ISSN 0250-7625

IIASA REPORTS

International Institute for Applied Systems Analysis

Volume 6 Number 1 July–September 1982

IIASA REPORTS

Volume 6 (1982)

Cover

Photograph: Paul H. Makin

International Standard Serial Number 0250-7625

IIASA Reports presents research conducted at IIASA that has been independently reviewed before publication. However, the views and opinions it expresses are not necessarily those of the Institute or the National Member Organizations that support it or of the institution that sponsored the research.

IIASA REPORTS

A JOURNAL OF INTERNATIONAL APPLIED SYSTEMS ANALYSIS

VOLUME 6 (1982)

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
Laxenburg, Austria

ENERGY FOR AGRICULTURE IN PAKISTAN

Muhammad Jameel
International Institute for Applied Systems Analysis, Laxenburg, Austria

SUMMARY

Traditional agriculture relies heavily on animal energy, i.e. bullocks or horses to till the land and to draw water; men for seeding and harvesting; dung for manure, and so on. The productivity of this mode of agriculture, in terms of yield per hectare per year, is proving insufficient to support the growing world population. Fortunately, the introduction of high-yield and early maturing varieties of crops have made it possible to enhance land productivity substantially, but at a cost: heavy applications of chemical fertilizers, pumps to draw underground water, mechanization to help multi-cropping, etc. All these measures require, directly or indirectly, energy from oil, gas, or electricity. With sharply rising fuel prices, it is of interest to examine the use of energy in agriculture, as in other sectors of economy.

A large number of studies have been performed to assess the energy requirements of agriculture in different countries using various agricultural practices. This report is also a step in the same direction: it analyzes energy use in agriculture at present and attempts to project its evolution to the year 2000. The perception of future is aided by a scenario approach: three different development paths for farm mechanization and two for the supply of macronutrients are considered. The energy implications of each "future" are examined in detail.

The results show that the present expenditure of commercial energy goes almost entirely into the production of fertilizers and for irrigation/drainage, the former accounting for approximately 45%, and the latter for 40% of total primary energy input to agriculture; the remainder is shared by tractors, threshers and pesticides. For the year 2000, energy data for the different scenarios are presented, but the major share will again be taken by fertilizers, followed by irrigation and drainage. The greatest savings in energy are therefore also to be effected if the use of chemical fertilizers is reduced, and if water resources are conserved. These measures should however be taken in ways that do not adversely affect agricultural productivity.

---

1 INTRODUCTION

For proper growth and good yields, plants need suitable environments (almost invariably soil), prescribed movements within narrowly defined times of the year (hoeing, sowing, cutting, etc.), water (from rainfall, canals, wells), nutrients (particularly nitrogen), sunlight, carbon dioxide, and help in reducing competing organisms (through the use of herbicides, insecticides, etc.). Among these, sunlight and carbon dioxide are abundantly available and are not considered limiting factors in most situations. What agricultural man has to think about are land, labor (aided by animals and machines to varying degrees), water, fertilizers, seeds, and pesticides. Each of these inputs has a common physical denominator – energy. People and animals need energy for maintenance and work; machines require energy to be produced and operated. Water, fertilizers, pesticides, etc., all require primary energy inputs in one form or another.

This study aims to assess this common denominator of agricultural activity in a developing country at the end of the 1970s and at the turn of the century. The approach adopted for looking into the future is a bottom-up one, viz:

(i) to examine existing nutritional conditions and to project their evolution over time;
(ii) to assess the implications of the future nutritional intake in terms of required levels of production of various agricultural commodities;
(iii) to translate these production levels into input requirements according to various technological or economic options; and finally
(iv) to aggregate the energy equivalents of the various inputs.

The main question addressed in this report is therefore: What are the energy requirements implied by the need to provide a reference average diet to the people of Pakistan in the year 2000 under different scenario assumptions related to the degree of mechanization, fertilizer application, and other similar parameters? Given this objective, attention is focused on the physical inputs necessary to produce the estimated quantities of wheat, rice, milk, etc., which will be required in the year 2000. Economic, cultural, and social issues, though important, are only indicated in context, and no attempts is made to anticipate their probable resolution. Instead, the technological choices that society might make, either freely or under socioeconomic pressures, are reflected in the different scenarios whose energy implications are examined. No particular "future" is singled out as desirable or probable, although the principal characteristics of each are indicated.

