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Modelling food policies and food production

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Abstract

The Centre for World Food Studies is developing economic policy models focussing on food and agriculture, and incorporating detailed agronomic information. The structure of these national models is such that they can be linked in order to analyse international trade. The developing country models emphasize and analyse the problem of hunger and poverty through the role of agronomic and livestock constraints, the changes in the distribution of income between agriculture and non-agriculture as well as within agriculture. Model alternatives can be analysed through changes in various parameters, such as direct and indirect tax rates, tariffs, buffer stocks, import and export quotas.

Introduction

National and international models of food policies and agricultural production have been the focus of research undertaken at the Centre for World Food Studies, founded by the participating institutes — Free University (Amsterdam), Agricultural University (Wageningen), Centre of Agrobiological Research (Wageningen), and the Agricultural Economic Research Institute (The Hague) — and the funding agencies: the Ministry of Agriculture and Fisheries and the Ministry of Development Cooperation.

The widespread occurrence of hunger in the world at present is generally recognized as unacceptable, for the moral reason that human deprivation should not be tolerated, and because natural and technological resources appear adequate to meet the food needs of all mankind.

Hunger problems stem from the interaction of factors at the local (particularly the national) level. The mechanisms which generate these local situations and determine their behaviour over time must therefore be identified. Consequently, the objective is to develop a set of models, presenting food and agricultural systems which are embedded in national economies, interacting with each other through international trade (Centre for World Food Studies, 1983). Models representing national economies have a key role in the system, recognizing national control over resources and their uses and the role of national government policies. The interaction between countries is complex, as local and global changes mutually condition each other.

National policy models attempt to simulate the effects of alternative policies on the important economic variables. The models describe the behaviour of three economic actors: producers, consumers, and government, representing supply and demand of both agricultural and non-agricultural commodities, price formation, and international trade.

The international model — the so-called Basic Linkage System — simulates the international flow of trade and the consequences of international agreements represented by trade between individual countries for the commodities explicitly accounted for in the modelling system. As a result the model generates the size and flow of trade and the world equilibrium price of traded commodities.

The relevance and usefulness of these models can best be ensured if they are developed in collaboration with government departments, research institutes and universities in the particular countries. For the models currently in progress — Bangladesh, Indonesia and Thailand — the main participating institutes are the Ministry of Finance and Planning (Dhaka), the Ministry of Agriculture (Jakarta), and the Thai Development Research Institute (Bangkok), respectively.

The character of the research effort as a multidisciplinary undertaking and the methodological nature of the exercise provides the Centre for World Food Studies with the *raison d'être* and an important role in the field of modelling food policies.

The Centre is by no means the only institution engaged in such a modelling exercise, even though it has particularly contributed to the formulation of the main characteristics of the national models and international models; their design as equilibrium models and the requirements for linkage of national models to the international model. The Food and Agricultural Program at International Institute for Applied Systems Analysis (IIASA) is responsible for the analyses with the international model (Parikh & Rabar, 1981) as well as for the development of a number of national models.

The economic model

The extent of hunger and malnutrition in a country does not depend only on the level but even more importantly on the distribution of resources and total national food supplies. The factors which determine this distribution are complex and not well understood, but they can be distinguished roughly between the ones describing the ownership structure of (particularly scarce) factors of production and those representing the effects of government policies. A substantial part of hunger and poverty appears to occur in rural areas where people are mainly dependent on agricultural activities to earn their livelihood. This suggests that the analysis of poverty and hunger must take account of the ownership of resources, of the size distribution and quality of land, of access to inputs and services, etc. Similarly, the operation of rural labour markets and the causes and effects of labour migration need to be taken into account. Government policies can be addressed to changes in control structures (land reform, education policies, for example) or to changing income and/or food distribution directly through transfer systems between population groups. These considerations constitute the basic premises for the formulation of the econo-

