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Abstract:
In this paper, a model of the nitrogen cycle in the soil is incorporated in a Computable General Equilibrium (CGE) model of the Tanzanian economy, thus establishing a two way link between the environment and the economy. For a given level of natural soil productivity, profit maximising farmers choose a production technique and the optimal production volume, which in turn influences the soil productivity the following years through the recycling of nitrogen from the residues of roots and stover and the degree of erosion.

The model is used to simulate the effects of typical structural adjustment policies: a reduction in agro-chemicals subsidies, reduced implicit export tax rate, a devaluation of the currency, a cut in governmental expenditure and a reduction of foreign transfers. The result of a joint implementation is a 9 percent higher GDP level compared to the baseline scenario after 10 years. The effect of soil degradation is found to represent a reduction in the GDP level of more than 5 percent for the same time period.

Keywords: CGE-model, soil degradation, economic growth, structural adjustment

JEL classification: C68, Q16, Q24

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1. Introduction

«Agriculture is the foundation of the Tanzanian economy, providing employment, food and exports. Some 84 per cent of the population are employed in agriculture, providing 61 per cent of both Gross Domestic Product (GDP) and merchandise exports.» (World Bank, 1994). This illustrates the important role agriculture plays in the Tanzanian economy. The International Monetary Fund (IMF) and the World Bank advocate export led growth as the path to economic prosperity for the African countries. This implies higher production volumes of the goods that the countries already export. In the case of Tanzania, production of *cotton, coffee, tea, tobacco* and *cashew nuts*, which constitutes 34 per cent of foreign exchange earnings, will probably have to increase in order to reach this goal. This might increase the pressure on land and forest reserves, as land for export crops will compete with land for basic food production.

Traditional agriculture in Tanzania is characterised by small scale farming with an average farm size of 0.9 hectares (World Bank, 1994). The farmers have limited access to agro-chemicals and machinery. Thus, the main production factors are human labour and natural soil fertility. Incomplete credit markets and lack of infrastructure tend to sustain this «low input - low output» technology, which so far has thrived on traditional fallow methods and access to virgin land. There is currently a clear tendency towards shorter fallow periods and permanent agriculture, reflecting an increased shortage of land. Combined with structural barriers against more intensive food production, and expansion of land used for export crops, the agricultural sector may end up mining the soil for subsistence. If the reduction in natural soil fertility is not compensated by nutrients from chemical fertilisers, the initiated export led economic growth may be difficult to sustain, because the soil productivity declines due to land degradation.

The soil productivity depends on different factors, such as the pH-level, salt-content, content of nitrogen and other nutrients, and the physical structure of the soil. In this paper we have chosen to focus on the content of nitrogen in the soil, because this is the most important limiting factor for many crops in Tanzania. The other factors are left out in order to simplify the analysis. By incorporating the Tropical Soil Productivity Calculator (Aune and Lal, 1995) in a Computable General Equilibrium (CGE) model for the Tanzanian economy, we have been able to establish a two way link between the economy and environment (i.e. soil productivity). The nitrogen content of the soil determines the soil productivity, which enhances yield and in turn influences soil productivity in the following years.

This paper describes briefly how soil productivity influences economic growth and vice versa. Through various model simulations we illustrate the changes in economic policy that Tanzania is undergoing today under the Structural Adjustment Program (SAP). Important components are the removal of subsidies on agro-chemicals, devaluation of the Tanzanian shilling, reduction in government spending and stricter fiscal policy. In the long run, the aim is also to make the country less dependent on aid from the developed countries, making it possible to reduce the direct transfers of money. We find that the SAP has a positive impact on economic growth, with a 10 per cent higher GDP in year 2000 compared to the baseline scenario, mostly due to higher producer prices in the agricultural sector.

We then analyse how the SAP affects the use of agro-chemicals and the resulting effects on agricultural production, via farmers' responses in input use and volumes produced and then how this in turn affects the soil's nitrogen content and hence the natural soil productivity. Even though total agricultural production is 17 per cent higher in the SAP-scenario, the reduction in use of chemical fertilizer is more than 50 per cent and pesticides 20 per cent compared to the baseline scenario in year 2000. Our model suggests that this has a minor effect on the natural soil productivity. The analysis shows that when a plot of land is under continual farming, the constant rate of reduction in soil organic nitrogen is the most important factor which determines the natural soil productivity. Different levels in the vegetation coverfactor, depending endogenously on production per unit of land, seems to have little effect on the natural soil productivity. However, we find that the inclusion of the endogenous soil degradation is significant for economic growth in Tanzania where agriculture constitutes a dominant share of the economy. The GDP level obtained using an integrated model version is more than 5 per cent lower after 10 years compared to using a conventional CGE-model with constant soil productivity.

This paper is organised as follows: chapter 2 describes the historic and political development leading to the implementation of the SAP towards the end of the 80s. In chapter 3, the CGE-model is presented, and the soil model follows in chapter 4. The state of the economy in the base year 1990, which is used to calibrate the model, is described in chapter 5, while the simulations of different economic scenarios are presented in chapter 6. Conclusions follow in chapter 7. Appendix 1 contains tables summarising the main results of the simulations. Appendices 2-7 present lists of equations, variables and parameters, the base year social accounting matrix (or input-output matrix) and finally a description of the soil module and its implementation in the CGE core model.

2. Economic transition

At the time of gaining independence in 1961, Tanzania was one of the poorest countries in the world, mainly dependent on subsistence agriculture (World Bank, 1992). The Arusha Declaration of 1967 initiated a period of pervasive state control over the economy and development under the slogan of «African Socialism». Economic policies comprised price controls, a huge public sector, parastatal enterprises with soft budget constraints, rigid discriminative exchange rates for foreign currencies, high import tariffs to protect the national industry against external competition and deficits in the governmental budget and the foreign account. However, small scale production and trade remained in private hands. Private farmers kept on farming since the collectivization program failed. Transportation and distribution systems, however, were controlled by the state.

This more or less centrally controlled economy was shaken by the oil-price shock in 1979-80 and the war with Uganda, which led to payment problems for import commodities. A deep recession hit the economy in the beginning of the 1980s. The government introduced the National Agricultural Policy (NAP) plan in 1982, which encouraged private investment in large scale farming (Eriksson, 1991). The World Bank and IMF supported the government in launching the Economic Recovery Program (ERP) in 1986. Step by step, the Tanzanian economy was supposed to change into a modern capitalistic economy by introducing the SAP.

An important task was to obtain «macroeconomic stabilisation», which implied scaling down the state sector to balance the public budget, dissolving parastatal enterprises and devaluating the Tanzanian Shilling. Another important component of the structural adjustment was to «get the prices right». This meant removing subsidies and price controls, dissolving state monopolies and letting private competition and market forces match supply and demand.

Of particular interest to the agricultural sector was the removal of subsidies on agro-chemicals and the dissolution of governmental price controls and the matching pan-territorial pricing system. This was meant to increase farmgate product prices, encouraging farmers to increase their efforts in order to raise output. Export-crop producers were expected to gain from the devaluation of the local currency and to become a motor behind export led growth.

3. The economic model

The CGE-model of this paper covers 20 production sectors (of which 11 are agricultural sectors) and 22 goods. The Social Accounting Matrix (SAM) for Tanzania for 1990 (Balsvik and Brendemoen, 1995) is used to calibrate the parameters in the CGE-model.

The model assumes that the producers maximise profits in a near perfect market economy where the producers exercise no market power. The Cobb-Douglas production functions are homogeneous of degree one, which implies that marginal cost equals average cost. The variable input factors are capital, labour, land, pesticides and fertilizers, while cross-deliveries of goods from other industries are proportional to total output. The productivity parameter of each variable input is calibrated to be equal to the input share of total variable cost.

Consumers receive all income from the production factors labour, real capital and land. After paying income taxes, a certain share is set aside as private savings and the rest is spent on consumption. With this constraint on total consumption expenditure, a consumption bundle is chosen so as to maximise a utility function of the Stone-Geary type. The result is the Linear Expenditure System (LES), where the consumer always will consume a minimum amount of each good independent of price changes, and the surplus money from the expenditure budget is spent with constant coefficients for each good. These coefficients are calibrated from the SAM, while minimum consumption is estimated from other sources.

The investment market is the main structural feature of the model. Total savings, i.e. private savings of consumers plus government savings, which are the difference between government net tax income and government spending, equals total investment, consisting of gross real investment, change in inventories and financial investment in foreign countries. The two last terms are, in fact, exogenous and leave gross real investment as the residual factor when total savings are set at the macro level. The amount available for real capital expenditure is then distributed to the different industries with a constant coefficient equal to the distribution of real investments in the base year. Thus, there is no profit maximisation behind the investment decisions since the industries do not have to pay for them directly. The result is an uneven marginal productivity of capital for the different industries. All government savings are classified as investments in private industries, and all government expenditure is defined as consumption.

The actual demand for goods is an aggregate of domestically produced and imported goods described by a Constant Elasticity of Substitution (CES) function. The purchaser seeks to minimise costs for a given level of total demand. Production in each industry is similarly divided between sale on the home market and exports using a Constant Elasticity of Transformation (CET) aggregate, where the producers will maximise the profit from a certain production level. The substitution elasticities in both types of functions are «guesstimates» based on experiences and estimates from other countries, while the other parameters in the functions are calibrated to the SAM of 1990.

Technically, in an equilibrium model where all endogenous variables are determined simultaneously, any exogenous variable «closes» the model (i.e. changing the value of an exogenous variable changes the resulting equilibrium values of the endogenous variables). In this model, foreign transfers (negative financial savings abroad) is one such important exogenous variable which closes the model. Aid and investments by foreign and multinational institutions are not in the control of the Tanzanians. The transfer from abroad is made in foreign currency and equals the foreign trade balance. This condition is formally excluded from the model as the dependent equation, due to Walras' law which postulates that the last market must be in equilibrium if supply equals demand in the other markets

In our CGE-model, we assume that all modelled markets are in equilibrium, which seems rather unrealistic for a country like Tanzania in the base year 1990, when parts of the command structure in the economy persisted. Either surplus demand or surplus supply is likely to arise when prices are set by an institution and by market forces. In Tanzania, most farmers received rather low prices for their goods. In return, they received subsidies for rationed input factors like fertilizer and pesticides.

