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## **Maize Trade Liberalization vs. Fertilizer Subsidies in Tanzania: A CGE Model Analysis with Endogenous Soil Fertility**

**Abstract:**

This paper presents an analysis on economy-environmental interlinkages for Tanzania by using a computable general equilibrium (CGE) model based on a social accounting matrix. The purpose of the analysis is to include general equilibrium effects when evaluating two suggested policy measures meant to stimulate growth and crop production. The model is multisectoral with a particular focus on crop producing sectors and soil mining processes. Maize trade liberalization and a fertilizer subsidy are considered. The model simulations show that both policy reforms have expansive effects and that there are significant sectoral complementarities between agriculture and non-agriculture in Tanzania. Fertilizer subsidies promotes cash crop production and a more land intensive production pattern in agriculture, while a maize trade liberalization stimulates food crops and a more land extensive agriculture. Fertilizer subsidies are found to imply far more expansive effects than a trade liberalization does. Only minor differences are identified between the two policy reforms as concerning their impact on the balance of trade, distribution and the environment..

**Keywords:** CGE-model, soil fertility, trade reform, agricultural subsidy.

**JEL classification:** C68, Q18, Q24.

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# 1. Introduction

Various avenues for achieving economic growth in developing countries are discussed in the literature. Most of the strategies are linked to trade or to specific sectors in the economy. One controversy is whether to encourage export promotion or import substitution. Another issue is whether to promote an agriculture-oriented strategy rather than an industry-driven growth. Many studies find agriculture to be a neglected sector in developing countries, which could have an important role to play in development processes. One obvious reason is the believed gap between potential and actual performance in agricultural in developing countries. Another reason is the growth linkages agriculture may have with other sectors in the economy (see e.g. Singer 1982, Rao and Caballero, 1990). Hwa (1983) finds that countries with high agricultural growth also are likely to have high industrial growth as well.

Tanzania has undergone major changes and reforms the last 10 years, most of them are a direct consequence of structural adjustment programs. The purpose of these reforms has been to promote growth and development. The reforms have reduced governmental intervention and strengthened the role of the private sector. In spite of the liberalization of virtually every aspect of the economy, additional reforms are being considered. A recent discussion is about further reforms in the agricultural sector. So far the government of Tanzania has not promoted grain trade and exports are restricted and can only be conducted through licenses obtained from regional authorities. As a consequence there are suggestions that Tanzania should take advantage of its favored position for supplying maize to neighboring countries. A challenging reform also discussed in the literature is to introduce fertilizer subsidies, which may act as an important stimulus to agricultural production.

This paper analyses the consequences of both fertilizer subsidies and the liberalization of maize trade by applying a CGE model for Tanzania where economy-environmental interlinkages are taken into account. Soil fertility is specified as an endogenous production factor in agriculture and is a function of how available soil nitrogen develops over time. The purpose of this study is to trace the economic effects of the two policy reforms by including general equilibrium effects with respect to the economy as well as the environment. Soil degradation processes depend on crop patterns, cropping intensity and input use. The objective is to reach more accurate information about possible effects of the two suggested policy reforms when taking into account the indirect effects the agricultural sector has on the rest of the economy. Particular emphasis is given to differences across the two policy scenarios considered.

The incorporation of environmental considerations in CGE-models is a recent development in the literature. Several works have addressed the consequences on natural resources from policy changes by applying this methodology. Deforestation processes are studied in works on Nicaragua and Costa Rica (Glomsrød et al., 1997; Person and Munasinge, 1995). Unemo (1993) analyses overgrazing of rangelands in Botswana due to property right externalities. A study on soil erosion is undertaken for Nicaragua (Alfsen et al., 1996). In this study average annual soil losses per hectare are estimated on the basis of land use maps. Subjective soil expert assessments determine the relationships between soil- and productivity losses (exogenous relationships) which again are fed into the CGE model. Alfsen et al. (1997) and Aune et al. (1997) address soil mining processes when analyzing the consequences of structural adjustment programs for Ghana and Tanzania, respectively. In both studies, soil degradation processes are an integrated part of the model thus becoming endogenously determined. Changes in soil productivity are in both studies modeled as a negative Hicks-neutral technical change. Our model is an extension of Aune et al. (1997) and the revisions include a further disaggregation of agricultural production and an updating of the social accounting matrix for Tanzania from 1990 to 1995<sup>1</sup>. In addition the model is changed so that the sum of chemical fertilizers and natural soil nitrogen now become one single production factor (available nitrogen). As a consequence, natural nitrogen and nitrogen from chemical fertilizers become perfect substitutes in crop production in our model.

## **2. Fertilizer subsidies and trade liberalization**

Both from the Economic Recovery Program of 1986 and in the Economic and Social Action Program of 1989 it follows that the main objective with implemented agricultural reforms in Tanzania has been to increase both domestic production of food and exports. In spite of the reforms, average yields still remains low and is about a third of world average which indicates a potential for domestic production increases. During the 80-ies Tanzania was a net importer of maize, but the country has been self-sufficient in maize production from the late 80-ies. Exports of maize can only be conducted if export licenses from regional authorities are obtained. On the same time an illegal cross-border trade of maize is observed the last 5 years. Crude estimates suggest that about 5% of total domestic production are exported annually.

The reluctance to promote maize export as a means to stimulate agricultural production arises because of concerns of risking food security and food self-sufficiency rates. The consequence of export

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<sup>1</sup> Major revisions are undertaken in the national accounting for Tanzania the last 5 years. The SAM matrix for our model builds upon the most recent figures available.

barriers is most probably suppressed producer prices and thus cheaper food available to domestic consumers, in particular to landless and the urban sector. At the same time barriers to export act as a disincentive for agricultural producers. Putterman (1995) is of the opinion that Tanzania's aggregate grain output could expand if international markets were further exploited. If exports on grains were allowed and encouraged, one would under normal weather conditions expect grain prices to rise and agricultural input use to become more profitable. Tanzania should go ahead to follow strategies that takes advantage of its favored position for supplying food to landlocked countries in Eastern and Southern Africa. «There is an increasing recognition of the need to relax official constraints on grain-exports to neighboring countries» (World Bank, 1996, p. 15). Food security concerns can be met due to Tanzania's easy access to international supply sources in seasons when crop failures occur.

There are, however, views which challenge the above strategy. Coulter and Lele (1993) finds that barring grain exports remains appropriate for the medium term, and instead advocates a subsidy on fertilizers which is considered imperative if progress toward agricultural modernization is to be sustained in Tanzania. Similar suggestions for other African countries are found elsewhere in the literature. Lele et al. (1989) considers increased use of chemical fertilizers as a crucial ingredient in raising agricultural output. Rao and Caballero (1990), when discussing agricultural input subsidies, stresses the importance of focusing on fertilizers rather than labor saving inputs in order to achieve gains in terms of employment.

The application of fertilizers is considered to be much too low in Tanzania. Fertilizer recommendations advocate significant increases in fertilizer consumption and studies find that the potential yield of many crops can be increased two to four times by using higher levels combined with improved cultivation techniques (Putterman, 1995; Lal, 1993). The average fertilizer rate per hectare in Africa is about 20 kg per hectare, compared to 41kg in Latin America, 85 kg in Asia and 225 kg in Western Europe (FAO, 1996)<sup>2</sup>. The increasing awareness of soil mining processes which steadily reduce the natural productivity of soils in low-input agriculture has given renewed support to the subsidization of chemical fertilizers. Structural adjustments programs which over time have removed input subsidies are now being accused of neglecting both potential positive distributive- and environmental impacts. A higher fertilizer intensity can also arrest soil erosion processes by providing land with a better vegetation cover against erratic rain and a better root structure in this way reducing off-farm externalities associated with erosion (Aune et. al, 1997; Grepperud, 1996). An additional rationale for fertilizer

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<sup>2</sup> However a high potential yield does not imply that fertilizers are not perceived as costly from the farm managers point of view due to transport inefficiencies and credit market imperfections.

subsidies is the persistence of other market imperfections in developing countries like cash and credit constraints.