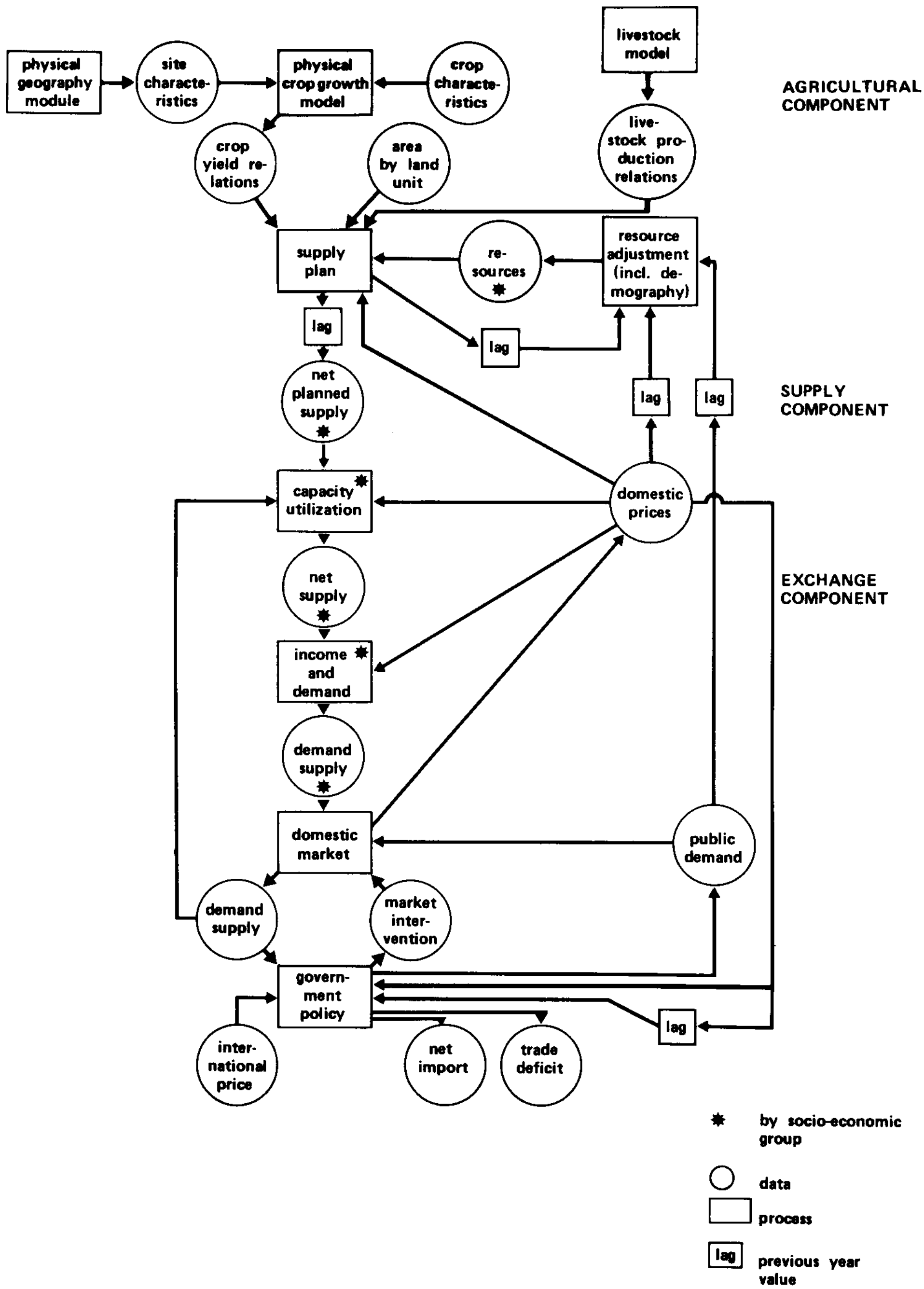

Fig. 1. Schematic representation of a national food and agriculture model.

mic policy model.

Because the economic policy models should also be linkable in one global model they should therefore meet a number of basic linkage requirements. Thus, international trade variables follow therefore a common commodity classification. Imports and exports are to be generated on an annual basis. Further, imports and exports should be functions of world market prices which are insensitive to the absolute level of prices. The economic process is modelled by first describing the behaviour of individual agents (producer, consumer, government) by means of a social accounting system (Tims, 1983) and then integrating this behaviour through the imposition of overall physical and financial balance equations, in the 'Walrasian Equilibrium' tradition (Keyzer & Rebelo, 1982). A schematic representation is shown in Fig. 1.

Each model consists of the following components:
- supply,
- demand,
- income and price formation, and
- national government policies.

Each model is an actor in the international model system, and national government policies influence its operation.

The formulation of the various model components for a specific national model raises several methodological issues. Without going into detail, three issues were of paramount importance with regard to establishing a common framework:
- commodity breakdown: which commodities to be distinguished in the model: how many agricultural, how many non-agricultural, how many factors of production?
- data collection and processing: establishment of the format of an internally consistent data bank
- computation: the design of algorithms which enable numerical solution of the model.