The parameters in the Cobb-Douglas production functions are calibrated to equal the cost shares of each input factor in the base year 1990. Agro-chemicals are imported and since the state had limited resources of foreign exchange, this lead to rationing of agro-chemicals. This rationing results in downward biased parameters for the input when we use the official prices. Hence, the productivity parameters for fertilizer and pesticides in our model are probably too low compared with the productivity found in field-experiments. The productivity parameters for labour, capital and land are, in turn, likely to be upward biased.

Another problem in the modelling of the agricultural sector in third world countries is the high proportion of subsistence agriculture used where no trade is feasible. However, the aim of this exercise is to examine how the Tanzanian economy will develop *if* the country accomplishes the transition to a modern market economy. It is then natural to employ a market based economic model with few structural features. The introduction of various actions in the SAP has, in fact, made the country more of a market economy. Studies indicate that the farmers respond to price signals, both regarding crop selection and total agricultural supply (Eriksson, 1993).

The SAM of 1990 which is used to calibrate the parameters of the model had certain features that we have chosen to change for the following years. Most important is probably the change in the private savings rate from -0.4 per cent in 1990 to 5 per cent for the simulation period.

Capital accumulation and technological change are the driving forces in this model. Technological change is Hicks neutral and set to 1 per cent per annum (p.a.) for all non-agricultural industries and 0.5 per cent p.a. for agricultural industries except coffee, which is assumed to have a rate of technological change of 1 per cent p.a.

4. The soil model

Soil degradation happens through soil-mining and soil-erosion, and we are able to assess both processes by incorporating the Tropical Soil Productivity Calculator (TSPC) into the economic model. Only the nitrogen cycle is integrated into the soil-mining concept so far. However, nitrogen limitation to plant growth is the most important factor of productivity decrease in Tanzania, and thus the major soil degradation effects are captured by our model of nitrogen mining and related effects.

Mineralized nitrogen to the plants is available from three sources: (i) atmospheric nitrogen from the rain water, (ii) external supply from chemical fertilisers and (iii) nitrogen recycling from the residues of roots and stover. When a crop is harvested, parts of the plant are taken away from the field. The residues are left in the soil to decompose. In this process, the available nitrogen is released through two different processes. One part is mineralized directly, but it takes two years before the process starts, and then it extends over a three year period before all the nitrogen has been released. The second part of the nitrogen content in roots and stover is absorbed in the stock of soil organic nitrogen in the humus layer in the following year, and this stock releases a certain percentage mineralized nitrogen each year. But the stock of soil organic nitrogen is a part of the soil organic matter in the 20 cm layer of top soil, which decreases every year because of soil erosion. Soil erosion, in turn, depends on the yield per hectare. More and bigger plants have a denser leaf canopy, which reduces the kinetic energy of rainfall, so that the drops hit the ground with less intensity. Big plants have more roots and are able to keep the soil from loosening when the raindrops hit the ground. More roots also have higher capability to recover lost soil eroded from other plots of land (see appendices 2 and 6).

The technical integration of the nitrogen cycle into the production function is explained in appendix 7. A major complication when integrating the economic and the soil models is to construct a common variable for the use of land. Land use in hectares for each crop are taken from the official agricultural statistics of Tanzania. However, our model's unit of measure is «homogenous» land, not hectares. If farmers move the agricultural frontier towards less fertile land, they need more hectares of land to produce the same amount of crop.

(7) $\mathrm{pkl} \cdot \mathrm{KL} = \mathrm{lan} \cdot \mathrm{PRFT}$

In the model, equation (7) determines the use of land (*KL*). We assume that a certain part (*lan* per cent) of the gross profits (*PRFT*) in the agricultural industries is in fact land rent and the rest is a return to real capital. The land rent differs among crops, reflecting different soil quality. Even though there is a lot of uncultivated land in Tanzania, land scarcity in some regions, for instance Kilimanjaro, results in high resource rents in industries like coffee. Lack of roads, the national parks and Tse-tse flies reduce the available land in Tanzania to 30 per cent of total arable land (World Bank,1994). Due to this scarcity of land suitable for coffee production, we have chosen to model this industry with a constant amount of homogeneous land. We have done the same for tobacco, because the the need for firewood to cure the tobacco acts as constraint on increased production. Consequently, the resource rent (*pkl*) on each unit of homogenous land is endogeneous in these two sectors, while use of land is endogenous and the land rent exogenous in the nine other agricultural industries of Tanzania.

The soil model is a separate module linked to the economic model through the natural soil productivity variable (*bbhat*) for each crop. The soil model is recursive in time-space, where *bbhat* is a function of the yield per unit land (*X/KL*) from the economic model in earlier years, through the soil-nitrogen variables. The model is not simultaneous in the sense that soil productivity, economic variables and soil variables are all endogenous variables in the same year. The status of the soil variables in one year (t) determines the value of the soil productivity the next year (t+1), which gives rise to the economic solution for that year (t+1). The economic variables from that year are the input to the soil variables the same (and following) years, thus determining the soil productivity variables the next year.

5. The Tanzanian economy in 1990

Our basis for calibration of the economic model is the Social Accounting Matrix (SAM) from the original base year 1990 (Balsvik and Brendemoen, 1994) constructed from official statistics and merged with other sources of information to make a consistent accounting system. The agricultural industries are important contributors to the Gross Domestic Product (GDP) in the economy, making up 24.0 per cent of total GDP at market prices which is high compared to other industrialised countries but far below the offisial numbers[1]. If we include the *livestock* industry with 7.3 per cent of GDP as an agricultural industry, the relative importance increases to 33.4 per cent of GDP. The other sectors in the economy are *forestry* (3.1 per cent), *food* (7.2 per cent), *textiles* (3.6 per cent), *other manufacturing industries* (14 per cent), *construction* (5.6 per cent), *electricity* (1 per cent) *transport* (7.7 per cent), *other private services* (17.4 per cent) and *governmental sector* (7.3 per cent).

The level of mechanisation in production is rather low in Tanzania. Only a few agricultural sectors (*coffee, tea, tobacco, cashew* and *maize*) use any machinery at all. Their share of total gross investment was only 1.6 per cent. The capital intensive sectors were *transport* (44 per cent) which mostly uses cars and other machinery and *other private services* (32 per cent) with buildings and some machinery. These shares of total gross investment are kept constant for all years and scenarios as explained in chapter 3.

An important component in the real capital stock is transport equipment and machinery of different kinds. Most of this is imported and other manufactured goods constitute 82 per cent of all imports measured in CIF-values. On the other hand, agricultural products constitute a large share of the exports, with 34 per cent of total exports in FOB-prices. Other important exports are *transport services* (19.7 per cent) which are mostly services to landlocked neighbour countries and *other private services* (19 per cent) among which is tourism.

Value added from the principal production factors labour, real capital and land equals GDP at market prices less indirect taxes. The land rent is the resource rent reflecting land scarcity, wages are rewards for labour efforts and profits are the surplus from sales, i.e. the reward for stock of real capital employed in production. Wages constitute 68 per cent of total value added (governmental employees included), profits 28 per cent and land rent 4 per cent.

[1] National Accounts in Tanzania are under major revision to capture the impact of a reorientation towards deregulation and privatization (World Bank, 1996). The official figures probably underestimate the national income level.

Agriculture is the main source of labour income in Tanzania, generating 35 per cent of all wage income but only 1 per cent of profits. Real capital intensive industries like *transport* and *electricity* have limited expenditure on wages, while *livestock, forestry, construction* and *other private services* are labour intensive.

6. Results of the simulations

The main objective of the following analysis is to estimate how policy changes of the SAP affect economic growth and agricultural productivity. The baseline scenario (A) is a business as usual scenario, where the soil degradation model is included. Then we compare the results with a similar baseline scenario without the soil degradation model (M), i.e. with constant natural soil productivity.

The policy changes of the SAP is introduced step by step, one on top of the other, from scenario B to scenario F. This means that all changes are included in scenario F (i.e. the difference from scenario E is just the last included policy change of reducing foreign transfers).

To look at the implications of our assumption of a Keynesian labour market with constant nominal wages, we have run a model scenario with the policy changes of the SAP (comparable to F) in the end. But in this scenario N, we have changed to constant real wages (i.e. nominal wages fluctuate with the consumer price index).

In the following, we will refer to the average annual growth rate from 1991 to 2000 in each of the scenarios and the percentage difference between the variable value in the actual scenario and the baseline scenario (A) in year 2000. The internal comparison between a scenario and the preceding is done in percentage points, when the level in year 2000 for each of them is measured in per cent of the baseline scenario (A) All references to variables in real terms will be in 1990 prices.

6.1 Economic features

Baseline scenario (A) with soil model

The baseline scenario shows a real GDP growth of 1.8 per cent per annum (p.a.). Most of this growth can be attributed to the increase in production in the non-agricultural industries, where especially *transport* (5.5 per cent), *electricity* (3.0 per cent) and *other manufacture* (2.6 per cent) experience high growth. Real GDP in agricultural industries grows by 0.6 per cent p.a.. The agricultural sectors with the highest growth rates are the cash crops *tobacco* (3.3 per cent), *coffee* (2.4 per cent) and *cashews* (1.6 per cent).

There are three important factors behind this economic growth. We assume Hicks neutral technological change in all production sectors. It is set to 1 per cent p.a. in the industrial sectors and 0.5 per cent p.a. in the agricultural sectors, except for the coffee sector where productivity increases by 1 per cent too. The agricultural sectors are, on the other hand, exposed to soil degradation, and the range of reduction in this Hicks neutral productivity coefficient is from 0.0 per cent for cashew nuts to 2.7 per cent p.a. on average for tea. Then, the stock of real capital (a variable input factor in production), increases by 4.2 per cent p.a. due to positive net investment rate in all sectors.