Holder and Shanmugaratam (1994) argues for agricultural production subsidies in combination with an increased use of soil conservation measures to promote both intensification and equity while conserving and enhancing soil capital. The role of fertilizer subsidies is also the focus of attention in the debate about high-input versus low-input strategies in LDC countries (see e.g. Reardon, 1989; Kesseba, 1989; Hansen, 1990). However, it seems that for some tropical soils there are no substitutes for chemical fertilizers like mulching, compost and manure (Lal, 1993; Repetto, 1987).

The two policy reforms discussed above both focus on the role of prices in order to achieve an agricultural push<sup>3</sup>. Input subsidies are clearly a direct price intervention while the promotion of free trade is of a more indirect measure, but both reforms can be viewed as short-term policy measures<sup>4</sup>. However, the two policy reforms differ with respect to the role of governments. Putterman's (1995) advice is neoclassical in that a further trade liberalization will reduce the role of governments (deregulation), thus representing a continuation of former reforms implemented in Tanzania. Lele and Coulter (1993), on the other hand, suggests a role for the government to play by intervening in the price formation of external inputs in agriculture. The reforms also diverge when it comes to consequences for governmental budgets. Input subsidies have a direct negative impact on budgets if not financed by external aid, while the same does not matter for the lifting of export regulations. The debate on input subsidies versus export promotion in Tanzania has similarities with discussions on whether to encourage output price or input subsidies for rice in Asia (see e.g. Barker and Hayami, 1976).

Both reforms have possible impacts on the most important asset in agricultural production; the stock of soil fertility. In a resource management perspective chemical fertilizer is a key input in tropical agriculture for offsetting both soil mining processes and erosion. Policies which affect maize production are also important, since maize is an erosive as well as nutrient-intensive crop. As a consequence, it is important to address environmental considerations when various agricultural policy reforms are analyzed.

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<sup>3</sup> To what degree agricultural outputs respond to prices changes have been given some attention in the literature. The overall price elasticity in agriculture is discussed in a.o. in Binswanger (1990) and Rao (1989).

<sup>4</sup> Rao and Caballero (1990), when discussing profitability in agriculture, prefer policies to keep high output prices instead of input subsidies.

### **3. Changes and challenges in the economy of Tanzania.**

Agriculture accounts for more than half of Gross Domestic Product (GDP) in Tanzania and is the crucial source of employment - about 80 percent of the population works in this sector. There are about 3.5 million farmers in Tanzania cultivating more than 4 million hectares of land. In addition more than 1 million hectares are occupied by about 700 larger farms mainly owned and operated by parastatals. Agricultural exports are lower now than in the 1970s, and agricultural productivity is lower than the LDC average. The unemployment rate in Tanzania in 1996 is estimated to be about 11 percent (World Bank, 1996).

In the first years following the 1961 independence, agricultural output expanded rapidly in Tanzania. Input delivery and marketing systems were well functioning and world market prices were favorable (World Bank, 1991). The economic policy in this period was a continuation of pre-colonial policies. In the end of the 60-ies the country embarked on a socialization path including wide-range nationalization and an increasing governmental control over prices and markets. In the late 70-ies severe problems showed up in terms up economic stagnation, the deterioration of physical infrastructure, and an increasingly overvalued exchange rate. Agricultural growth averaged only 1 percent a year from 1976 to 1985, while agricultural exports were reduced by 50 percent in the same period (World Bank, 1991).

From 1985 an economic recovery program was launched. A key objective was to stimulate agriculture by increasing producer incentives by liberalizing agricultural markets. The program also emphasized the need for structural reforms in the financial sector, the reorganization of parastatals, and in the system of public administration. A number of governmental restrictions have been phased out since the mid 80-ies including a gradual elimination of price controls on input, outputs, credits, exchange rate and quantitative import controls. Input subsidies have been removed together with restrictions on traditional exports and the retention of export receipts (World Bank, 1996). More responsibility is given to the private sector both on the production side as well as on the marketing side. Today a multi-channel marketing system exists where private traders operate alongside with governmental agencies. Reforms still in progress include a simplification of the tax structure, further privatization and liquidation of parastatals, and the promotion of private banking.

The annual growth rate in agriculture was about 5 % from 1991 to 1994, while real export growth in agriculture averaged about 4 to 5 percent a year during the same period<sup>5</sup>. The real exchange rate experienced a substantial depreciation since the mid-1980s but has been more or less stable since 1993 (MOF,1996)<sup>6</sup>. Many reforms still remain to be implemented especially in fiscal management, in the banking sector, and in public administration. Debt overhang also represents a problem and the total external debt is equivalent to 200 percent of GDP, and debt service would absorb about half of the export earnings under existing terms. Another challenge is to undertake an effective tax reform in order to raise revenues which falls short of governmental expenditures.

Tanzania is still in a transitional phase and in spite of many important reforms dating back to the 80-ies, it will take time before their full effect is visible. Structural constraints are still effective partly due to a weak banking sector. It is reason to believe that restrictions on the supply side have been as important as prices as concerning modern input consumption in agriculture the last 10 years. In spite of an increasing number of private stockists and marketing agents the last few years, there are still inefficiencies in the marketing system. This matters in particular for modern inputs like fertilizers and pesticides which have to be distributed over long distances. In some sectors there is still a mismatch between capacity and actual output<sup>7</sup>. An important example is the textile industry where capacity utilization is quite low and the activity demand driven.

Agriculture is closely linked to the management of environmental resources in developing countries. Tanzania, as most Sub-Saharan countries, is believed to face an increasing pressure on environmental resources, in spite of Tanzania being a nation with rich resource endowments in relation to population size. The problems gaining most attention are deforestation, soil erosion, and soil mining processes, all believed to be strongly connected to agricultural production decisions. Deforestation is believed to happen because of expanding agricultural frontiers, but also due to fuel wood extraction. Reliable figures on deforestation, however, are not available. One report suggests a figure for deforestation equal to 520.000 hectares per year with about half of this being regenerated (Kulinda and Schechambo, 1994). Mayawalla (1996) reports deforestation to be 130.000 hectares per year. Soil erosion is considered a significant problem only in specific areas like the Kondo region, where losses of productive soils ranges from 1-2 mm per year and is the result of overgrazing and the cultivation of hillsides (Mbegu, 1994). An increasing number of studies mention soil mining as the most severe

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<sup>5</sup> There is considerable uncertainty associated with these figures. Weaknesses about the National Accounts of Tanzania are discussed in Bagachwa and Naho (1995).

<sup>6</sup> However, other sources observe an appreciation in Tanzania since 1993.



environmental problem in southern Africa (see e.g. Stoorvogel and Smaling, 1990). Soil nitrogen is the limiting factor and is rapidly being harvested. Tanzania, as well as some other sub-Saharan countries, is believed to move along a path of declining soil fertility, due to losses in nutrients which are not fully replaced by external sources of nutrients like chemical fertilizers. Such a development may constitute a future hindrance for a rapid increase in agricultural production.

## **4. The model**

The CGE model applied in this paper consists of two submodels, an economic model and a soil model, which are integrated. The model (s) is static and as similar models it can be thought of as a medium-term model reflecting the time it takes for all markets to reach a new equilibrium, but before major dynamic effects can take place. The model differs from "standard" CGE models in that agriculture is disaggregated into many sectors (12 crop producing sectors) and since soil fertility is modeled as an endogenous variable<sup>8</sup>.

### *Economic model*

In the economic submodel, producers are profit maximizers and choose their levels of production and purchase their inputs on the basis of prices. On the supply side they decide whether to sell on the domestic market and/or to export on the basis of relative prices. Domestic products and imports are imperfect substitutes and their demand composition depends on their relative prices. Households maximize utility and choose their levels of consumption based on income and prices. In addition some behavior in the model are not price responsive like public consumption and public employment.