Apart from these general issues, a number of specific ones pertaining to individual model components had to be resolved. With respect to the modelling of (particularly agricultural) supply behaviour, a way had to be devised for representing technological relations and to obtain estimates of technical parameters; also, an approach was needed to describing producers' behaviour and the interaction between producers (e.g. small vs. large farmers).

The modelling of demand required the description, by income group, of consumer demand as a function of prices and incomes, adequately describing both short-term and long-term substitution effects between commodities and generating realistic nutritional intakes under changing incomes and prices.

Income and price formation follows partly from production activities and the operation of markets, but in addition needs a description of income transfers among income groups and between government and income groups. Also a number of linkages need to be built, i.e. between foreign and domestic prices and at different points in the domestic market, e.g. by relating changes in retail prices and changes in farm gate prices.

Finally, national government policies require the description, in a simplified and generalized way, of government economic operations and a quantification of the relations between those and the main economic variables which they affect.

The international modelling activities will not be treated here in detail. It is sufficient to say that through international linkage of models, individual countries exchange international tradeable goods and services. Based on the volume of trade and a constraint on the national balance of payments deficit, the effects of national policies on international trade to other countries can be analysed.

The economic policy models consist of four major components, that will be discussed in some detail below:

Model components

Supply

As far as the national model is concerned, the supply module only serves as a device to generate commodity supplies at varying domestic prices and resource levels such as land, labour, machinery, and herd size. The decision to produce is seen as a rational process. At given resource availabilities and prices the producer determines which combination of production activities would yield the highest benefit (e.g. net revenue) (Stolwijk, 1983). The producer thus selects among the alternatives which are technically feasible to him/her. It is the task of the agriculture and livestock scientists in the Centre to formulate quantitatively these possibilities. As a first approach a linear framework was selected to describe these alternatives, so that the production decisions are generated within a linear programming framework (i.e. optimization with linear objective and linear constraints).

Supply behaviour. The behavioural coefficients of an economic actor cannot be determined on synthetic, a priori grounds. The mere imposition of a revenue maximization upon technically feasible alternatives, does not necessarily yield realistic supply behaviour, but has so far been the methodology applied.

Agronomic/economic interface. In order to avoid the dimensionality problem it is necessary to design a systematic approach, for the description of the available production alternatives. The approach is to group the various factors affecting crop growth and livestock production according to hierarchical levels, to be dealt with in sequence. The structure of the interface follows the same hierarchy. It uses the information stepwise through three computer programmes which dovetail to the linear programming module describing the production decisions.

Demand

Demand systems. The demand functions express consumer demand as a function of prices and income. They describe the allocation of the consumer's budget over commodities and together form a demand system. In most countries the demand functions (including the savings function) can only be estimated by combining national time-series obtained from national accounts with household data for one point in time provided through budget and expenditure surveys. Several problems still remain, however. What price should be assigned to home-grown food? How to keep a reasonable nutritional balance at increasing income? Both questions are being studied in the context of a constrained utility maximization problem with parameter estimation routines for non-linear optimization problems (Kennes, 1984).

Nutritional situation. Differentiation of regions and of income groups within regions is particularly important for the assessment of the nutritional status of population groups and the changes occurring over time. The commodity classification used as a standard in all national models provides the minimum detail necessary to obtain an insight into food intake in terms of main components — calories, proteins — by income groups. The farm income groups, which can be distinguished according to land ownership classes with their own features in the production module, are central to this analysis.

An area in which further analysis is required concerns the links between nutritional status on the one hand, and indicators of health and of demographic characteristics on the other. Their significance for the assessment of labour supplies and for future demographic trends can hardly be doubted.

Income and price formation

The description of income generation, and income transfers among income groups (socio-economic classes), and between government and income groups is one of the essential elements of the model. Too, the distribution of income within groups and among groups as well as the distribution between rural and urban income groups is essential for economic policy analysis.

As regards price formation, a description of the factors that determine prices and that cause price distortion in the domestic market is required, for instance by relating changes in retail prices to changes in farm prices, and by relating changes in world market prices to changes in domestic prices.