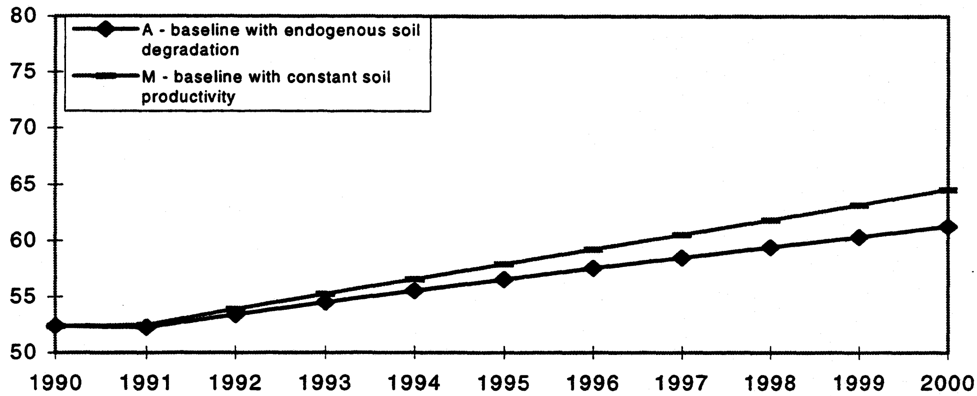
Technological progress implies that less variable input factors are needed to produce the same amount of output and thus that the marginal cost of production of goods is reduced. Higher volumes will be produced, and the price will go down in order to let demand equal supply. Then the production sectors need more inputs of goods, and there is a secondary demand effect working through the economy. Higher real GDP and an net disposable income for the consumers are the results.

Productivity reduction due to soil degradation will reduce these effects in the agricultural sectors. The total Hicks neutral productivity (technological progress and soil degradation) even falls in the *tea*, *maize* and *other crops* sectors leading to higher marginal cost in production as time passes by. In the other agricultural sectors, technological progress overshadows the soil degradation effect. Since demand is price elastic, it is profitable for the sectors to use relatively more input factors to compensate for the reduced natural productivity. The total effect could even be higher production volumes since the overall size of the economy increases. Looking at maize production as an example, labour use increases with 1.9 per cent p.a., fertilizers with 1.7 per cent p.a. and land with 1.7 per cent p.a., as the net Hicks neutral productivity falls by 1.6 per cent p.a. (a positive technological change of 0.5 per cent p.a. and a negative change in natural soil productivity due to soil degradation by 2.1 per cent p.a.). The total effect is a small increase of 0.2 per cent p.a. in produced volumes.

This effect of using more inputs to replace natural soil productivity, is even more visible if we look at comparable baseline scenario (M) without the soil degradation effect. Then the use of labour in the *maize* sector is 15 per cent lower in year 2000 compared to the baseline scenario (A) with the soil degradation process, even though the production volume is 5 per cent higher. When markets adjust prices upwards, (the producer prices in the agricultural sectors is 13 per cent higher in scenario A), the negative effect of soil degradation on GDP is counteracted. The cash crop producers are most affected by the reduction in soil productivity, since the world market price are constant and independent of the exported volumes from this country. And the total effect of soil degradation on economic development is painful for the Tanzanian society. The annual growth rate in real GDP falls by 0.5 percentage point, from 2.3 per cent p.a. in scenario M without soil degradation to 1.8 per cent p.a. in scenario A. The resulting GDP level in year 2000 is 5.2 per cent lower in the A than in M, due to the soil degradation process.

10 billion T.sh.

Impact of soil degradation on GDP in constant 1990 prices



There is a positive investment rate in both baseline scenarios which is an important factor behind economic growth. In the baseline scenario A, real capital increases by 4.2 per cent p.a. This increases the marginal productivity of the other input factors and reduces the marginal cost of production. The result is more use of inputs and higher production volumes, leading to higher economic growth. Since total production increases more in scenario M when there is no negative soil productivity effect, there is even more investment in the economy. The difference in net investment is still not very important, as the capital stock is just 0.1 per cent higher in scenario M in year 2000 than in scenario A.

The growth of GDP in constant prices in the baseline scenario A is due to growth in consumption (1,4 per cent) and gross real investment (1.5 per cent). Governmental demand is an exogenous variable and is held constant. Gross foreign trade increases, with growth in exports of 3.5 per cent p.a. and imports of 1.1 per cent p.a. The resulting deficit on foreign trade is constant by assumption.

Scenario B:(Scenario A + removal of agro-chemical subsidies)

The endogenous soil degradation process is included in this scenario. Fertiliser and pesticide subsidies are then gradually reduced from 60 per cent (fertilizers) and 50 per cent (pesticides) in 1990, to zero in 1995. Surprisingly, the GDP level in constant prices falls by 2.0 per cent compared with the baseline scenario (A) in year 2000.

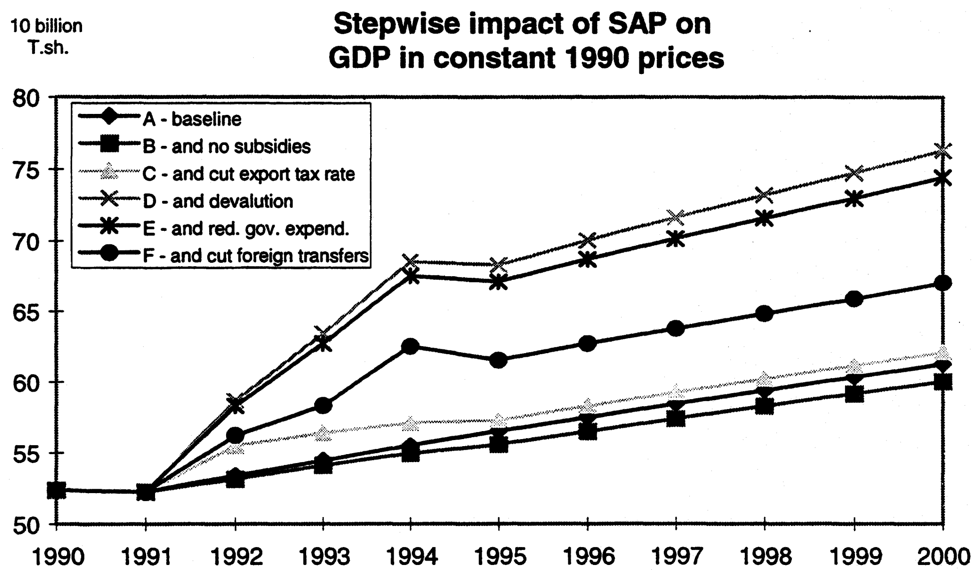
The reduction in subsidies leads to a proportionally increase in purchaser prices, since all agro-chemicals are imported and the world market prices are constant. The result is a huge reduction in the use of these input factors. Fertiliser use falls by 61 per cent and pesticide use by 70 per cent compared to the baseline scenario A. There is a substitution effect, which encourages the farmers to use more labour and land instead of those imported input factors. But the marginal cost of production has increased and then the produced volume will fall. This is especially important for the cash crop producers since the export price are constant. These sectors are also hardest hit by the removal of subsidies, because they are the most important purchasers of agro-chemicals. The result is a reduction in agricultural exports in constant 1990 prices of 33 per cent compared to the baseline scenario A. Since the activity level falls, the need for inputs from other sectors is reduced too, thus leading to a general contraction in the economy.

Removing subsidies partially increases net governmental revenues. But other tax income sources are adversely affected. The implicit export tax on agricultural products (explained in the next paragraph) is high and the reduction in tax income from this source due to reduced agricultural exports nearly outweighs the savings of less subsidies. If we include the reduction in other tax sources due to lower economic activity, net governmental revenues in year 2000 is 1.1 per cent lower than in scenario A. In this model, there seems to be a huge efficiency loss in the agricultural export sectors due to heavy taxation. The subsidies on agro-chemicals have, in fact, corrected this efficiency loss (Harberger triangle) by increasing the produced volume, leading to higher economic growth. Since both governmental revenues and private savings decrease, expenditure on real investment is 0.6 per cent lower in year 2000 compared to the baseline scenario A and the stock of real capital is reduced.

Scenario C: (Scenario B + reduction in export crop taxes)

Another way to correct the efficiency loss is to reduce the implicit export tax on agriculture. It is important to notice the rationale behind this policy change. In the base year 1990, parastatal marketing boards bought the crops directly from the farmers in the countryside at given prices in Tanzanian shilling and sold for dollars on the world market. The difference has been registered as a tax on export crops in our model. In this scenario, the implicit tax on agricultural exports falls from 87.5 to 50 percent the first year, illustrating a move from governmental to private marketing services. This shifts the cost burden from the public to private sector since the farmers have to buy the marketing service from private companies. This is not included in the model, as the input-output coefficients are held constant. It is, however, expected that a marketing reform will initiate a significant rise in marketing efficiency and that the farmers' cost increase might be much smaller than the reduction in the implicit export tax. Still, both the negative effect of a reduction in subsidies in the preceding scenario (B) and the positive effect of an export crop tax rate reduction in this scenario (C), are probably over stated.

Anyhow, when the reduction in implicit export taxes is added to the preceding scenario with removed subsidies (B), the simulations show an annual growth in GDP in constant prices of 2.1 per cent, leading to a 3.2 percentage point higher level in 2000 than in the preceding scenario. GDP is now even higher than the GDP in the baseline scenario A, as illustrated in the following figure:



This increased GDP level is mainly due to the rise in real agricultural exports of 23.8 percentage points compared to the preceding scenario B in year 2000, which is a result of the increase in export producer prices when the implicit export taxes are reduced. Since there are no subsidies in this scenario, the farmers increase production by increasing their use of all endogenous variable input factors like labour, land, fertilizers and pesticides at the same rate. Rising private incomes lead to a general demand effect in the economy, and production increases in all sectors.

The export volume effect overshadows the cut in the implicit export tax rate, increasing total implicit export tax income by 15.6 percentage points compared to the preceding scenario B. This positive effect shows that the taxation rate is set to high (e.g. negative side of the Laffer curve). Higher economic growth also leads to higher tax income from other sources, and the total effect on governmental revenues is an increase of 4.5 percentage points. This entails higher governmental savings, more expenditure on real investment and a 1.0 percentage higher capital stock in year 2000 in this scenario compared to the preceding scenario B.

Scenario D: (Scenario C + devaluation of the Tanzanian shilling)
Another way of increasing the producer prices of exported goods is to devaluate the local currency. In this scenario, there is a 10 per cent nominal devaluation in each of the years 1992, 1993 and 1994, in addition to the policy changes carried out in the preceding scenarios.

