1-ty) \cdot Y$$

$$(25)\qquad PC_i \cdot CD_i = PC_i \cdot csub_i + q_i \cdot (EXPEND - \sum_j csub_j PC_j) \qquad i, j \in GD$$

Public income, saving and investments:

$$(26)\qquad GR = \sum_i \left[td_i \cdot PD_i \cdot XD_i + tm_i \cdot pm_i \cdot M_i + te_i \cdot pe_i \cdot E_i + tf_i \cdot PCV_{manu} \cdot F_i \right]$$

$$- \sum_{j \in AGR} P_j \cdot tsub_j X_{ij} + ty \cdot Y + PRFT_{gove} \qquad i \in I1$$

$$(27)\qquad GR = \sum_i PC_i \cdot gshare_i \cdot dgtot + SGOB \qquad i \in GD$$

$$(28)\qquad INV = s \cdot (1 - ty) \cdot Y + SGOB + er \cdot sfor$$

$$(29)\qquad INV = \sum_{i,j} PC_j \cdot imat_{ji} \cdot kshare_i \cdot DKTOT \qquad i \in I1,\ i \in GD$$

Material balance:

$$(30)\qquad XC_i = \sum_j a_{ij} \cdot X_j + CD_i + gshare_i \cdot gdtot + \sum_l \cdot imat_{il} \cdot kshare_l \cdot DKTOT$$

$$i, l \in GDM,\ j \in I1$$

$$(31)\qquad XC_{manu} = \sum_j a_{manu,j} \cdot X_j + CD_{manu} gshare_{manu} \cdot gdot +$$

$$\sum_l imat_{manul} \cdot kshare_l \cdot DKTOT + \sum_i F_i \qquad i \in AGR,\ l \in GD,\ j \in I1$$

Exogenous fuel price:

$$(32)\qquad P_{fuel} = 1$$

Soil model:

$$(33)\qquad NRR_i = \xi_i \cdot \frac{X_i}{KL_i} \cdot \left(ncs_i \frac{1 - h_i}{h_i} + ncr_i \frac{1}{h_i sr_i} \right) \qquad i \in AGR2$$

$$(34)\qquad NE_i = 1000 \cdot rkswm \cdot ncc \left(1 - cpar_i \cdot \xi_i \frac{X_i}{KL_i} \right) \qquad i \in AGR2$$

$$(35)\qquad NS_i = (1 - rn) \cdot NS_{t-1,i} + (1 - \Gamma) \cdot NRR_{t-1,i} - NE_{t-1,i} \qquad i \in AGR2$$

(36) $$NR_i = \tfrac{1}{2}\left[rn \cdot NS_i + \tfrac{1}{3}\Gamma \sum_{s=t-4}^{t-2} NRR_{s,i} + nat\right] \qquad i \in AGR2$$

(37) $$AD_i{}' = ad_i \frac{(a_i^0 + a_i^1 \cdot NR_i)(\varphi_i \kappa_i)^{b_i^0 + b_i^1 \cdot NR_i}}{(a_i^0 + a_i^1 \cdot NR_{0,i})(\varphi_i \kappa_i)^{b_i^0 + b_i^1 \cdot NR_{0,i}}} \qquad i \in AGR2$$

(38) $$AD'_i = ad_i \cdot (1 - \zeta)^t \cdot (1 - \chi \cdot es_i) \qquad i \in AGR1$$

(39) $$es_{t,i} = es_{t-1,i} + 1000 \cdot rksw \cdot \left(\boldsymbol{\varepsilon}_0 - \boldsymbol{\varepsilon}_1 \cdot \psi_i \frac{X_i}{KL_i}\right) \qquad i \in AGR1$$

List of variables

Endogenous variables:

Variable name	*Definition*	*Number of variables*	*List*
AD_i	Adjusted productivity variable	4	*AGR*
CD_i	Demand for commodity *i*	16	*GD*
DKTOT	Total real investments	1	
E_i	Exports of commodity *i* in local currency	12	*EX*
EXPEND	Expenditure on consumption	1	
F_i	Fertilizer	4	*AGR*
GR	Total income to the government	1	
INV	Total nominal investment	1	
KL_i	Land capital	4	*AGR*
LC_i	Labour per activity unit in sector *i*	19	*I*1
M_i	Imports of commodity *i* in local currency	11	*IM*
NE_i	Nitrogen loss due to erosion	2	*AG*2
NR_i	Natural mineralized nitrogen	2	*AG*2
NRR_i	Nitrogen in plant residual	2	*AG*2
NS_i	Stock of soil organic nitrogen	2	*AG*2
P_i	Output price	24	*I*
PC_i	Price of composite commodity *i*	16	*GD*
PD_i	Price of domestic commodity *i*	16	*GD*
$PRFT_i$	Total profit in sector *i*	19	*I*1
SGOB	Government saving	1	
X_i	Activity in sector *i*	24	*I*
XC_i	Composite commodity of domestic and imported products	16	*GD*
XD_i	National production for the domestic market	16	*GD*
Y	Nominal income	1	