The economic model consists of 21 products and 23 goods in which sectors and goods coincide with the exception of two variable inputs; fertilizer and pesticides. Both fertilizers and pesticides are imported and fertilizers are applied in the six most important agricultural crop producing sectors (coffee, cotton, tea, tobacco, maize and beans) while pesticides are applied in the production of cotton, coffee and cashew. Other agricultural production factors are labor, capital, and land. In addition to the 7 crop producing sectors already mentioned, banana, cassava, rice, other cereals, and other crops are specified in the model. Additional production sectors are livestock, forestry, food, textiles, electricity, transport and communication, construction, other manufacture, and other private services.

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<sup>7</sup> Supply constraints in Tanzania during the 70- and 80-ies are discussed in Lipumba et al. (1988) and Ndulu (1986).

<sup>8</sup> See Appendix for a full description of the model.

Table 1 provides information on the assumptions made about the crop-producing sectors. It follows that 7 sectors are exporting while 3 are importing. The production factor elasticities vary to some extent across sectors but labor is the most significant in all agricultural sectors<sup>9</sup>. It is further noticed that for all food crops sectors, except maize, no real capital is present in production.

**Table 1. Technical assumptions about crop producing sectors.**

Agricultural sectors	Ex- port crop	Im- port crop	Elasticities						
			Area	Capital	Labor	Nitro- gen	Pesti- cides	Export <sup>a</sup>	Import <sup>b</sup>
<i>Cash crops</i>									
- Cotton	X		<b>0.011</b>	-	<b>0.86</b>	<b>0.08<sup>d</sup></b>	<b>0.05</b>	0.9	-
- Coffee	X		<b>0.005</b>	<b>0.03</b>	<b>0.67</b>	<b>0.15<sup>d</sup></b>	<b>0.14</b>	0.9	-
- Tea	X		<b>0.002</b>	<b>0.11</b>	<b>0.80</b>	<b>0.09<sup>d</sup></b>	-	0.9	-
- Tobacco	X	X	<b>0.003</b>	<b>0.03</b>	<b>0.61</b>	<b>0.35<sup>d</sup></b>	-	0.3	0.9
- Cashew	X		<b>0.008</b>	<b>0.04</b>	<b>0.81</b>	<b>0.10</b>	<b>0.04</b>	0.9	-
<i>Food crops</i>									
- Maize	(X) <sup>c</sup>		<b>0.007</b>	<b>0.03</b>	<b>0.75</b>	<b>0.21<sup>d</sup></b>	-	0.9	-
- Rice		X	<b>0.002</b>	-	<b>0.96</b>	<b>0.04</b>	-	-	0.9
- Other crops	X	X	<b>0.004</b>	-	<b>0.95</b>	<b>0.04</b>	-	0.9	0.9
- Bananas			<b>0.002</b>	-	<b>0.98</b>	<b>0.02</b>	-	-	-
- Cassava			<b>0.010</b>	-	<b>0.93</b>	<b>0.06</b>	-	-	-
- Other Cereals			<b>0.006</b>	-	<b>0.95</b>	<b>0.04</b>	-	-	-
- Beans			<b>0.005</b>	-	<b>0.88</b>	<b>0.12<sup>d</sup></b>	-	-	-

a) Elasticity of export substitution

b) Elasticity of import transformation

c) The parenthesis is to reflect that Maize becomes an export crop after liberalisation.

d) Crop producing sectors which apply chemical fertilizers.

The production function in all sectors are Cobb-Douglas, as a consequence the technology is quite flexible and the elasticities in the production functions presented in Table 1 are calculated on the basis of cost shares in the base year 1995. The elasticity of nitrogen for each sector is calculated in a way that deserves some more explanation. First, the average quantity of natural nitrogen for each crop is estimated on the basis of Tanzanian field studies. Second, the unit value of natural nitrogen is assumed to equal the market price of a unit of nitrogen from chemical fertilizers. The value of natural nitrogen

<sup>9</sup> All elasticities in the production functions are calibrated to reproduce the base year figures while export and import elasticities are based on figures from other studies.

can now easily be derived so that cost shares are arrived at<sup>10</sup>. The cost share of land area is now derived by subtracting the value of natural nitrogen from the land rent. The land rent again is derived by attributing a certain part of the gross profits in agricultural industries to land. It follows from table 1 that the elasticities of land area in general is lower than the elasticities of nitrogen, which support opinions of nitrogen rather than land area being the scarce production factor in Tanzanian agriculture.

On the consumer side a Stone-Geary utility function is assumed which yields a linear expenditure system (LES) with a minimum basic consumption. The coefficients are calibrated from the SAM. The model allocates sectoral domestic output to domestic demand and exports, and divides domestic demand between domestic production and imports. The elasticities of export substitutions (CES) in exporting sectors and the elasticities of import transformation (CET) for importing sectors are all assumed constant and equal to 0.9 (low to medium substitutability). The only exception matters for tobacco where it equals 0.3 (low substitutability). The elasticities of substitution of production goods are in general lower (0.3) than those of consumption goods<sup>11</sup>.

In addition the model contains some structuralist features to reflect some rigidities still present in the Tanzanian economy. All resources are not fully utilized since labor is not fully employed and nominal wages are assumed to be fixed. An infinite elastic supply at a given wage rate seems more appropriate than a neo-classical clearing of the market<sup>12</sup>. It is chosen not to distinguish between skilled and unskilled labor. There is no explicit investment behavior in the model, capital is allocated in fixed proportions according to the base-year. Such an exogenous investment allocation rule is common in CGE-modeling (see e.g. de Janvry and Sadoulet, 1987; Robinson, 1989). Dynamic scenarios consist of year-by-year sequences of static equilibria based on the updating of the capital stock from the investment allocation rule. The model use a savings function specified by a constant savings ratio and the closure rule of the model is standard since total investment is determined by total savings.<sup>13</sup> Other features of the model are an endogenous deficit of current account and an exogenous exchange rate which is to reflect a dirty float exchange rate management system.

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<sup>10</sup> For agricultural sectors which apply chemical fertilizers, the value of fertilizer consumption is added with the value of natural nitrogen in order to arrive at elasticities for nitrogen. As a consequence institutional obstacles to fertilizer consumption in Tanzania is reflected in the magnitude of the elasticity of nitrogen.

<sup>11</sup> Estimated price elasticities of supply in Tanzanian agriculture is presented in Mshomba (1989) and Dercon (1993).

<sup>12</sup> A labour market with such features is often assumed to reflect the presence of short-run institutional constraints.

<sup>13</sup> Some CGE models assume different closure rules. Investments can be determined by other factors than savings or assumed exogenous due to an active participation of the state in the investment program.

Private income is composed of wage earnings and profits in the private sectors. A constant share of private income is saved. Public saving is the sum of total tax income and public profits less exogenous expenditures. Total savings determine together with exogenous foreign borrowing the level of investments, which again is allocated across sectors according to base-year coefficients. A crucial factor behind economic growth in this model is the assumptions made about technological change. Technological change is assumed to be Hicks-neutral and equals 0.5 % annually for all industries.

### *Soil model*

The soil model draws upon a work by Aune and Lal (1995) in which a tropical soil productivity calculator for Tanzania is developed. In this work nitrogen constitutes the main limiting factor for soil fertility in Tanzanian agriculture, and the calculator describes soil nitrogen cycles. This framework is adopted into the CGE model. Average agricultural output per hectare and soil fertility (represented by available nitrogen) is the two variables, which link the two submodels. Soil fertility (soil nitrogen) is an input in every agricultural crop-sector and is a function of both the quantity of nitrogen coming from the use of chemical fertilizers and natural soil nitrogen.

The natural nitrogen available for crop production in any year is a function of three processes of which the first is an exogenous source following from atmospheric nitrogen from rainwater<sup>14</sup>. The two endogenous and most important sources of mineralized nitrogen are i) the decomposition of crop residues and ii) the stock of soil organic matter. Crop residues are left on the field after harvesting to decompose, and they represent a future source of nitrogen. This supply is assumed to extend over three crop seasons, and the process starts two years after residues are left in the soil.