The average growth in GDP in constant prices now reaches a respectable 4.2 per cent p.a., which results in a 23.2 percentage point higher GDP level in 2000 than in the preceding scenario (C). The main partial effect is an increase in total exports in constant 1990 prices by 42.6 percentage points due to a total increase of 33.1 per cent in producer prices for exported goods. There is a scale effect in production which implies more use of all endogenous input factors like labour (up 34.6 percentage points), fertilizers (up 6.7 percentage points), pesticides (up 31.1 percentage points) and land (up 19.7 percentage points) compared to the preceding scenario C. But the rise in production in the export industries is also due to a substitution effect, since the relative producer price between the export and domestic markets increases, and producers prefer to sell their goods on the world market instead. But this effect is counteracted by the home market demand side in two ways. When supply to the home market decreases, the prices increase and the relative change is not that big anymore. The devaluation of the currency has also made imports more expensive, and purchasers turn their demand towards the home produced goods, giving rise to an extra demand effect. The result is a price increase for domestically produced goods of 10.7 percentage points compared to the preceding scenario C and total production increases.

When total production increases, more money is paid in wages and profits. This entails extra private savings (36.0 percentage points increase compared to the preceding scenario) and more governmental savings (78.1 percentage points), due to higher governmental tax revenues. The extra savings are all used on investment expenditure and the stock of real capital is 7.9 percentage points higher in year 2000 than in the preceding scenario. This increases the marginal productivity of the other input factors, reduces marginal cost and leads to higher production.

There is also a positive effect on economic growth from the foreign trade balance which is constant in foreign currency. Since the partial effects of a devaluation are more exports and less imports, there has to be higher economic growth in order to close this gap.

Scenario E: (Scenario D + cut in government consumption)

In this scenario, we reduce both governmental consumption of goods and use of labour by 3 per cent each year (26 per cent reduction in level by year 2000), on top of the policy changes in the preceding scenarios. This leads to an average real GDP growth rate of 3.9 per cent, representing a reduction in the GDP level by year 2000 of 3.1 percentage points compared to the preceding scenario D.

The first order effect of a reduction in government employees is a reduction in GDP by the same amount. The reduction in private wage income entails a negative demand effect on the economy in addition to the equivalent reduction in private savings. But the reduction of governmental demand for goods also leads to less production and entails a contraction in the economy. The result is a reduction in governmental revenues of 2.8 percentage points compared to the preceding scenario, but governmental savings increases by 13.4 percentage points because of the reduction in expenditure. The net effect of more governmental but less private savings is positive, and the stock of real capital is 1.2 percentage points higher in year 2000 than in the preceding scenario D. This should lead to higher production in the economy. However, the marginal productivity of real capital differs a lot between the industries, from 0.3030 in the food processing industry to 0.0005 in the electricity producing industry. Since most of the investment is distributed to sectors with low marginal productivity of real capital, the increase in the stock of real capital contributes little extra production to the GDP compared to the negative demand effects.

Scenario F: (Scenario E. + reduction in foreign transfers)

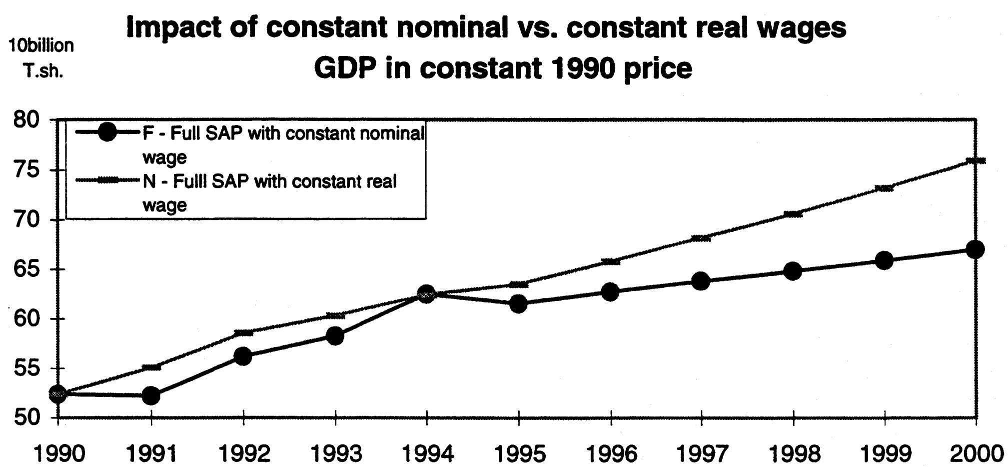
In this last scenario, all policy changes of the SAP are included. Foreign transfers (or foreign account balance) is one of the important exogenous variables closing the model. In the long run, an important goal for the SAP-program is to reduce the African countries' dependence on foreign aid. In this scenario, we have reduced the transfers by 9 per cent from 1991 to 1992 and by 9 per cent from 1992 to 1993 (the total reduction is 17.2 per cent). Then, average growth in real GDP is reduced to 2.8 per cent p.a., which results in a 9.4 per cent higher GDP level in year 2000 than the baseline scenario A.

This reduction in the trade balance (foreign transfers) has to increase the relative importance of exports compared to imports. A general contraction in the economy gives rise to this result, since imports (15.2 percentage points reduction) decrease more that exports (11.5 percentage points reduction). This originates from the first order effect of a reduction in foreign transfers which is a corresponding reduction in on real investment expenditure, since we assume that none of these transfers is spent on consumption, either by the private or the governmental sector. Hence, the total effect on real capital accumulation, is a reduction in the stock by 9.1 percentage points in year 2000 compared to the preceding scenario, and this entails a significant downturn in economic growth.

Total effect of all the SAP policy changes in this scenario F is positive compared to the baseline scenario without any changes (A). GDP in constant 1990 prices is higher, and the composition is turned more towards agricultural production which is 17.2 per cent higher than in the baseline scenario (A). The agricultural share of GDP (excluding livestock production) in year 2000 increased from 20.8 per cent of GDP in the baseline scenario (A) to 24.5 per cent in this full SAP scenario (F).

Scenario N: Full SAP-scenario (F) with constant real wages

In this special scenario, we want to look at the implications of the assumed Keynesian labour market with constant nominal wages. A constant real wage is introduced in the corresponding full SAP-scenario (F) by letting the nominal wage vary with the consumer price index. This leads to a decline in nominal wages by year 2000 of 12.5 per cent.



When labour become cheap, producers want to use relatively more labour power compared to other input factors. The total use of labour increases by 25.5 percentage points compared to the corresponding scenario F with constant nominal wages. There is a small reduction in use of land (0.9 percentage points down), and the use of fertilisers (13.8 percentage points up) and pesticides (22.4 percentage points up) increases. The result is an increase in production, and GDP in constant 1990 prices rises with 14.6 percentage points compared to scenario F. More savings due to higher production is the other major force behind this result since the stock of real capital is 3.1 percentage points higher.

6.2 Soil features

Natural soil productivity, soil depth and use of land are three important environmental variables that are assessed in this model. The fall in natural soil productivity differs a lot between crops, from constant productivity for cashews, which is not dependent on the nitrogen content in the soil, to an average annual decline of 2.8 per cent for tea, 2.1 per cent for maize and 1.9 per cent for other crops in the baseline scenario A. This loss of soil productivity is partly compensated by the technological progress, set to increase by 0.5 per cent p.a. for all crops except coffee with 1.0 per cent a year. The soil productivity (bbhat) is determined in the soil model and is dependent on three main components: the constant rate of mineralization from the stock of soil organic nitrogen (*NS*), directly mineralized nitrogen from the residual roots and stover (*NRR*) and nitrogen from the atmospheric nitrogen deposition (*nas*).

Theoretically, the level of production per unit of land (X/KL) influences the available nitrogen both trough NS and NRR, but our results show that the latter effect is small compared to the mineralization process from the initial NS stock. The natural soil productivity variable (*bbhat*) declines more or less at the same rate for all the scenarios in the SAP (A-F). The exceptions are cotton which has 0.1 per cent lower bbhat-level in scenario F in year 2000 than in A, coffee with 0.5 per cent higher bbhat-level, *tobacco* 0.04 per cent higher *bbhat* level and maize 0.6 per cent lower *bbhat* level. For the other agricultural products there is no difference at all. We will illustrate the effect of the different scenarios on various variables for the most important crop: maize.

Maize, deviation from scenario A in year 2000 (%)

	A	B	C	D	E	F	M	N
bbhat	0.00	-0.43	-0.43	-0.59	-0.59	-0.59	23.23	-0.05
D	0.00	0.00	0.00	0.00	0.00	0.00	na.	0.00
NS	0.00	-0.13	-0.13	-0.17	-0.17	-0.17	na.	0.02
NR	0.00	-0.92	-0.93	-1.24	-1.22	-1.25	na.	-0.11
NRR	0.00	-5.40	-5.40	-7.08	-6.97	-7.26	na.	3.69
NE	0.00	0.59	0.59	0.76	0.75	0.78	na.	-0.46
KL	0.00	3.96	5.18	16.46	14.96	11.28	-15.85	4.88
u	0.00	-5.40	-5.40	-7.08	-6.97	-7.27	24.22	3.69

The crop intensity (u) is the production yield from one unit of homogenous land (*KL*) and is the only factor influencing the soil variables of the model. The removal of subsidies in scenario B entails less use of fertilisers and pesticides, reducing the crop intensity and equally reducing the nitrogen from residuals in roots and stover (*NRR*) and increasing the amount of nitrogen lost due to soil erosion (NE). But the level of soil organic nitrogen (*NS*) only falls by 0.13 per cent in year 2000. Since NS constitutes 83.2 per cent of all mineralised nitrogen in 1990, the total amount of nitrogen from natural sources (NR) is only 0.9 per cent less in year 2000 than in the baseline scenario. The elasticity of the natural soil productivity parameter with respect to NR is less than one, and the resulting reduction in bbhat is 0.43 per cent compared to the baseline scenario. This has a minimal effect compared to the scale of reduction in the use of fertilisers (61.8 per cent) and pesticides (70.0 per cent).