National government policies

The open exchange model provides a framework for describing agricultural policy. In the open exchange model, the national government is given the role of formulating a target price of each commodity in terms of international prices. It can set bounds to international trade (quotas). When such a bound becomes effective, the actual price may start to deviate from the target level: otherwise the target can be reached through imposition of an appropriate tariff/levy on international trade. Governments can prevent price deviation from the target level by adjusting the level of buffer stocks. These policies involve budgetary costs/revenues, which are covered either by adjusting taxes or by adjusting government expenditures on goods and services (which include investment in agriculture). Budget deficits are, however, constrained and resources needed to maintain prices within the target range may exceed the resources which are available. The trade deficit (value of goods and services imported by the nation) is given to each nation and domestic policies do therefore only influence the commodity composition of the trade deficit but not its overall level.

This policy framework is general enough to depict the main features of government policies in countries with very different political regimes. The specific features of a nation can be brought in through the specification of the adjustment of policy targets and bounds to changing national and international circumstances. Thus, fully isolated national economies, or open, liberal trade economies and large oligopolistic economies can be represented within this framework.

The model of agricultural production potentials and constraints

The crop simulation model

The economic model approach described above is linked through the interface with a model of crop production potentials and constraints based on quantitative land evaluation procedures. This part of the Centre's activity is focused on the physical and agronomic factors which determine crop output in technical terms.

Clearly, the agricultural production model is useful not only in conjunction with socio-economic analysis. It has a value of its own in that it permits to judge technical potentials and constraints as an analysis by itself. For this reason, the agricultural production model is described in a separate contribution on Quantified Land Evaluation procedures elsewhere in this issue (Driessen, 1986). The structure of the model as outlined there can be used for any given crop growing at a particular site at a given time. However, in a farming system more crops are grown in rotation, at a great many sites with varying climate and soil conditions and under various levels of land reclamation and available technologies. This adds up to a very large number of possible combinations. In actual practice only a small subset of the feasible activities is selected, based on the agro-ecological and geographical information system and relevant for the purpose of the study (van Keulen & Wolf, 1986).

The livestock production simulation model

Farming systems, especially in south and south-east Asia, are often characterized by a close relationship between crop and livestock production. Neither of the two subsectors can be modelled in isolation because of the existing interactions such as draught power and manure for crop production and crop by-products and waste for the animal consumption. Livestock and livestock production is therefore modelled by a simulation approach.

In the livestock simulation model, the farm is taken as the smallest agricultural entity. The effect of different marketing and development strategies on the farm can be analysed in conjunction with individual animal responses to different husbandry practices. The model attempts to quantify physiological relationships and the relationships between feed supply and livestock performance.

The relationships between feed supply and feed intake are based on the idea that at all levels of energy and crude protein, both factors interact in the regulation of intake. The physiological relationships contain conversion of energy and protein into meat, milk, draught and off-spring. A module is developed in which the discrete events — reproduction and mortality — are simulated, thereby facilitating analysis of herd dynamics.

The model requires detailed information on the feed characteristics (i.e. protein content, energy content and digestibility), feed availability and genetic potential of the animal breed(s) for growth and milk production (Hermans, 1985).

Applications

Impact of fertilizer subsidies on agricultural production in Bangladesh

For a given level of disaggregation of commodities and of the population into socio-economic groups, the economic model dicussed above is applied to Bangladesh and can be used for analysis of policy on a variety of issues. The impact of the policy measures can be traced in detail right through individual commodities and specific socio-economic groups. The Bangladesh model, with adaptions, is at present being used to support the preparation of the Third Five-Year Plan (1985-1990) and the Perspective Plan (1985-2000). The model application described here concerns the comparative static analysis of various issues. Only selected results are presented for each case as the purpose is to indicate the broad range of applicability of the model and to illustrate its working rather than to discuss the issue analysed. In the example presented below, a base run and results of three scenarios are given (Stolwijk, 1985). The results of the base run reproduce the empirical observation of economic variables for the base year, demonstrating the logical consistency between the data and the formulation of the model which is a prerequisite for the model to be a valid representation of the economy. The three variants are:

(a) abolishing the fertilizer subsidy; the fiscal resources saved are used to increase subsidized food supplies in ration shops, particularly for the landless, the rural and urban informal households;

(b) as the preceding scenario but the resources saved are transferred to the government investment budget;

(c) an increase of the fertilizer subsidy to 70% of the market price, with the additional costs to the government compensated by: (i) abolishing subsidized supplies for the poorest groups in ration shops, (ii) a reduction of government investments for the remaining costs.