The quantity of soil nitrogen available from crop residues will now depend positively on output per hectare in each sector, since higher outputs imply more crop residues and thus a higher future supply of nitrogen. As concerning available nitrogen from the stock of soil organic matter the relationships are somewhat more complex. The stock of nitrogen present in the soil releases a certain percentage mineralized nitrogen available to crops every year. In addition a share of annual crop residues also adds to the stock of soil organic matter while some nitrogen present in the soil organic matter are lost every year due to leaching and soil erosion (the removal of top soil layer). As with nitrogen from crop residues, also the stock of soil organic matter will depend on output per hectare due to its linkages with crop residues.

The use of chemical fertilizers has an immediate effect and a long-term effect on soil fertility in the model. First, agricultural production will immediately increase with more nitrogen from fertilizer use. Second, this increase in production will again raise the quantity of crop residues, in this way providing soils with additional nutrients in future periods. Higher outputs in the model will also affect soil erosion since more output per hectare provides soils with a better cover against erratic attacks from wind and rain and a better root structure which also protects the soil (cover factor). The soil calculator, however, is not able to incorporate all factors which may influence soil depth changes such as cultivation timing decisions, plowing techniques and the use of soil conservation measures - all factors which may change in response to increased profitability (see Grepperud, 1997). As a consequence, erosion in our model must be viewed as a net effect arising from cover effects, only. As follows from the above presentation, the model considers chemical fertilizers and soil nitrogen as perfect substitutes in crop production.

Soil-nutrient cycles are modeled for each of the 12 crop-producing sectors. The parameter values are taken from Aune and Lal (1995) and are in general based upon field studies in Tanzania and reflect that different crops have different impacts on soil mining- and soil erosion processes. Perennials like coffee, for example, are less erosive than annual crops like maize. As concerning cashew soil fertility is assumed to be exogenous and constant since phosphorous, and not nitrogen, is considered to be the limiting nutrient for this crop and since cover effects are absent. It also assumed that soil erosion does not depend on outputs in tea production (no cover effect).

Land area devoted to each agricultural crop is endogenous for all crops except coffee and tobacco in the economic model. It is furthermore assumed that land already cultivated is the most fertile<sup>15</sup>. Since crops differ with respect to their effects on soil-mining processes, changes in crop patterns will have consequences for soil-nitrogen cycles in this model. The dynamic of the soil model consists of year by year sequences of static equilibria based on the updating of the stock of soil organic matter and soil depth.

## **5. Policy simulation results**

In this section the consequences of the two policy reforms are presented. The endogenous variables, which are focused upon, are production figures, input use, trade, indicators of self-sufficiency, and

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<sup>14</sup> By natural soil nitrogen is meant mineralised nitrogen which is available for plants.

<sup>15</sup> Which is a fairly good description of Tanzanian agriculture, with the exception of some areas in the southern highlands.

variables which can tell about environmental changes. The effects from the two reforms are not quantitatively comparable since they do not have the same budgetary costs. Subsidies need to be financed while a trade reform does not. As a consequence the focus in this paper is mainly on relative changes rather than comparing the magnitude of various effects across the two reforms.

The two scenarios will be contrasted to a reference scenario. In Table 2 the time development for some important figures along the reference scenario is presented. The base year of the model is 1995, when the agricultural sector (all crop producing sectors) constitutes 36% of GDP, while non-agricultural sectors represent the residual. Non-agriculture includes food processing and animal production in addition to industry and services. Cash crops and food crops represent respectively 17% and 83% of agricultural GDP, but cash crops represent a high share of the total export value. Maize is the single most important agricultural crop representing about 22% of total agricultural production. Along the reference scenario the share of agricultural to total production (in constant prices) is gradually reduced. The annual growth rate in the economy in 1996 is about 5% and declines over time. As seen from Table 2, the average annual growth rate from 1995-2000 is 3.8%, while the same rate the next 10 years is below 2%. One reason for this decline is that fertilizer consumption is not growing rapid enough to prevent the average soil productivity (available nitrogen) from declining along the reference scenario.

In scenario A we analyze the consequences of introducing fertilizers subsidies from 1996 and throughout the model horizon. For the time being there is no domestic production of chemical fertilizers in Tanzania, thus all fertilizers are imports. Most imports in Tanzania are levied import-taxes, as a consequence a subsidization of fertilizers can easily be introduced in the model by lowering the import-tax rate on fertilizers. We have reduced the tax-rate on the value of imported fertilizers from 15% to 7%. Such a reduction will, *ceteris paribus*, reduce total import-tax revenues in 1996 with more than 3%.

In scenario B a trade liberalization of the most important crop in Tanzania, maize, is introduced. A barring of export in the model means that maize exports are exogenous and equal to zero (non-traded good). Due to observations about illegal exports of maize amounting to about 5% of total domestic production annually the last few years, we have in the reference scenario chosen to calibrate an export price on maize which generates this export share under the assumption of the elasticity of export transformation being low (0.3%). Estimates on unrecorded cross-border trade from Tanzania are found in Ackelloa and Echessah (1997) and MOA/SUA (1997). Furthermore, it is assumed that the export-

tax rate of maize is zero. A trade liberalization in the model can now be interpreted as a positive shift in the export price together with a higher elasticity of export transformation and the introduction of a positive export-tax rate. Both the elasticity and the tax-rate are approximately set equal to the ones that matter for traditional Tanzanian exports crops. It is, however, difficult to find a reliable estimate for the average increase in the export-price of maize due to a trade liberalization. We know that the regulation on domestic food grains (distribution and trading) in Tanzania was lifted in 1987. In 1990 the government decontrolled producer prices for all food crops which implied that also cereals prices became indicative for the first time. However, some information on producer price differentials on maize between Tanzania and Kenya is available in Lele et al. (1989). Applying purchasing power parities, producer prices were found to be 50-100% higher in Kenya in the period 1983-87. Figures for the time period after the reforms of 1987 and 1990 were not available, but the observed cross border trade do suggests price-differentials. In this analysis it is assumed that the export price will increase by 20% as a consequence of the lifting of the barriers to maize export.

**Table 2. Reference scenario. Average annual growth. 1995 to 2000 and 2001 to 2010.**

<b>Activities</b>	<b>Reference 1995-2000</b>	<b>Reference 2001-2010</b>
<b><i>GDP</i></b>	3.8	1.8
- Agriculture	1.8	0.8
- Non agriculture	5.3	2.5
<b><i>Input use</i></b>		
- Labor	1.3	0.4
- Fertilizer	4.6	2.5
- Land use	3.2	2.4
<b><i>Trade</i></b>		
- Export	6.6	2.7
- Import	2.7	1.3

As seen from the above scenario definitions, both policy reforms are interpreted as short-term strategies. No governmental long-term investments are assumed necessary to support the policy reforms. Most likely the success of both policies will also depend on future investments in transport and marketing. In the 80-is the supply of modern inputs in Tanzania was mainly conducted by the government via parastatals. During this period bottlenecks on the supply side were more decisive for fertilizer consumption than prices. The situation has changed gradually the last 5 years due to privatization, especially in the southern highlands, but there is still a way to go.

Before we present the main results arrived at from the policy simulations, we will contrast the economic development in the reference scenario with the same scenario now without the soil submodel. A simulation without the soil submodel implies that natural soil fertility becomes a constant in agricultural production functions. From Figure 1 it is observed that the removal of the soil model implies a higher GDP in constant prices over time. After 18 years (2013) the GDP level is 2% percent higher than GDP in the reference scenario with a soil model. The presence of the soil model illustrates that fertilizer consumption in this scenario is not sufficient to prevent soil fertility from declining over time. As a consequence we are in a situation in which the agricultural sectors harvest soil nutrients at a higher rate than their replacement.

Whether or not the soil model is included has consequences for all endogenous variables in the model. Both fertilizer- and land use, for example, are significantly higher in the scenario with a soil model than without. In Figure 2 the development in fertilizer consumption across the two scenarios is compared. In year 2010 fertilizer consumption is about 30% higher with an endogenous soil fertility compared to the model with an exogenous one. The increased use of inputs contributes to a dampening of the GDP losses illustrated in Figure 1. If land use and fertilizer consumption remained equal across the two scenarios the GDP loss would be substantially higher.