The export tax reduction and devaluation in the next scenarios have the effect of expanding production. But use of land increases more, leading to a decline in crop intensity, thereby reducing the natural soil productivity. However, this effect is rather small since the exogenous mineralization rate of NS is the most important factor in determining the total amount of available nitrogen. The decline in soil productivity continues more or less independently of the crop intensity when a plot of land first is opened for continuous farming. The only way to keep the productivity at the same level is to add more fertilisers. By year 2000, this inexorable decline in natural soil productivity results in a 23.2 per cent reduction in natural soil productivity in scenario A compared to the same policy scenario where the natural soil productivity is exogenously held constant at the base year level. In the model, new land is assumed to be as productive as formerly cultivated land. In reality, land at the margin is likely to be even less productive.

The soil depth is even less sensitive to the different policy scenarios. The removal of subsidies in scenario B causes a 0.5 per cent reduction of the soil depth for tobacco in year 2000 compared to the baseline scenario. For the other crops, there is no difference between the scenarios. But the degradation process reduces the initial soil depth of 0.2 meter to a range from 0.190 meter for maize and sorghum (i.e. 5 per cent reduction) to 0.199 meter for rice (i.e. 0.5 per cent reduction) in year 2000. This small erosion effect is also due to the short time period of 10 years, and the cumulative effect would of the problem would probably be more apparent if we had run the model over more years.

Total land use is another environmental aspect. In this model we use the variable unit of homogeneous land which is linked to the amount of profits in each agricultural industry. The initial amount of hectares in one unit of homogenous land differs among crops in the initial year 1990, and the amount of hectares per unit of homogeneous land increases when productivity declines. We do not have any measure for how much more land in physical terms is needed to meet demand. In order to summarise land use for all crops, we have chosen to use a fixed coefficient of hectares per unit of homogeneous land over time adn in this way we underestimate the total use of land for the variable «total use of land», as presented in appendix 1. The result is that total use of land is 3.5 per cent higher in 2000 when subsidies are removed in scenario B, this way substituting the relatively cheaper input of land for fertilizer. This is also due to a shift towards more land intensive crops like cotton and cashews, while production is reduced in food crops like cassava, rice and other crops due to the reduction of private income and food consumption. Thus, the use of land then increases in proportion to the increase in production, in the scenarios C to F. 6.1 per cent less land is used in the baseline scenario without the soil model (M), since there is less need for variable input factors to produce the same amount of food. In the total SAP scenario with constant real wages, gross production in the agricultural sectors increases by 19.7 percentage points compared with the SAP scenario with constant nominal wages, while the use of land decreases by 0.9 percentage points, thereby illustrating the need for more labour in production as the nominal wage declines.

7. Conclusions

Tanzania, like most African countries, depends heavily on agricultural production, which constitutes a major part of GDP and exports. In this model, we find that this situation may change as soil degradation undermines economic growth. In 10 years time, the GDP level falls by more than 5 per cent in our model with endogenous soil degradation, compared to a traditional CGE-model with constant soil productivity.

The macroeconomic impact of structural adjustment policy measures like the devaluation of the currency and a reduction in the implicit tax on export crops have positive impacts on the economy, mainly due to the sharp rise in agricultural exports. On the other hand, the cut in subsidies, governmental expenditure and foreign transfers seems to have a negative effect on economic growth. All measures in the SAP combined, have a positive impact on economic growth in this model, and raise GDP growth from 1.8 per cent to 2.8 per cent p.a.

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Main results

Table 1. Gross Production and Gross Domestic Product at constant 1990 market prices

		GP in const. 1990 prices		GDP in const. 1990 prices	
	Scenario	*growth (% p.a.)*[1]	*dev. 2000 (%)*[2]	*growth (% p.a.)*	*dev. 2000 (%)*
A	Baseline	2.04	0.00	1.77	0.00
B	and no subsidies	1.77	-2.47	1.54	-2.00
C	and implicit exp. tax reduction	2.13	0.74	1.92	1.36
D	and devaluation	4.55	25.28	4.21	24.58
E	and red. gov. cons.	4.39	23.47	3.93	21.50
F	and cut foreign transfers	3.10	10.02	2.76	9.36
M	Baseline w. cons. soil prod.	2.55	5.10	2.30	5.39
N	SAP w. cons. real wage	3.93	24.83	3.59	23.49

1)«growth» is the average annual growth rate in per cent for the actual variable from 1991 to 2000
2)«dev. 2000» is the deviation in per cent for the variable value in year 2000 in the actual scenario compared to the baseline scenario A.

Table 2. Gross Product and Gross Domestic Product at constant 1990 market prices in the agricultural industries

		Agricultural GP in cons.1990 prices		Agricultural GDP in cons.1990 prices	
	Scenario	*growth (% p.a.)*	*dev. 2000 (%)*	*growth (% p.a.)*	*dev. 2000 (%)*
A	Baseline	0.62	0.00	0.58	0.00
B	and no subsidies	-0.36	-8.46	0.11	-4.16
C	and implicit exp. tax reduction	0.42	-1.77	0.86	2.56
D	and devaluation	3.11	25.05	3.76	33.20
E	and red. gov. cons.	2.97	23.55	3.61	31.38
F	and cut foreign transfers	2.37	17.06	2.94	23.71
M	Baseline w. const. soil prod.	1.61	10.25	1.66	11.28
N	SAP w. const. real wage	3.40	36.71	4.02	45.83

Table 3. Use of variable production input factors in industries

		Total use of labour		Total stock of capital	
	Scenario	*growth (% p.a.)*	*dev. 2000 (%)*	*growth (% p.a.)*	*dev. 2000 (%)*
A	Baseline	0.70	0.00	4.17	0.00
B	and no subsidies	0.42	-2.44	4.16	-0.06
C	and implicit exp. tax reduction	0.87	1.50	4.27	0.93
D	and devaluation	4.12	36.06	5.11	8.84
E	and red. gov. cons.	3.89	33.26	5.23	10.06
F	and cut foreign transfers	2.75	20.25	4.27	0.93
M	Baseline w. const. soil prod.	0.78	0.77	4.24	0.62
N	SAP w. const. real wage	3.85	45.76	4.57	3.71

		Total use of fertilisers		Total use of pesticides		Total use of land (ha)	
	Scenario	*growth (% p.a.)*	*dev. 2000 (%)*	*growth (% p.a.)*	*dev. 2000 (%)*	*growth (% p.a.)*	*dev. 2000 (%)*
A	Baseline	1.96	0.00	2.09	0.00	0.99	0.00
B	and no subsidies	-8.72	-61.77	-11.26	-69.93	1.37	3.45
C	and implicit exp. tax reduction	-7.42	-57.02	-5.07	-47.52	1.66	6.20
D	and devaluation	-5.81	-50.32	0.09	-16.45	3.55	25.91
E	and red. govn. cons.	-5.76	-50.11	0.04	-16.88	3.39	24.10
F	and cut foreign transfers	-6.15	-51.84	-0.33	-19.57	2.83	17.98
M	Baseline w. const. soil prod.	1.18	-7.56	4.37	25.96	0.37	-6.09
N	SAP w. const. real wage	-3.15	-38.01	0.64	3.26	3.37	17.11

Table 4. Units produced in the industries in the different scenarios

	Average growth 1991-2000 (%)								Level difference from baseline (A) in 2000 (%)							
X[3]	A	B	C	D	E	F	M	N	A	B	C	D	E	F	M	N
COT	1.43	0.77	2.09	6.81	6.50	5.31	2.43	7.50	0	-6	6	62	58	42	10	87
COF	2.42	-10.42	-0.95	6.18	6.22	6.11	5.42	6.72	0	-69	-26	40	41	39	36	87
TEA	1.30	0.91	1.97	5.78	5.57	4.42	2.94	5.63	0	-3	6	50	47	32	19	61
TOB	3.29	-0.50	3.72	14.21	14.37	14.27	4.44	18.82	0	-29	4	167	171	168	12	390
CAH	1.66	-0.40	0.60	3.10	2.92	1.86	2.23	2.73	0	-17	-9	14	12	2	6	16
CAS	0.01	-0.02	0.02	0.47	0.40	0.23	0.12	0.42	0	0	0	4	4	2	1	5
MAI	0.15	-0.01	0.11	1.03	0.91	0.50	0.62	0.88	0	-1	0	8	7	3	5	9
RIC	0.62	0.48	0.65	2.15	1.99	1.39	0.98	1.93	0	-1	0	15	13	7	4	16
SOR	0.30	0.19	0.33	1.37	1.23	0.80	0.54	1.20	0	-1	0	10	9	5	2	11
BEA	0.14	0.05	0.15	0.92	0.82	0.49	0.32	0.82	0	-1	0	7	6	3	2	8
OCC	0.45	0.27	0.51	3.07	2.89	2.08	1.48	2.94	0	-2	1	27	25	16	11	33
LIV	1.18	0.88	1.29	4.48	4.08	2.83	1.71	3.95	0	-3	1	35	30	16	5	39
FOR	2.22	2.00	2.35	6.23	5.95	4.55	2.70	5.97	0	-2	1	43	40	23	5	54
FOO	2.01	1.70	2.09	4.63	4.40	3.18	2.73	4.10	0	-3	1	27	24	11	7	27
TEX	1.24	0.80	1.33	4.38	4.03	2.80	2.16	4.01	0	-4	1	33	29	15	9	36
OMS	2.60	2.50	2.74	5.14	5.25	3.70	2.93	4.40	0	-1	1	26	27	10	3	24
CON	2.14	1.98	2.30	5.07	5.07	3.46	2.52	4.19	0	-1	1	30	30	13	4	30
ELE	2.95	2.77	3.06	4.88	4.14	2.97	3.35	3.86	0	-2	1	19	11	0	4	11
TRA	5.52	5.45	5.61	7.29	7.31	6.34	5.68	6.77	0	-1	1	17	18	8	2	16
OPS	2.34	2.16	2.47	5.16	5.05	3.65	2.82	4.49	0	-2	1	29	28	13	5	29

3) Short for crop names, see appendix 4

Table 5. Soil productivity parameter by agricultural industries in the different scenarios