Most fertilizers are used for the various rice crops. The effects of changes in the fertilizer subsidy can be traced to farmer's expenditures, the production of rice, the employment effects in agriculture and in the processing sector and the demand for non-traditional forms of energy. A reduced fertilizer application reduces rice production and employment in the cultivation and processing of rice. Lesser production in rice by-products, assuming unchanged needs for cattle feed, increases the demand for non-traditional fuels. The third scenario with a higher subsidy on fertilizers gives the opposite chain of consequences. The main results on the side of pro-

Table 1. Macro-economic results of alternative scenarios on fertilizer subsidy (in billions of Taka). Base year 1977.

		(a)	(b)	(c)
GNP	109.1	108.7	109.0	109.4
Trade deficit	7.0	7.3	7.1	6.7
Rice imports	0.9	1.4	1.2	0.4
Non-agricultural imports	7.8	7.7	7.8	7.9
National savings	7.4	7.1	7.9	7.5
Government investment	6.2	6.2	6.8	6.0
Private investment	7.3	7.3	7.3	7.3
Fertilizer subsidy	0.6	–	–	1.2
Flexible food ration subsidy	0.4	1.0	0.4	–

(a): subsidy abolished; resources saved directed to increased subsidized food supplies in ration shops particularly for the landless, rural and urban informal.
(b): subsidy abolished; resources saved transferred to government investment budget.
(c): fertilizer subsidy increased to 70 % of the market price; additional public cost compensated by:
– abolishing subsidized supplies for the poorest groups in ration shops,
– a reduction of government investments for the remaining costs.

duction, by socio-economic groups, can be summarized as follows. Abolishing the fertilizer subsidy reduces rice production by 127 000 t (metric tonnes) or 1.2 %. These percentual declines are slightly less for small farmers and slightly more for the larger ones. Lesser availability of by-products used as a source of fuel increases the demand for oil products by 16 000 t. Part of the income losses of the larger farmers are compensated by lesser use of hired labour, mainly supplied by the landless and the small farmer households. Incomes of the landless decline by 0.2 %. The scenario with higher subsidy on fertilizers is almost the mirror image.

Table 1 summarizes the macro-economic effects of fertilizer subsidy changes, as obtained from the exchange component of the model and given the changes discussed above on the production side.

Abolishing the subsidy results in a marginal decline of the GNP, particularly when public funds are diverted to rations for the poorest groups. The latter cause large rice imports to take place and also increase transport and processing value added. The higher subsidy on fertilizers leads to a marginal GNP increase and also has a positive effect on the trade balance, mainly through lower rice import needs. It should be noted that this scenario (c) assumes no change in net external capital inflows, even if food aid may be reduced.

National savings are the residual between the (varying) level of investments and the current account deficit. Savings are therefore boosted most in scenario (b) with a higher level of government investment and a marginal increase of the current account deficit.

As the fertilizer subsidy is only a small amount compared to the base-year GNP (0.6 %) the income effects on the various socio-economic groups can only be mar-

Table 2. Income effects by socio-economic groups (% change as compared to base year 1977).

	Per capita income (Taka)	(a)[1)]	(b)[1)]	(c)[1]
Landless labourers	881	1.7	–0.2	–1.0
Small farmers	1005	0.4	–0.6	–
Medium farmers (tenants)	1155	–0.7	–1.0	0.8
Medium farmers (owners)	1323	–0.5	–0.8	0.6
Large farmers	1647	–1.2	–1.2	0.9
Very large farmers	2442	–1.3	–1.4	1.0
Rural informal	910	1.0	–0.2	–0.8
Rural formal	1824	–0.5	–0.2	0.3
Urban informal	1162	0.6	–	–0.2
Urban formal	2909	–0.9	–0.1	0.6
Bangladesh (average)	1297	–0.2	–0.6	0.2

(a): fertilizer subsidy abolished; resources saved directed to increased subsidized food supplies in ration shops particularly for the landless, rural and urban informal.
(b): fertilizer subsidy abolished; resources saved transferred to government investment budget.
(c): fertilizer subsidy increased to 70 % of the market price; additional public cost compensated by:
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ginal. These are presented in Table 2.

Abolishing the subsidy has a slight contractive effect on incomes in general, more so in case of increased government investment than in the alternative of more food rations and subsidies for the poor. Still, the effects on the various groups are divergent, but easily explained according to the particular set of policy assumptions underlying each scenario. For example, the negative effects of lower wage earnings of landless labourers due to lower rice production in scenario (a) are more than compensated by more subsidized food.