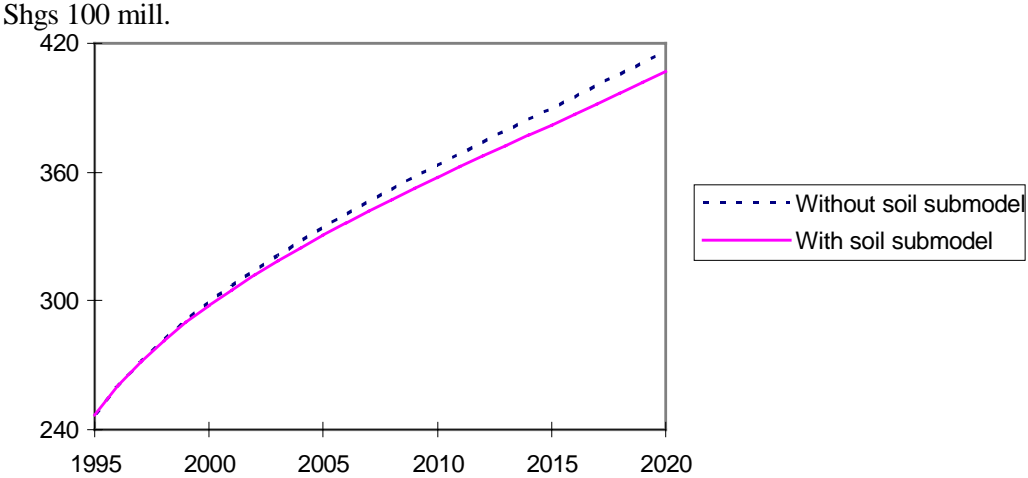
Table 3 presents the main results from the two policy simulations. First, it is observed that both policies produce changes as compared to the reference scenario. Second, the economic impacts which arise from a fertilizer subsidy are in general much more significant than those which follow from a maize trade liberalisation. The increase in economic activity as measured by GDP in constant prices is between 4-5 times stronger in percentage points for the fertilizer subsidy than for the maize liberalisation. A fertilizer subsidy (scenario A) increases the GDP level in year 2000 and year 2010 by 5.3% and 7.2% as compared to the reference scenario. The increase in GDP level, which follows from the maize-trade liberalization (scenario B) at the same two dates, are only 1.2% and 1.5%, respectively. Part of the explanation for the difference in impact between the two scenarios is probably that an input support have a direct effect in most crop producing sectors, while the trade liberalisation has a direct beneficial effect on maize producers only<sup>16</sup>. An additional observation is that fertilizer subsidies tend to strengthen the agricultural sector relatively more than the non-agricultural sector. The opposite tendency seems to matter for a maize trade liberalisation. Hence, the maize producing sector in Tanzania seems too have strong non-agricultural complementarities.

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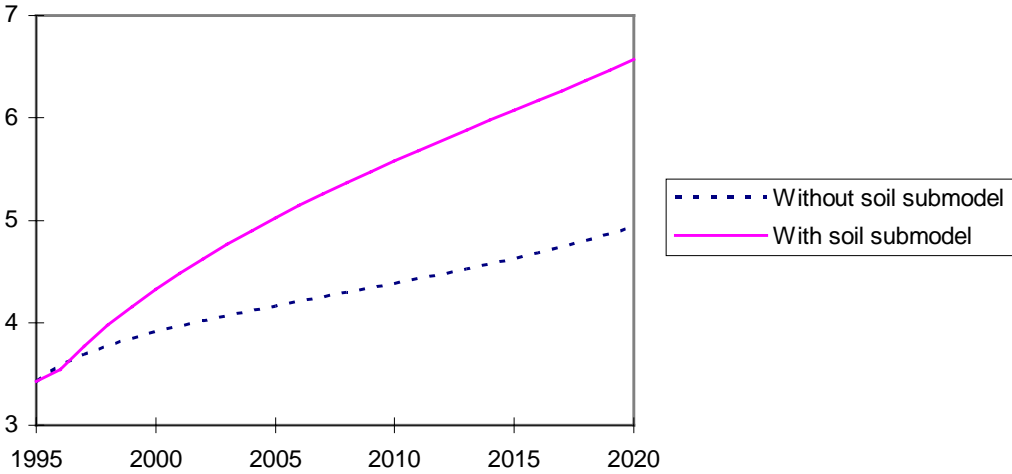
<sup>16</sup> The effects arising from a maize trade liberalisation turned out to be quite sensitive to upwards adjustments of the elasticity of export transformation for maize.



**Figure 1. GDP at constant 1995 prices. Reference scenario with and without soil submodel.**



**Figure 2. Fertilizer consumption at constant 1995 prices. Reference scenario with and without soilmodel.**



**Table 3. Simulation results. Percentage deviation from the reference scenario in year 2000 and 2010.**

<b>Activities</b>	<b>Fertilizer subsidies</b>	<b>Fertilizer subsidies</b>	<b>Maize trade liberalisation</b>	<b>Maize trade liberalisation</b>
	<b>(A)</b>	<b>(A)</b>	<b>(B)</b>	<b>(B)</b>
	<b>2000</b>	<b>2010</b>	<b>2000</b>	<b>2010</b>
<b><i>GDP</i></b>	5.3 %	7.2 %	1.2 %	1.5 %
- Agriculture	5.7 %	7.9 %	1.0 %	1.3 %
- Non agriculture	5.0 %	6.7 %	1.3 %	1.6 %
<b><i>Input use</i></b>				
- Labor	5.6 %	7.6 %	1.3 %	1.6 %
- Fertilizer	21.3 %	23.8 %	2.0 %	2.4 %
- Land use	2.4 %	3.3 %	1.4 %	1.9 %
<b><i>Trade</i></b>				
- Export	11.9 %	14.2 %	1.7 %	2.0 %
- Import	5.7 %	7.5 %	1.2 %	1.5 %
<i>Governmental revenue</i>	5.2%	6.8%	1.6 %	1.9 %
<b><i>Sufficiency indicators</i></b>				
- Consumer price of maize	- 0.4 %	-1.5 %	- 0.3 %	-1.4 %
-Maize consumption	2.0 %	2.9 %	0.9 %	1.1 %
-Ratio of home production to consumption <sup>a</sup> .	0.0%	- 0.02 %	0.0 %	-0.02 %
<b><i>Environmental variables</i></b>				
- Soil depth (cm)	0.0%	0.0%	0.0%	0.0%
- Nitrogen <sup>b</sup>	7.0 %	7.4 %	- 0.1 %	-0.1 %

a) This ratio is calculated only for food crops which are both imported and consumed at home.

The consequences on input use vary much across the two policy reforms. As expected, the application of fertilizers, increases much more in scenario A than is the case for scenario B. This conclusion is also valid if compare the changes for each scenario with the percentage changes which are experienced for agricultural GDP. The increase in percentage points as concerning fertilizer subsidies is significantly higher than the increase in percentage points for agricultural production, while the same difference is much smaller for maize liberalisation. The total use of labor in the economy increases more or less proportionally to changes in the economic activity (GDP) for both scenarios. The most striking difference across the two scenarios is the development in land use. We do not observe any

significant difference in percentage points as concerning land use changes across the two scenarios. However, compared with agricultural GDP growth the two scenarios differ with respect to land use. The trade reform speeds up the rate at which new lands are devoted to crop production in spite of a relatively weak impact on production in agriculture. For a fertilizer subsidy, the opposite tendency is observed.

Both policy reforms seem at first sight to improve the balance of trade since imports increase less than exports in relative terms. In absolute terms, however, the trade balance remains more or less unchanged for both scenarios. A fertilizer subsidy in scenario A increases the export of all traditional cash crops like coffee, tea, and tobacco as well as the imports of modern inputs (fertilizer and pesticides). The share of fertilizer import to total imports in this scenario is 18% in year 2010, while the same ratio in scenario B is 4%. The export of maize, however, is 25% higher in scenario B in year 2000 as compared to the baseline scenario. Imports to all sectors increase more or less proportional to output in most sectors for both scenarios.