	Average growth 1991-2000 (%)								Level difference from baseline (A) in 2000 (%)							
bbhat	A	B	C	D	E	F	M	N	A	B	C	D	E	F	M	N
COT	-0.29	-0.30	-0.30	-0.30	-0.30	-0.30	0.00	-0.30	0.00	-0.08	-0.08	-0.12	-0.12	-0.12	3.01	-0.04
COF	-0.65	-0.74	-0.68	-0.59	-0.59	-0.59	0.00	-0.55	0.00	-0.83	-0.29	0.54	0.54	0.54	6.84	0.88
TEA	-2.78	-2.78	-2.78	-2.78	-2.78	-2.78	0.00	-2.78	0.00	0.00	0.00	0.00	0.00	0.00	32.16	0.00
TOB	-0.26	-0.26	-0.26	-0.25	-0.25	-0.25	0.00	-0.25	0.00	0.00	0.00	0.04	0.04	0.04	2.66	0.07
CAH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CAS	-0.41	-0.41	-0.41	-0.41	-0.41	-0.41	0.00	-0.40	0.00	0.00	0.00	0.00	0.00	0.00	4.32	0.13
MAI	-2.09	-2.13	-2.13	-2.15	-2.15	-2.15	0.00	-2.09	0.00	-0.43	-0.43	-0.59	-0.59	-0.59	23.23	-0.05
RIC	-0.39	-0.39	-0.39	-0.39	-0.39	-0.39	0.00	-0.37	0.00	0.00	0.00	0.00	0.00	0.00	4.01	0.12
SOR	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	0.00	-0.24	0.00	0.00	0.00	0.00	0.00	0.00	2.67	0.12
BEA	-0.47	-0.47	-0.47	-0.47	-0.47	-0.47	0.00	-0.46	0.00	0.00	0.00	0.00	0.00	0.00	4.87	0.11
OCC	-1.94	-1,.94	-1.94	-1.94	-1.94	-1.94	0.00	-1.90	0.00	0.00	0.00	0.00	0.00	0.00	21.10	0.38

Table 6. Soil depth by agricultural industries in the different scenarios

	Average growth 1991-2000 (%)								Level difference from baseline (A) in 2000 (%)							
D	A	B	C	D	E	F	M	N	A(4)	B	C	D	E	F	M	N
COT	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	0.193	0	0	0	0	0	0	0
COF	-0.17	-0.17	-0.17	-0.17	-0.17	-0.17	-0.17	-0.17	0.197	0	0	0	0	0	0	0
TEA	-0.17	-0.17	-0.17	-0.17	-0.17	-0.17	-0.17	-0.17	0.197	0	0	0	0	0	0	0
TOB	-0.28	-0.28	-0.23	-0.23	-0.23	-0.23	-0.28	-0.17	0.194	0.00	0.52	0.52	0.52	0.52	0.00	1.03
CAH	-0.22	-0.22	-0.22	-0.22	-0.22	-0.22	-0.22	-0.22	0.196	0	0	0	0	0	0	0
CAS	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	0.193	0	0	0	0	0	0	0
MAI	-0.51	-0.51	-0.51	-0.51	-0.51	-0.51	-0.51	-0.51	0.190	0	0	0	0	0	0	0
RIC	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	0.199	0	0	0	0	0	0	0
SOR	-0.51	-0.51	-0.51	-0.51	-0.51	-0.51	-0.51	-0.51	0.190	0	0	0	0	0	0	0
BEA	-0.46	-0.46	-0.46	-0.46	-0.46	-0.46	-0.46	-0.46	0.191	0	0	0	0	0	0	0
OCC	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	0.193	0	0	0	0	0	0	0

4) Soil depth measured in meters in year 2000 in the baseline scenario A

Table 7. Use of homogeneous land by agricultural industries in the different scenarios

	Average growth 1991-2000 (per cent)								Level difference from baseline (A) in 2000 (per cent)							
KL	A	B	C	D	E	F	M	N	A	B	C	D	E	F	M	N
COT	1.17	1.54	2.88	7.91	7.60	6.39	2.06	8.40	0	3	17	83	78	60	8	92
TEA	3.39	3.39	4.51	9.19	9.19	7.70	2.16	9.19	0	0	11	68	68	47	-11	68
CAH	0.00	3.20	4.51	8.59	8.59	7.70	1.71	8.59	0	33	50	117	117	100	17	117
CAS	-0.08	-0.16	-0.08	0.40	0.32	0.16	-0.33	0.18	0	-1	0	4	4	2	-3	-7
MAI	1.72	2.15	2.28	3.41	3.27	2.91	0.00	3.07	0	4	5	16	15	11	-16	5
RIC	0.55	0.37	0.55	2.06	1.90	1.25	0.46	1.68	0	-2	0	15	13	6	-1	3
SOR	0.00	0.00	0.00	1.21	1.02	0.62	0.00	0.89	0	0	0	12	10	6	0	0
BEA	0.09	0.17	0.26	1.07	0.91	0.59	-0.17	0.72	0	1	2	9	8	5	-3	-2
OCC	1.89	1.71	1.95	4.52	4.33	3.52	0.98	4.17	0	-2	1	27	25	16	-9	18

Equations of the economic model and the soil model

	Economic model	list	numbers
1.	$X_i = tech_i \cdot bbhat_i \cdot L_i^{\alpha_i} \cdot kk_i^{\beta_i} \cdot F_i^{\gamma_i} \cdot PA_i^{\chi_i} \cdot KL_i^{\mu_i}$	i=AG1	9
2.	$X_i = tech_i \cdot bbhat_i \cdot L_i^{\alpha_i} \cdot kk_i^{\beta_i} \cdot F_i^{\gamma_i} \cdot PA_i^{\chi_i} \cdot kl_i^{\mu_i}$	i=AG2	2
3.	$X_i = tech_i \cdot bb_i \cdot L_i^{\alpha_i} \cdot kk_i^{\beta_i}$	i=IND	9
4.	$w \cdot L_i = \alpha_i \cdot X_i \cdot \left(P_i - \sum_j PC_j \cdot (1 + ta_j) \cdot a_{ji} \right)$	i=Z j=J	20
5.	$PC_{pes} \cdot (1 + ta_{pes}) \cdot PA_i = \chi_i \cdot X_i \cdot \left(P_i - \sum_j PC_j \cdot (1 + ta_j) \cdot a_{ji} \right)$	i=AG j=J	11
6.	$PC_{fer} \cdot (1 + ta_{fer}) \cdot F_i = \gamma_i \cdot X_i \cdot \left(P_i - \sum_j PC_j \cdot (1 + ta_j) \cdot a_{ji} \right)$	i=AG j=J	11
7.	$pkl_i \cdot KL_i = lan_i \cdot PRFT_i$	i=AG1	9
8.	$PKL_i \cdot kl_i = lan_i \cdot PRFT_i$	i=AG2	2
9.	$PC_i \cdot XC_i = (1 + td_i) \cdot PD_i \cdot XD_i$	i=NIM	11
10.	$PC_i \cdot XC_i = (1 + td_i) \cdot PD_i \cdot XD_i + pm_i \cdot (1 + tm_i) \cdot M_i$	i=IM	11
11.	$XC_i = XD_i$	i=NIM	11
12.	$XC_i = qq_i \cdot \left[q_i \cdot M_i^{-\tau} + (1 - q_i) \cdot XD_i^{-\tau} \right]^{\frac{-1}{\tau}}$	i=IM1	9
13.	$XC_i = M_i$	i=CHEM	2
14.	$\frac{M_i}{XD_i} = \left[\frac{PD_i \cdot (1 + td_i)}{pm_i \cdot (1 + tm_i)} \cdot \frac{q_i}{1 - q_i} \right]^{\frac{1}{1+\tau}}$	i=IM1	9
15.	$P_i \cdot X_i = PD_i \cdot XD_i$	i=NEX	7
16.	$P_i \cdot X_i = PD_i \cdot XD_i + pe_i \cdot E_i$	i=EX	13
17.	$X_i = XD_i$	i=NEX	7
18.	$X_i = hh_i \cdot \left[h_i \cdot E_i^{\rho} + (1 - h_i) \cdot XD_i^{\rho} \right]^{\frac{1}{\rho}}$	i=EX	13
19.	$\frac{E_i}{XD_i} = \left[\frac{pe_i}{PD_i} \cdot \frac{1 - h_i}{h_i} \right]^{\frac{1}{\rho - 1}}$	i=EX	13
20.	$PRFT_i = X_i \cdot \left[P_i - \sum_j a_{ji} \cdot PC_j \cdot (1 + ta_j) \right] - w \cdot L_i - PC_{pes} \cdot (1 + ta_{pes}) \cdot PA_i - PC_{fer} \cdot (1 + ta_{fer}) \cdot F_i$	i=AG j=J	11

21.	$PRFT_i = X_i \cdot \left[P_i - \sum_j a_{ji} \cdot PC_j \cdot (1 + ta_j) \right] - w \cdot L_i$	i=IND j=J	9
22.	$Y = \sum_i (w \cdot L_i + PRFT_i) + w \cdot lg$	i=Z	1
23.	$EXPEND = c \cdot (1 - ty) \cdot Y$		1
24.	$PC_i \cdot CD_i = PC_i \cdot \theta_i + \kappa_i \cdot \left[EXPEND - \sum_j PC_j \cdot \theta_j \right]$	i=J j=J	22
25.	$GR = ty \cdot Y + \sum_j td_j \cdot PD_j \cdot XD_j + \sum_l te_l \cdot pe_l \cdot E_l +$ $\sum_i tm_i \cdot pm_i \cdot M_i + \sum_k ta_{pes} \cdot PC_{pes} \cdot PA_k +$ $\sum_k ta_{fer} \cdot PC_{fer} \cdot F_k + \sum_n \sum_j ta_n \cdot PC_n \cdot a_{nj} \cdot X_j$	j=Z l=EX i=IM k=AG n=J	1
26.	$SGOV = GR - \sum_i PC_i \cdot gc_i - w \cdot lg$	i=J	1
27.	$JJ = (1 - c) \cdot (1 - ty) \cdot Y + SGOV - \sum_i PC_i \cdot cs_i - er \cdot sfor$	i=J	1
28.	$PC_j \cdot DK_{ji} = imat_{ji} \cdot kshare_i \cdot JJ$	i=I1 j=I2	28
29.	$XC_i = \sum a_{ij} \cdot X_j + cs_i + gc_i + CD_i$	i=I3 j=Z	18
30.	$XC_i = \sum a_{ij} \cdot X_j + cs_i + gc_i + CD_i + \sum_l DK_{il}$	i=I2 l=I1	2
31.	$XC_i = \sum_k PA_k + \sum_j a_{ij} \cdot X_j + cs_i + gc_i + CD_i$	i=pes j=Z k=AG	1
32.	$XC_i = \sum_k F_k + \sum_j a_{ij} \cdot X_j + cs_i + gc_i + CD_i$	i=fer j=Z k=AG	1
		sum	276