Exogenous variables and parameters:

α_i	Cost share of labour
β_i	Cost share of real capita/fertilizers
γ_i	Share parameter in export equation
Γ	Share of N in plant residues directly mineralized
δ_i	Share parameter in creation of composite commodity
ξ_i	Share parameter in regional aggregation
ξ_0	Erosion parameter
ξ_1	Erosion parameter
κ_i	Conversion to physical fertilizer intensities
ξ_i	Conversion to physical food production intensities
ρ_{ei}	Transformation parameter in export equation
ρ_{mi}	Transformation parameter in import equation
ρ_{ri}	Transformation parameter in regional aggregation
χ	Conversion of soil loss to prod. loss
ζ	Depletion of natural P
φ_i	N content of fertilizer
ψ_i	Conversion to physical values for cocoa
a_0	Parameter in productivity index
a_1	Parameter in productivity index
a_{ij}	Input–output coefficient
ac_i	Shift parameter in creation of composite commodity
ad_i	Shift parameter in Cobb–Douglas production function
ar_i	Shift parameter in regional aggregation
at_i	Shift parameter in activity equation
b_0	Parameter in productivity index
b_1	Parameter in productivity index
$cpar_i$	Parameter for vegetation coverage
$csub_i$	Basic consumption
$depre$	Depreciation rate of capital
er	Exchange rate
es	Soil loss due to erosion
g	Growth rate of population
$gdtot$	Total real government consumption in base year
$gshare_i$	Government expenditure coefficient
h_i	Food share
$imat_{ij}$	Conversion matrix from destination to origin in investment
ipc	Consumer price index for class k
kf_i	Capital by sector
$ksare_i$	Share coefficient on total investment
nat	Atmospheric nitrogen
ncc	Index for concentration of N in soil
ncr_i	Index for concentration of N in roots
ncs_i	Index for concentration of N in stover
pe_i	Price of exports in local currency
pkl_i	Price on land
pm_i	Price of competitive imports in local currency
q_{ik}	Budget share of consumption by class
$rksw$	Combined erosion parameter from USLE

rkswm	Combined erosion parameter from USLE
rn	Parameter for N mineralization
s_k	Marginal propensity to consume by class
sfor	Foreign savings
sr_i	Weight between surface N and root N
td_i	Tax on domestic sale
te_i	Tariff rate on exports
tf_i	Tax on fertilizers
tm_i	Tax on competitive goods imports
trxk	Transfers from abroad in $
$tsub_i$	Agricultural subsidies to producers
ty	Direct taxes on income
w_i	Wage rate

Sectors and lists

I	*I1*	*NAGR*	*AGR*	*AG1*	*AG2*	*GD*	*GDM*	*SP*	*IM*	*IM1*	*EX*
	(I)	*(I1)*	*(I1)*	*(AGR)*	*(AGR)*	*(I)*	*(GD)*	*(GD)*	*(GD)*	*(IM)*	*(GD)*
	Sector	*Non-agriculture sectors*	*Agriculture sectors*	*Cocoa*	*Other agriculture*	*Goods*	*Goods excl. manufacture*	*Aggregated*	*Import*	*Import less fuel*	*Export*
agrw	x		x		x						
agrr	x		x		x						
agr						x	x	x	*x*	x	x
cocw	x		x	x							
cocr	x		x	x							
coc						x	x	x			x
forw	x	x									
forr	x	x									
for						x	x	x	x	x	x
fish	x	x				x	x		x	x	x
minw	x	x									
minr	x	x									
min						x	x	x	x	x	x
food	x	x				x	x		x	x	x
wood	x	x				x	x		x	x	x
meta	x	x				x	x		x	x	x
manu	x	x				x			x	x	x
cons	x	x				x	x				
elec	x	x				x	x				x
wate	x	x				x	x				
serv	x	x				x	x		x	x	x
gove	x	x				x	x		x	x	x
tran	x	x				x	x				
fuel						x	x		x		