The expansive effects, which are presented in Table 3, in particular for a fertilizer subsidy, is a consequence of several effects. One effect is that a fertilizer subsidy will increase the profitability in agriculture. Higher profitability raise private incomes and increase the overall activity in the economy which again have consequences for exports and imports. All such changes will, *ceteris paribus*, increase both public revenues and savings. Due to the closure rule of the model, more savings raise investments in all sectors of the economy. The assumptions made about the labor market and the cost free access to additional agricultural lands in the model reinforce the expansive effects from the policy reforms. In addition the use of Cobb-Douglas production functions implies a flexible technology in all sectors.

However, one would expect that fertilizer subsidies (a lowering of the tax-import rate) also would introduce contractive effects due to lower import tax revenues. However, from table 3 we see that this is not the situation. The immediate decline in revenues which follows from the tax-rate reduction is in fact offset via increased fertilizer imports<sup>17</sup>. Even more important is probably the fact that a reduction of the import-tax on fertilizers reduces efficiency losses associated with import-taxation. Such effects appear since a fertilizer subsidy is interpreted as a lowering of the import-tax on fertilizer.

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<sup>17</sup> The most important source to higher governmental revenues given a maize trade liberalisation are production tax- and export tax revenues on maize.

We have also studied the results from the two policy reforms in a model version where the soil model is absent, to see whether the incorporation of soil-nutrient cycles in our analysis has consequences for the results arrived at. A first conclusion is that all expansive effects are weakened for both policy scenarios when the soil model is absent. Soil-nutrient cycles make agricultural policy reforms more expansive. This result follows from agricultural outputs being strictly concave in available nitrogen. In a model with declining soil nitrogen, the marginal productivity of additional soil nitrogen will be higher than for models where soil fertility is constant. As a consequence, agricultural reforms may have a stronger and more prevalent expansive effects. A second conclusion is that the relative relationship between the two policy reforms also change when the soil model is disregarded. A fertilizer subsidy becomes less advantageous compared to a maize trade liberalisation when soil-nutrient cycles are not considered. However, the expansive effects as concerning production and input use are still significantly higher for a fertilizer subsidy than for a maize trade liberalisation.

As mentioned above, one reason for not promoting maize trade in Tanzania has been concerns about food security and food self-sufficiency. In spite of income classes being absent in our model, some information on possible distributive consequences can be derived by looking at production and consumption of the most important staple crop, maize, in Tanzania. The consumption of maize increases in both policy scenarios as compared to the reference scenario, but is somewhat more significant given a fertilizer subsidy (scenario A). In Table 3 the development in the ratio of domestic production to domestic consumption for food crops (all being both imported and produced domestically) is presented. It follows that the ratios do not change much in either policy reform as compared to the reference scenario.

Fertilizer subsidies are often accused of having negative distributive consequences since cash crop production is a fertilizer-intensive activity and is believed to be conducted by well-endowed farmers. However, household surveys on fertilizer consumption patterns in Tanzania does not support such views. Forty percent of farmers above the poverty line while 30 percent of those below the poverty line use chemical fertilizers (NSCA, 1996). «The distribution of all farmers who use fertilizer is heavily weighted towards the smaller holdings» (World Bank, 1994, p.75). A reason for this observation is probably that the Tanzanian government the last decades has given priority to fertilizer consumption in the maize production sector and in particular to the maize regions in the southern highlands. In spite of the dual character of Tanzanian agriculture a fertilizer subsidy need not discriminate smallholders at the expense of cash crop producing estates.

The effects on the environment from the two policies differ to some extent. Natural soil nitrogen (available nitrogen per hectare of cultivated land from other sources than chemical fertilizers) increases strongly compared to the reference scenario for scenario A (fertilizer subsidy), while a small decline is observed for scenario B (trade liberalization). The increase, which is, observed for scenario A follows from the strengthening of soil-nutrient cycles due to higher fertilizer consumption. More nutrients are now recycled to the soil over time since fertilizer application produces a higher amount of crop residues. As concerning soil erosion (remaining top soil depth) there are no detectable differences compared to the reference scenario. There are probably several reasons for this finding. Most of the agricultural production in Tanzania has so far occurred on flat lands where erosion is less a problem. As a consequence, the parameters applied in the soil submodel, which describe relationships between crop production and erosion (cover effects), are low.

**Table 4. Simulation results. Percentage deviation in agricultural production across sectors from reference scenario in year 2000 and year 2010.**

	<b>Fertilizer subsidies(A) 2000</b>	<b>Fertilizer subsidies(A) 2010</b>	<b>Maize trade liberalisation (B) 2000</b>	<b>Maize trade liberalisation (B) 2010</b>
<b>Cash crops</b>	19.9	23.8	0.7	1.1
- Cotton	10.9	15.3	0.8	1.2
- Coffee	44.6	46.9	0.0	0.5
- Tea	7.6	9.9	1.1	1.5
- Tobacco	23.5	30.2	1.5	1.7
- Cashew	4.9	6.5	0.9	1.2
<b>Food crops</b>	2.2	3.2	1.1	1.4
- Cassava	1.0	1.3	0.2	0.2
- Maize	2.1	3.0	2.3	3.1
- Rice	1.8	2.5	0.5	0.6
- Other cereals	1.7	2.5	0.4	0.6
- Beans	1.6	2.4	0.3	0.5
- Bananas	1.9	2.5	0.5	0.6
- Other crops	3.3	4.7	0.8	1.1

Furthermore, soil erosion processes occur slowly over time and represents cumulative effects and a longer model time horizon may be needed to detect differences across the scenarios considered. The

most severe environmental effect arises probably via land extensive processes triggered by the policy reforms. A trade liberalisation, for example, implies that agricultural land use increases with about 2% by the year 2010 compared to the baseline scenario, which represents about 150.000 additional hectares of land. Such a development may threaten natural forest reserves and savannas.

If we look closer at each crop producing sector further differences across the two policies are identified. From Table 4 it is observed that fertilizer subsidies promote cash crops relatively to food crops, while for a maize liberalization the opposite matter. The production of cash crop and food crops increases with 23.8% and 3.2% compared to the reference scenario in year 2010 given a fertilizer subsidy, while the overall increase in agricultural production due to a fertilizer subsidy is 7.9% in year 2010. The same figures for a trade liberalisation is 1.1% and 1.4% in year 2010. It is further noticed that fertilizer subsidies increase the production of coffee significantly, but also strengthens the production of tobacco, while increases in food crop production (including maize) is lower. Given a trade liberalization, maize production experiences the strongest relative increase while the impacts on all other crops do not differ much.

## **6. Conclusions**

This study analyses the consequences of two policy reforms suggested in the literature in order to stimulate agricultural production in Tanzania. The purpose of our study is not only to provide a more formal and accurate analysis of arguments that have been put forward in the literature but also to consider other possible effects which can be of importance when the suggested policy reforms are discussed. The analysis is conducted in a CGE model - an effective tool for evaluating policy packages according to multiple criteria.

Tanzania can be said to be in a transitional phase - moving rapidly from a state with heavily governmental intervention to private sector decision-making. It is demanding to develop a CGE model, which captures rigidities still present in the economy. In this model we have assumed a Keynesian labor market and a capital market where investments are not allocated according to relative profitability but to observed shares in the base year. Furthermore, both policy reforms are interpreted as short-term measures in that no investments in marketing and infrastructure are needed to implement the reforms.