	Soil-model		
33.	$bbhat_i = bb_i \cdot \frac{(a_{0i} + a_{1i} \cdot NR_i) \cdot (phis_i)^{(b_{0i}+b_{1i} \cdot NR_i)}}{bbnorm_i}$	i=AG5	10
33.	$bbhat_i = bb_i$	i=cah	1
34.	$NR_i = \left[rns \cdot NS_i + \frac{1}{3} \cdot \sum_{s=2}^{4} NRR_{i,t-s} + nas \right] \Big/ 2$	i=AG	11
35.	$NS_i = (1 - rns) \cdot NS_{i,t-1} + (1 - l_i) \cdot NRR_{i,t-1} - NE_{i,t-1}$	i=AG	11
36.	$NRR_i = exxs_i \cdot \frac{X_i}{KL_i} \cdot \left(retain_i \cdot ncss_i \cdot \frac{1 - hs_i}{hs_i} + ncrs_i \cdot \frac{1}{hs_i \cdot srs_i} \right)$	i=AG	11
37.	$NE_i = rs_i \cdot ks \cdot ss_i \cdot ws \cdot ms \cdot \frac{NS_i}{bds \cdot 10 \cdot D_i} \cdot cpa_i$	i=AG3	2
38.	$NE_i = rs_i \cdot ks \cdot ss_i \cdot ws \cdot ms \cdot \frac{NS_i}{bds \cdot 10 \cdot D_i} \cdot \left(cp_i - cpars_i \cdot exxs_i \cdot \frac{X_i}{KL_i} \right)$	i=AG4	8
39.	$NE_i = rs_i \cdot ks \cdot ss_i \cdot ws \cdot ms \cdot \frac{NS_i}{bds \cdot 10 \cdot D_i} \cdot \left(cp_i - cpars_i \cdot exxs_i \cdot \frac{X_i}{kl_i} \right)$	i=tob	1
40.	$D_i = D_{i,t-1} - \frac{rs_i \cdot ks \cdot ss_i \cdot ws \cdot cpa_i}{bds \cdot 10}$	i=AG3	2
41.	$D_i = D_{i,t-1} - \frac{rs_i \cdot ks \cdot ss_i \cdot ws \cdot \left(cp_i - cpars_i \cdot exxs_i \cdot \frac{X_i}{KL_i} \right)}{bds \cdot 10}$	i=AG4	8
42.	$D_i = D_{i,t-1} - \frac{rs_i \cdot ks \cdot ss_i \cdot ws \cdot \left(cp_i - cpars_i \cdot exxs_i \cdot \frac{X_i}{kl_i} \right)}{bds \cdot 10}$	i=tob	1
		sum	66

List of variables and parameters

Endogenous variables

Economic model

CD	Private consumption of goods	22	J
DK	Real investment of good in industries	28	I1/I2
E	Exports from industries	13	EX
EXPEND	Total nominal private expenditure on consumption	1	
F	Use of fertilisers in agricultural industries	11	AG
GR	Government nominal net revenues	1	
JJ	Total nominal real investment expenditure	1	
KL	Units of homogeneous land	9	AG1
L	Use of labour	20	Z
M	Import of goods	11	IM
P	Producer price of composite deliveries	20	Z
PA	Use of pesticides in agricultural industries	11	AG
PC	Composite purchaser price	22	J
PD	Producers price on home-market deliveries	20	Z
PKL	Price of homogenous land in «cof» and «tob»	2	AG2
PRFT	Total nominal profits in the industries	20	Z
SGOV	Government nominal savings	1	
X	Units of production by industries	20	Z
XC	Units of composite purchaser good	22	J
XD	Units delivered to the home-market	20	Z
Y	Nominal private income	1	
		276	

Soil model

bbhat	Soil productivity parameter (here variable)	11	AG
D	Soil depth	11	AG
NE	Lost nitrogen due to erosion	11	AG
NR	Naturally mineralised nitrogen	11	AG
NRR	Nitrogen from roots and residues	11	AG
NS	Stock of nitrogen in Soil Organic Matter	11	AG
		66	

Parameters and exogenous variables

Economic model

α	Productivity of labour in production function
β	Productivity of real capital in production function
γ	Productivity of fertilisers in production functions for agricultural industries
χ	Productivity of pesticides in production functions for agricultural industries
μ	Productivity of homogenous land in production functions for agricultural industries
θ	Basic consumption in LES-functions
κ	Budget share of available expenditure after spending on basic consumption
τ	Substitution elasticity for consumption between imports and home produced goods
ρ	Transformation elasticity between exports and home marked deliveries in production
a	Units input of goods per unit output of goods in industries

bb	Calibration coefficient in non-agricultural industries
bbhat	Soil productivity parameter
c	Marginal propensity to consume
cs	Change in stocks
er	Currency exchange rate (T.sh./USD)
gc	Government real consumption
h	Export share parameter in the export/home-market transformation function
hh	Shift parameter in the export/home-market transformation function
imat	Each investment good's share of nominal expenditure on investment in industries
kshare	Each industry share of total nominal expenditure on investment
lan	Land resource rent share of total profits in agricultural industries
lg	Governmental use of labour
pkl	Price of homogeneous land in agricultural industries where use of land is endogenous
pe	Unit price to the producer for export goods
pm	Unit price of imports at the border
q	Import share parameter in the import/home-market substitution function
qq	Shift parameter in the import/home-market substitution function
sfor	Nominal financial transfers abroad (USD)
ta	Subsidy rate
td	Taxation rate on goods delivered to the home market
te	Taxation rate on goods for export
tech	Technological productivity parameter
tm	Taxation rate on imported goods
ty	Income taxation rate
w	Nominal wage

<u>Soil model</u>

λ	Percentage direct mineralization from roots and stover
a_0	Parameter in soil productivity index
a_1	Parameter in soil productivity index
b_0	Parameter in soil productivity index
b_1	Parameter in soil productivity index
bb	Calibration constants in the production function in the base year
bbnorms	Normalised calibration constant
bds	Soil density
cp	Vegetation cover function coefficient
cpa	Vegetation cover index
cpars	Vegetation cover function coefficient
crs	Nitrogen concentration in roots
exxs	Transfer parameter for crops from money to physical units
hs	Food's share of food and stover
ks	Erodability of the soil index
nas	Atmospheric nitrogen deposition
ncss	Nitrogen concentration in stover
phis	Transfer parameter for nitrogen from money to physical units)
ms	Nitrogen content in eroded soil
retain	Proportion of stover kept in soil
rns	Nitrogen mineralization from SON
rs	Climate and rainfall index
srs	Proportion food and stover to roots
ss	Slope index
ws	Depletion of eroded soil index

List of industries and goods

	J	Z	AG	AG1	AG2	AG3	AG4	AG5	IND	I1	I2	I3	IM	IM1	NIM	EX	NEX	CHEM
cot - cotton	X	X	X	X			X	X				X			X	X		
cof - coffee	X	X	X		X		X	X		X		X			X	X		
tea - tea	X	X	X	X		X		X		X		X			X	X		
tob - tobacco	X	X	X		X			X		X		X	X	X		X		
cah - cashew	X	X	X	X		X				X		X			X	X		
cas - cassava	X	X	X	X			X	X				X			X		X	
mai - maize	X	X	X	X			X	X		X		X			X		X	
ric - rice	X	X	X	X			X	X				X	X	X			X	
sor - sorghum	X	X	X	X			X	X				X			X		X	
bea - beans	X	X	X	X			X	X				X			X		X	
occ - other crops	X	X	X	X			X	X				X	X	X		X		
liv - livestock	X	X							X	X		X	X	X		X		
for - forestry	X	X							X	X		X	X	X		X		
foo - food	X	X							X	X		X	X	X		X		
tex - textiles	X	X							X	X		X	X	X		X		
oms - other manufacture	X	X							X	X	X		X	X		X		
con - construction	X	X							X	X	X				X		X	
ele - electricity	X	X							X	X		X			X		X	
tra - transport	X	X							X	X		X			X	X		
ops - other private services	X	X							X	X		X	X	X		X		
fer - fertilisers	X												X					X
pes - pesticides	X												X					X
SUM	22	20	11	9	2	2	8	10	9	14	2	18	11	9	11	13	7	2

J = goods
Z = industries
AG = agricultural industries
AG1 = agricultural with variable use of land
AG2 = agriculture with constant use of land
AG3 = agriculture with constant soil erosion
AG4 = agricultural with variable soil erosion
AG5 = agriculture with variable soil productivity
IND = production industries
I1 = capital utilising industries
I2 = capital producing industries
I3 = non-capital producing industries