Potential production increase form fertilizer in semi-arid regions of Africa

Food and agricultural production have increased at a very low rate in sub-Saharan Africa. The index of total food production shows an increase from 100 in 1975 to 112 in 1983, while on a per caput basis the index has declined from 100 to 95 during the same period (FAO, 1985a), showing the per caput food production decreasing from the already very low level of 1975. The moderate increase in total production has been more than offset by the relatively high rate of population growth.

The causes underlying the poor performance of agricultural production in sub-Saharan Africa are manifold and have been the subject of a large number of studies. Besides a high rate of population growth, important factors that have contributed to the decline in the per caput food production are unfavourable weather conditions over extended periods of time, a less than adequate organization of agriculture, and poor agricultural policies.

One policy to stimulate agricultural production may be the enhancement of the use of chemical fertilizers. In a recent study the Centre for World Food Studies analysed the effects of fertilizer on agricultural production in the semi-agrid regions of Burkina Faso, Ghana and Kenya.

Chemical fertilizer may be considered as a possible means to increase agricultural production, as low soil fertility is one of the most serious production constraints, even under arid and semi-arid conditions. However, under such conditions, availability of water may limit any yield increase that can be brought about by fertilizer application. Therefore, first an assessment has been made what yields can be expected under rain-fed conditions, as if there were no limitations to nutrient supply. With the Centre's methodology, for each land unit, defined along agro-ecological criteria, the yield level for each of four crops (cassava, maize, millet and sorghum) has been calculated assuming that water availability is the only yield-limiting factor.

The physiologically based crop growth simulation model is used, for the calculations, requiring data on climate, soil moisture characteristics and rootable soil volume. The necessary information has been obtained from weather station reports and soil maps.

After the water-limited yields have been calculated, the nutrient-limited yields are estimated, assuming that the nutrients — nitrogen (N), phosphorus (P) and potassium (K) — available to the plant originate only from the soil, i.e. the natural soil fertility. For this purpose use is made of a quantitative soil fertility classification system, in order to transform soil maps into soil fertility maps. The nutrient-limited yields, corrected for yield losses because of weeds, pests, diseases, and harvesting, are then compared with reported yields from statistical sources.

The difference between the water-limited yield and the nutrient-limited yield is the potential yield increase that can be obtained by application of fertilizers. In view of the very low actual yields, it may be assumed that potential yield increases can be very substantial. As an example, the effect of nutrient applications on the maize yield has been calculated for the average soil fertility classes in three African countries, Burkina Faso, Ghana and Kenya.

In according with the methodology, a pre-specified increase in maize yield is set, for example a target yield increase of 900 kg ha^{-1}, without exceeding the water-limited yield level. In order to realize this target yield increase, the required amount of nutrients has to be sufficient for a theoretical yield increase without losses of 1200 kg ha^{-1} accounting for an average yield reduction of about 25 % due to weeds, pests, diseases and harvest losses.

For the average soil fertility class of Burkina Faso, the nutrients required for a target yield increase of 900 kg ha^{-1} are 55 kg N and 75 kg P_2O_5 per hectare, or 130 kg of nutrients. Assuming the use of a fertilizer compound containing 40 % of nutrients (N, P_2O_5 or K_2O), $130 \times 100/40 = 325$ kg of fertilizer product per hectare is needed. Similar calculations can be made for different target yields, soil fertility classes, and crops. In Kenya and Ghana nutrient requirements to achieve the same yield level are somewhat lower because of the higher average soil fertility.

The yield response to fertilizer nutrients for the specified target yield increase shows to be remarkably different among the three countries:

Country	Soil fertility class	Target yield increase (kg ha^{-1})	Required fertilizer (kg of N-P_2O_5-K_2O)	Yield response to fertilizer nutrients (kg maize/kg fertilizer nutrient)
Burkina Faso	low to mediocre	900	75-55-0	6.9
Ghana	mediocre	900	68-50-3	7.4
Kenya	mediocre	900	30-60-3	9.7

These data indicate that for every kg of fertilizer nutrient applied, the maize yield will increase by 6.9 to 9.7 kg, despite the actual limited water availability. These results bear out that sub-Saharan countries could significantly increase crop yields by removing the nutrient limitation. However, to realize increased yields in practice, and therefore increased fertilizer use, economic factors such as fertilizer and product prices, risk behaviour, and fertilizer availability, must be taken into account. The economic model could provide the answer to these questions.

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