Our analysis indicates that a future fertilizer consumption in Tanzania at current rates will cause the growth rate both in agricultural and in the economy as a whole to decline. In fact, a relatively high positive growth rate can only be sustained by significant higher levels in fertilizer application and by

bringing additional land into use, combined with a relatively high rate of technological change in agriculture. The model simulations also suggest that CGE models with endogenous soil fertility make policy reforms in agriculture relatively more advantageous compared to models not considering soil-nutrient cycles. Of the two policy reforms analysed in this paper, the introduction of fertilizer subsidies stimulates to higher production and increased economic growth than does a maize trade liberalisation. The analysis points to relatively strong sectoral complementarities between agricultural and non-agricultural sectors. The two policy reforms also differ in that a fertilizer subsidy gives priority to traditional agricultural export sectors in Tanzania, while a maize liberalization stimulates food crops. In addition, a fertilizer subsidy induces a more intensive agricultural production while for the liberalization of maize trade, on the other hand, extensive processes are observed.

If a choice has to be made between fertilizer subsidies and the promotion of maize trade, our result favors the first. This conclusion follows first and foremost from the significant expansive effects, which arise from fertilizer subsidies. The magnitude of these effects, however, depends of course on the assumptions made about the economic model. In addition, fertilizer subsidies seem in relative terms to have environmental advantages compared to a maize trade liberalisation since extensive processes may have possible malign effects on the natural forest reserves in Tanzania.

Furthermore, no large differences as concerning distributive effects from the two reforms are detected in our analysis, and household's surveys indicate that a fertilizer subsidy need not necessarily give priority to well-endowed farmers. However, a more formal analysis of distribution impacts should be a subject for future research. Another extension of our analysis will be to consider the consequences of governmental policies and long-term measures meant to support various pricing reforms.

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## Appendix

### Model description and list of variables

#### A. The economic model

No.	Name	Equations	sectors goods
1.	Prodag1	$X_i = tech_i \cdot bb_i \cdot L_i^{\alpha_i} \cdot kk_i^{\beta} \cdot N_i^{\gamma_i} \cdot PA_i^{\chi_i} \cdot KL_i^{\mu}$	i=AG1
2.	Prodag2	$X_i = tech_i \cdot bb_i \cdot L_i^{\alpha_i} \cdot kk_i^{\beta} \cdot N_i^{\gamma_i} \cdot PA_i^{\chi_i} \cdot kl_i^{\mu}$	i=AG2
3.	Prodind	$X_i = tech_i \cdot bb_i \cdot L_i^{\alpha_i} \cdot kk_i^{\beta}$	i=IND
4.	Nitroland1	$LN_i = \Omega_i \cdot NR_i \cdot KL_i$	i=AG1
5.	Nitroland2	$LN_i = \Omega_i \cdot NR_i \cdot kl_i$	i=AG2
6.	Nitrogen	$N_i = F_i + LN_i$	
7.	Demlab	$w \cdot L_i = \alpha_i \cdot X_i \cdot \left( P_i - \sum_j PC_j \cdot (1 + ta_{ji}) \cdot a_{ji} \right)$	i=Z j=J
8.	Dempes	$PC_{pes} \cdot (1 + ta_{pes,i}) \cdot PA_i = \chi_i \cdot X_i \cdot \left( P_i - \sum_j PC_j \cdot (1 + ta_{ji}) \cdot a_{ji} \right)$	i=AG j=J
9.	Demfer	$PC_{fer} \cdot (1 + ta_{fer,i}) \cdot N_i = \gamma_i \cdot X_i \cdot \left( P_i - \sum_j PC_j \cdot (1 + ta_{ji}) \cdot a_{ji} \right)$	i=AG j=J
10.	Demland1	$KL_i = \frac{\mu_i}{\left[ \left( PC_{fer} \cdot NR_i \left( \frac{exxs}{phis} \right) + pkl_i \right) - \left( P - \sum_j a_{ij} PC_j \cdot (1 + ta_{ij}) \right) \cdot X_i \cdot \frac{\gamma_i \cdot NR_i \cdot exxs}{phis \cdot N_i} \right]}$	i=AG1

11.	Demland2	$kl_i = \frac{\mu_i}{\left[ \left( PC_{fer} \cdot NR_i \left( \frac{exxs}{phis} \right) + PKL_i \right) - \left( P - \sum a_{ij} PC_j \cdot (1 + ta_{ij}) \right) \cdot X_i \cdot \frac{\gamma \cdot NR_i \cdot exxs}{phis \cdot N_i} \right]}$	i=AG2
12.	Pricomp1	$PC_i \cdot XC_i = (1 + td_i) \cdot PD_i \cdot XD_i$	i=NIM
13.	Pricomp2	$PC_i \cdot XC_i = (1 + td_i) \cdot PD_i \cdot XD_i + pm_i \cdot (1 + tm_i) \cdot MM_i$	i=IM1
14.	Pricomp3	$PC_i \cdot XC_i = (1 + tm_i) \cdot pm_i \cdot MM_i$	i=pes, fer
15.	Compagg1	$XC_i = XD_i$	i=NIM
16.	Compagg2	$XC_i = qq_i \cdot \left[ q_i \cdot MM_i^{-\tau} + (1 - q_i) \cdot XD_i^{-\tau} \right]^{\frac{-1}{\tau}}$	i=IM1
17.	Compagg3	$XC_i = MM_i$	i=pes, fer
18.	Demimp	$\frac{MM_i}{XD_i} = \left[ \frac{PD_i \cdot (1 + td_i)}{pm_i \cdot (1 + tm_i)} \cdot \frac{q_i}{1 - q_i} \right]^{\frac{1}{1 + \tau}}$	i=IM1
19.	Valsale1	$P_i \cdot X_i = PD_i \cdot XD_i$	i=NEX
20.	Valsale2	$P_i \cdot X_i = PD_i \cdot XD_i + pe_i \cdot EE_i$	i=EX
21.	Allgood1	$X_i = XD_i$	i=NEX
22.	Allgood2	$X_i = hh_i \cdot \left[ h_i \cdot EE_i^\rho + (1 - h_i) \cdot XD_i^\rho \right]^{\frac{1}{\rho}}$	i=EX
23.	Suppex	$\frac{EE_i}{XD_i} = \left[ \frac{pe_i}{PD_i} \cdot \frac{1 - h_i}{h_i} \right]^{\frac{1}{\rho - 1}}$	i=EX
24.	Profitt1	$PRFT_i = X_i \cdot \left[ P_i - \sum_j a_{ji} \cdot PC_j \cdot (1 + ta_j) \right] - w \cdot L_i -$ $PC_{pes} \cdot (1 + ta_{pes}) \cdot PA_i - PC_{fer} \cdot (1 + ta_{fer}) \cdot F_i$	i=AG j=J

25.	Profitt2	$PRFT_i = X_i \cdot \left[ P_i - \sum_j a_{ji} \cdot PC_j \cdot (1 + ta_j) \right] - w \cdot L_i$	i=IND j=J
26.	Income	$Y = \sum_i (w \cdot L_i + PRFT_i) + w \cdot lg$	i=Z
27.	Expendd	$EXPEND = c \cdot (1 - ty) \cdot Y$	
28.	Privcons	$PC_i \cdot CD_i = PC_i \cdot \theta_i + \kappa_i \cdot \left[ EXPEND - \sum_j PC_j \cdot \theta_j \right]$	i=J j=J
29.	Govrev	$GR = ty \cdot Y + \sum_j td_j \cdot PD_j \cdot XD_j + \sum_l te_l \cdot PE_l \cdot EE_l +$ $\sum_i tm_i \cdot pm_i \cdot MM_i + \sum_k ta_{pes} \cdot PC_{pes} \cdot PA_k +$ $\sum_k ta_{fer} \cdot PC_{fer} \cdot F_k + \sum_n \sum_j ta_n \cdot PC_n \cdot a_{nj} \cdot X_j$	j=Z l=EX i=IM k=AG n=J
30.	Govsav	$SGOV = GR - \sum_i PC_i \cdot gc_i - w \cdot lg$	i=J
31.	Totinv	$JJ = (1 - c) \cdot (1 - ty) \cdot Y + SGOV - \sum_i PC_i \cdot cs_i - er \cdot sfor$	i=J
32.	Invgood	$PC_j \cdot DK_{ji} = imat_{ji} \cdot kshare_i \cdot JJ$	i=I1 j=I2
33.	Eqcomp1	$XC_i = \sum_j a_{ij} \cdot X_j + cs_i + gc_i + CD_i$	i=I3 j=Z
34.	Eqcomp2	$XC_i = \sum_j a_{ij} \cdot X_j + cs_i + gc_i + CD_i + \sum_l DK_{il}$	i=I2 l=I1
35.	Eqcomp3	$XC_i = \sum_k PA_k + \sum_j a_{ij} \cdot X_j + cs_i + gc_i + CD_i$	i=pes j=Z k=AG
36.	Eqcomp4	$XC_i = \sum_k F_k + \sum_j a_{ij} \cdot X_j + cs_i + gc_i + CD_i$	i=fer j=Z k=AG