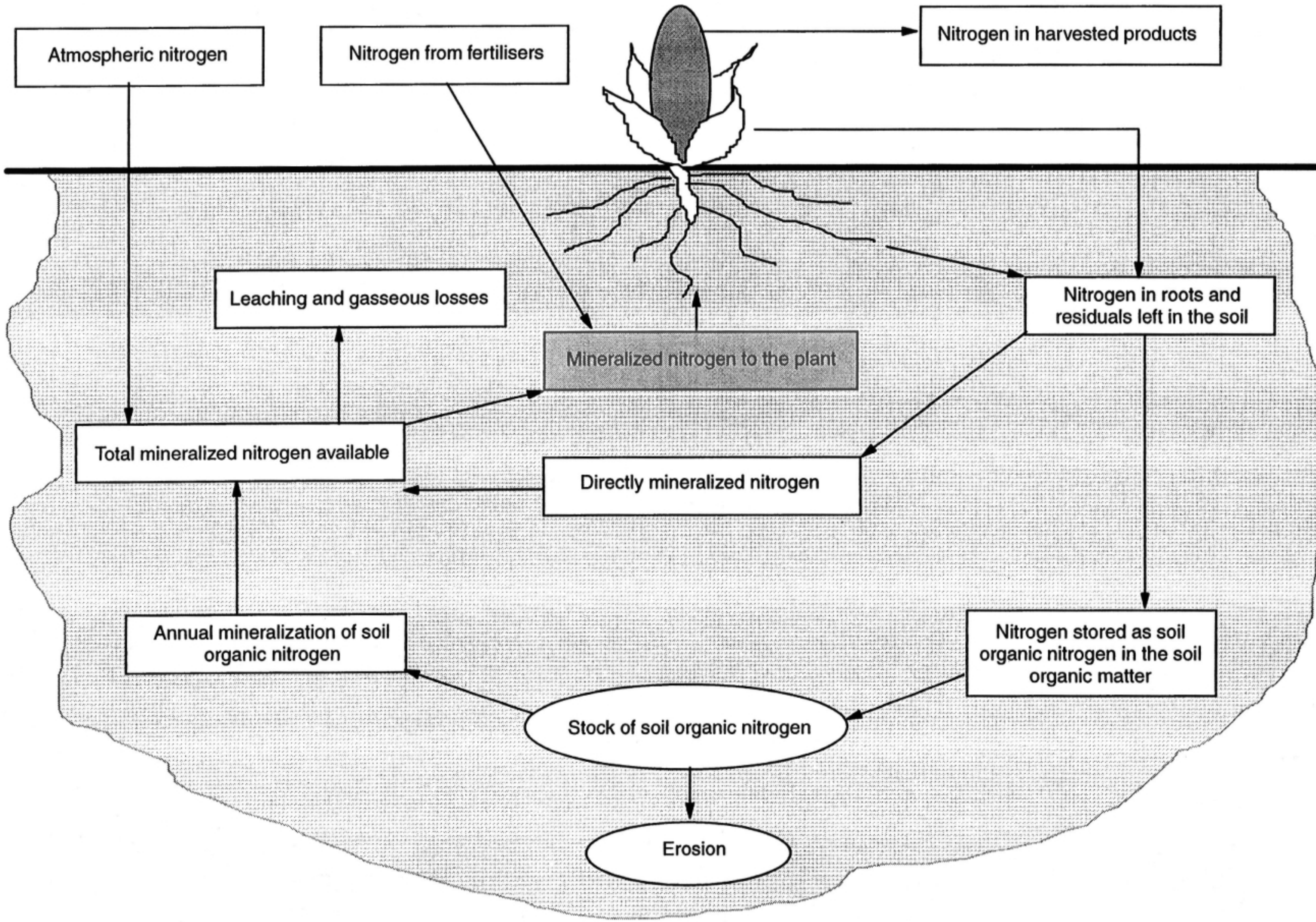
IM = imported goods
IM1 = imp. goods less agro-chemicals
NIM = non imported goods
EX = exporting industries
NEX = not exporting industries
CHEM = agrochemical goods

The Social Accounting Matrix (million T.sh.)

goods \ industries	GP	Imports	tax on imports	cot	cof	tea	tob	cah	cas	mai	ric	sor	bea	occ
cot	8208			687										
cof	10932				90									
tea	1530					185								
tob	1576	41					140							
cah	1674													
cas	9396													
mai	26895									2600				
ric	9139	551									612			
sor	4118											334		
bea	10579												1425	
occ	67404	5162	566											2059
liv	42560	1121												
for	17471	372												
foo	94634	3385	371											
tex	69057	6435	706	420	32		90	390	120	1170	450	180	90	90
oms	245147	209142	24106											
con	61757													
ele	7890													
tra	50725			632	175	7	90	20		2271	166	54	158	1000
ops	192367	16487	1809											
fer		3844		86	266	84	367			2801			240	
pes		5943		1173	3582			1188						
Sum	933059	252483	27558	2998	4145	276	687	1598	120	8842	1228	568	1913	3149
Operating surplus					133	165	14	17		953				
Compensation of employees				4755	3546	841	514	359	9276	18781	7911	3550	8810	64255
Indirect taxes on production				455	3108	248	361	-300		-1681			-144	
export tax				1094	5059	298	581	294						
sales tax														
fertiliser subsidies				-52	-160	-50	-220			-1681			-144	
pesticide subsidies				-587	-1791			-594						
Sum (GP)				8208	10932	1530	1576	1674	9396	26895	9139	4118	10579	67404

goods \ industries	liv	for	foo	tex	oms	con	ele	tra	ops	Priv. Invest.	Govern. consump.	Private consump.	Exports	Change in stocks
cot				5177									2344	
cof													10842	
tea			706										639	
tob			232										1245	
cah			564									480	630	
cas												9396		
mai			2516									21779		
ric			2221									6857		
sor			356									3428		
bea									380			8774		
occ			11091	7586	166				7313			36242	8675	
liv			516		1461				4585		290	35974	855	
for		125	108		1001	1174			7767		858	3394	3416	
foo	1537		5372		826				22695		214	83961	1168	-17383
tex	321	684	1464	4155	3033				451		295	39137	4439	19187
oms	751	393	7890	17122	83511	21270	1998	5314	18916	188618	5004	88058	9452	30098
con			68	23	1776	86	124	1287	5214	28785	424	23970		
ele			344	363	1774	40	60	111	1346		2752	1100		
tra		96	1155	274	5689	1328	160	741	8383		1915	12411	14000	
ops	1647	383	24185	16330	76403	10168	575	4628	28913		5751	19568	13522	8590
fer														
pes														
Sum	4256	1681	58788	51030	175640	34066	2917	12081	105963	217403	17503	394529	71227	40492
Operating surplus	1915	789	15568	7522	22729	6391	4439	31115	29163					
Compensation of employees	36389	15001	6173	2981	9012	21302	534	7529	57241		35133			
Indirect taxes on production			14105	7524	37766									
export tax														
sales tax			14105	7524	37766									
fertiliser subsidies														
.pesticide subsidies														
Sum (GP)	42560	17471	94634	69057	245147	61758	7890	50725	192367		52636			

Figure of the nitrogen cycle



Integrating the soil model in the CGE model

The point of departure is a Cobb-Douglas production function of the following form:

$$\frac{X}{KL} = bb' \cdot I_n \cdot \left(\frac{L}{KL}\right)^{\alpha} \cdot \left(\frac{kk}{KL}\right)^{\beta} \cdot \left(\frac{PA}{KL}\right)^{\chi}$$

where X is the crop output, KL is the homogeneous land input, kk is input of real capital and PA the input of pesticides. I_n is the soil productivity index of nitrogen content in the Tropical Soil Productivity Calculator (Aune, J. and R. Lal,1995).This soil productivity index varies for different crops (cashew has no limitation on nitrogen).

a) $\quad I_n^i = 1 - Q^i \cdot e^{q^i \cdot (NR^i + NF^i)}$ $\quad$ i = cot, cof, tob, ric, mai, sor,

b) $\quad I_n^i = q_1^i + q_2^i \cdot (NR^i + NF^i) + q_3^i \cdot (NR^i + NF^i)^2$ $\quad$ i = tea, cas, bea, occ

NR is the supply of mineralised nitrogen (kg./ha.) from natural processes and NF nitrogen from chemical fertilisers (kg./ha.). Before substituting this I_n function into the production function, we separate the effects coming from NR and NF by approximating the soil productivity indicator in the following manner:

$$I_n = (a_0 + a_1 \cdot NR) \cdot NF^{(b_0 + b_1 \cdot NR)}$$

where a's and b's are fixed coefficients. This function is then incorporated in the production function

$$\frac{X}{KL} = bb' \cdot (a_0 + a_1 \cdot NR) \cdot NF^{(b_0 + b_1 \cdot NR)} \cdot \left(\frac{L}{KL}\right)^{\alpha} \cdot \left(\frac{kk}{KL}\right)^{\beta} \cdot \left(\frac{PA}{KL}\right)^{\chi}$$

But the definition of fertiliser nitrogen use is kilogram per hectare and we utilise other measurements for both variables, i.e. homogeneous land (KL) and monetary units of fertilisers (F). So, we have to convert this by a transfer coefficient φ which reflects both the nitrogen content and units of land .

$$\varphi \cdot \frac{F}{KL} = NF$$

This is put in the production function, and we simplify further by assuming that the fertiliser dependent exponent is fairly stable over the relevant range of levels for our analysis, i.e.

$$b_0 + b_1 \cdot NR = \overline{b}$$

Hence,

$$\frac{X}{KL} = bb' \cdot (a_0 + a_1 \cdot NR) \cdot \varphi^{(b_0 + b_1 \cdot NR)} \cdot \left(\frac{L}{KL}\right)^{\alpha} \cdot \left(\frac{kk}{KL}\right)^{\beta} \cdot \left(\frac{PA}{KL}\right)^{\chi} \cdot \left(\frac{F}{KL}\right)^{\overline{b}}$$

We want to replace the technical productivity parameters (from the soil experiments) to be consistent with the use of fertilisers by profit-maximising farmers in the base year SAM, i.e. $\bar{b} = \gamma$ which is the input cost share.

Then we use the homogeneity of degree one assumption, i.e. $\mu = 1 - \alpha - \beta - \chi - \gamma$

$$X = bb' \cdot (a_0 + a_1 \cdot NR) \cdot \varphi^{(b_0 + b_1 \cdot NR)} \cdot L^{\alpha} \cdot kk^{\beta} \cdot PA^{\chi} \cdot F^{\gamma} \cdot KL^{\mu}$$

Then we want to normalise the parts dependent on nitrogen from natural processes

$$bb' = \frac{bb}{bbnorms}$$

bb is the calibration constant from the SAM and bbnorms $= (a_0 + a_1 \cdot NR_{1990}) \cdot \varphi^{(b_0 + b_1 \cdot NR_{1990})}$. Then the part of the production function dependent on the nitrogen from natural processes is reduced to the productivity parameter;

$$bbhat_t = bb \cdot \frac{(a_0 + a_1 \cdot NR_t) \cdot \varphi^{(b_0 + b_1 \cdot NR_t)}}{bbnorms}$$

and the production function

$$X = bbhat \cdot L^{\alpha} \cdot kk^{\beta} \cdot PA^{\chi} \cdot F^{\gamma} \cdot KL^{\mu}$$

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