## B. The soil model

37.	$NR_i = rns \cdot NS_i + \frac{\lambda_i}{3} \cdot \sum_{s=2}^4 NRR_{i,t-s} + nas_i$	i=AG
38.	$NS_i = (1 - rns) \cdot NS_{i,t-1} + (1 - \lambda_i) \cdot NRR_{i,t-1} - NE_{i,t-1}$	i=AG
39.	$NRR_i = \frac{X_i}{KL_i} \cdot \left( retain_i \cdot nc_{ss_i} \cdot \frac{1 - hs_i}{hs_i} + ncr_{s_i} \cdot \frac{1}{hs_i \cdot srs_i} \right)$	i=AG1
40.	$NRR_i = \frac{X_i}{kl_i} \cdot \left( retain_i \cdot nc_{ss_i} \cdot \frac{1 - hs_i}{hs_i} + ncr_{s_i} \cdot \frac{1}{hs_i \cdot srs_i} \right)$	i=AG2
41.	$NE_i = rs_i \cdot ks_i \cdot ss_i \cdot ws_i \cdot ms_i \cdot \frac{cpa_i \cdot NS_i}{bds_i \cdot 10 \cdot D_i}$	i=AG3
42.	$NE_i = rs_i \cdot ks_i \cdot ss_i \cdot ws_i \cdot ms_i \cdot \frac{NS_i}{bds_i \cdot 10 \cdot D_i} \cdot \left( cp_i - cpars_i \cdot exxs_i \cdot \frac{X_i}{KL_i} \right)$	i=AG4
43.	$NE_i = rs_i \cdot ks_i \cdot ss_i \cdot ws_i \cdot ms_i \cdot \frac{NS_i}{bds_i \cdot 10 \cdot D_i} \cdot \left( cp_i - cpars_i \cdot exxs_i \cdot \frac{X_i}{kl_i} \right)$	i=AG5
44.	$D_i = D_{i,t-1} - \frac{rs_i \cdot ks_i \cdot ss_i \cdot ws_i \cdot cpa_i}{bds_i \cdot 10}$	i=AG3
45.	$D_i = D_{i,t-1} - \frac{rs_i \cdot ks_i \cdot ss_i \cdot ws_i \cdot \left( cp_i - cpars_i \cdot exxs_i \cdot \frac{X_i}{KL_i} \right)}{bds_i \cdot 10}$	i=AG4
46.	$D_i = D_{i,t-1} - \frac{rs_i \cdot ks_i \cdot ss_i \cdot ws_i \cdot \left( cp_i - cpars_i \cdot exxs_i \cdot \frac{X_i}{kl_i} \right)}{bds_i \cdot 10}$	i=AG5

## C. List of good and sectors

J	goods
Z	industries
AG	agricultural industries
AG1	agriculture with variable use of land
AG2	agriculture with constant use of land
AG3	agriculture with constant cover index
AG4	agriculture with variable cover index and variable use of land
AG5	agriculture with variable cover index and constant use of land
IND	production industries
I1	capital utilising industries
I2	capital producing industries
I3	non-capital producing industries
IM	imported goods
IM1	imported goods less fertilizers and pesticides
NIM	non imported goods
EX	exporting industries
NEX	non exporting industries

## D. List of variables

### Endogenous variables

#### Economic model

CD	Private consumption of goods
DK	Real investment of good in industries
EE	Exports from industries
EXPEND	Total nominal private expenditure on consumption
F	Use of fertilizers in agricultural industries
GR	Government nominal net revenues
JJ	Total nominal real investment expenditure
KL	T.sh. units of land
LN	Nitrogen from land measured in T.sh. units
L	Use of labour
MM	Import of goods
N	Nitrogen
P	Producer price of composite deliveries
PA	Use of pesticides in agricultural industries
PC	Composite purchaser price
PD	Producers price on home-market deliveries
PKL	Price of homogenous land in «cof» and «tob»
PRFT	Total nominal profits in the industries
SGOV	Government nominal savings
X	Units of production by industries
XC	Units of composite purchaser good



XD	Units delivered to the home-market
Y	Nominal private income

#### Soil model

D	Soil depth
NE	Lost nitrogen due to erosion
NR	Naturally mineralised nitrogen
NRR	Nitrogen from roots and residues
NS	Stock of nitrogen in Soil Organic Matter

### **Parameters and exogenous variables**

#### Economic model

$\alpha$	Productivity of labour in production function
$\beta$	Productivity of real capital in production function
$\gamma$	Productivity of nitrogen in production functions for agricultural industries
$\chi$	Productivity of pesticides in production functions for agricultural industries
$\mu$	Productivity of homogenous land in prod. functions for agricultural industries
$\theta$	Basic consumption in LES-functions
$\kappa$	Budget share of available expenditure after spending on basic consumption
$\tau$	Substitution el. for consumption between imports and home produced goods
$\rho$	Transformation el. between exports and home marked deliveries in production
$\Omega$	Transformation coeff. for land-nitrogen to physical unit as fertilizer-nitrogen
a	Units input of goods per unit output of goods in industries
bb	Calibration coefficient in non-agricultural industries
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	Investment good's share of nominal expenditure on investment in industries
kshare	Each industry share of total nominal expenditure on investment
kl	Constant land area
lg	Governmental use of labour
pkl	Price of homogeneous land in agriculture 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

### Soil model

$\lambda$	Percentage direct mineralization from roots and stover
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
ncrs	Nitrogen concentration in roots
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

### **E. List of Industries and Goods**

	J	Z	AG	AG1	AG2	AG3	AG4	AG5	IND	I1	I2	I3	NIM	IM	IM1	EX	NEX
Cotton	X	X	X	X		X	X					X	X			X	
Coffee	X	X	X		X	X				X		X	X			X	
Tea	X	X	X	X					X	X		X	X			X	
Tobacco	X	X	X		X	X				X		X		X	X	X	
Cashew	X	X	X	X				X		X		X	X			X	
Cassava	X	X	X	X		X	X					X	X				X
Maize	X	X	X	X		X	X		X			X	X			X	
Rice	X	X	X	X		X	X					X		X	X		X
Other cereals	X	X	X	X		X	X					X					X
Beans	X	X	X	X		X	X					X	X				X
Bananas	X	X	X	X		X	X					X	X				X
Other Crops	X	X	X	X		X	X					X		X	X	X	
Livestock	X	X							X	X		X	X	X	X		X
Forestry	X	X							X	X		X		X	X	X	
Food	X	X							X	X		X		X	X	X	
Textiles	X	X							X	X		X		X	X	X	
Other Manufacture	X	X							X	X	X			X	X	X	
Construction	X	X							X	X	X			X	X		X
Electricity	X	X							X	X		X	X				X
Transport	X	X							X	X		X	X			X	
Other Private Services	X	X							X	X		X		X	X	X	
Pesticides	X													X			
Fertilizers	X													X			
<b>Total</b>	<b>23</b>	<b>21</b>	<b>12</b>	<b>10</b>	<b>2</b>	<b>10</b>	<b>8</b>	<b>2</b>	<b>9</b>	<b>14</b>	<b>2</b>	<b>19</b>	<b>11</b>	<b>12</b>	<b>10</b>	<b>13</b>	<b>8</b>