End-use estimates are made, wherever possible, in contrast to the more widely used "demand projections" based essentially on a judgmental extrapolation of past trends. For a developing country, the planning process ought to begin with an assessment of actual societal needs, and should then proceed to a formulation of means to approach their fulfilment coherently and expeditiously. For this purpose, the patterns of the past are not always useful guidelines at all, and might in fact lead to unbalanced development. Of course, the projected growth rates of different activities that emerge from end-use considerations should be viewed against the corresponding historical data in order to ensure that national effort is directed to the areas where it is needed most. This briefly is the raison for the methodology used in this work.

2 ASSESSMENT OF FOOD REQUIREMENTS

An agricultural system is assumed to have the following functions:

(1) to feed the growing population with a balanced diet, i.e. adequate quantities of carbohydrates, proteins, fats, minerals, and vitamins;
(2) to provide raw materials such as cotton for industry; and
(3) to generate an export surplus.

Let us first look at the primary objective of agriculture – the production of adequate food supplies for the population. For comparison, the food consumption patterns of Pakistan and a few other selected countries/regions are presented in Table 1. Since the intake of minerals and vitamins is strongly dependent upon dietary habits, cooking practices, etc., and also because the minute quantities normally required to not pose any *production* problem, attention is focused on energy*, protein, and fat.

TABLE 1 Food consumption patterns of selected countries.

	Intake per capita per day (1975–77)				
	Energy	Protein (g)		Fat (g)	
Country/region	(kcal)	Vegetable	Animal	Vegetable	Animal
India	1949	43.2	5.2	22.4	7.0
Pakistan	2255	46.3	15.6	22.0	19.4
Africa	2308	46.7	12.0	32.4	10.9
Japan	2847	44.6	41.8	37.0	35.3
Western Europe	3378	41.0	53.2	48.4	89.7
North America	3519	33.7	72.0	62.3	100.0

SOURCE: FAO (1980).

The quantities in Table 1 are averages for whole populations. In developing countries, however, nutritional deficiency is further aggravated by inequitable food distributions among the various segments of society, as has been described in a number of studies such as that of Muhammad *et al.* (1976). The discussion of maldistribution, however, is beyond the scope of this report, which seeks to quantify the physical inputs required to meet *total* production targets, a necessary though not sufficient condition for attaining adequate nutritional levels for everyone.

With the above caveat, we note from Table 1 that while the energy and vegetable protein intakes are comparable, there is a wide disparity in the consumption of animal products. It may be argued that the North American dietary pattern is wasteful and even unhealthy, but there can be little doubt that the diet of the average Pakistani is deficient in animal protein. The average nutritional requirement of a "normal healthy person" has

*In literature on nutrition, the term "food calorie" is sometimes used to designate 1000 calories. In this study, we adhere to the usage in physical sciences, i.e. a calorie is the amount of energy required to raise the temperature of 1 g of water through 1 °C.

TABLE 2 Average daily human nutritional needs.

Source/country	Energy need (kcal) Child (10 yr)	Adult male (30 yr)	Adult female (30 yr)	Pregnant or lactating	Protein need (g) Child (10 yr)	Adult male (30 yr)	Adult female (30 yr)	Pregnant or lactating
US Food and Nutrition Board	2400	2700	2000	2400	36	56	46	70
UK Department of Health and Social Security	2400	3000	2200	2550	60	75	55	65
UN Food and Agriculture Organization[a]		3200	2300			46	39	
Central America[a]		2700	2000			65	60	
German Democratic Republic		2700	2300			85	75	
India		2800	2300			55	45	
Philippines		2400	1800			53	46	

[a]Age of adults is specified as 25 years.
SOURCE: Burton (1976).

been the subject of many studies, but no absolute figures can be quoted because of the variety of factors that must be taken into account, such as age, sex, body weight, climate, occupational activity, etc. A typical spread of requirements, worked out in different countries and by different organizations, is displayed in Table 2.

Despite considerable variations, the average adult needs are taken here to be 2900 kcal and 65 g of protein for a male; 2200 kcal and 50 g of protein for a female (with an extra allowance during pregnancy and lactation); and for a ten-year-old child 2400 kcal and 50 g of protein. Assuming that the population of Pakistan in the year 2000 will have about the same age and sex distribution as in the base year (1977), and by adding a margin to cover pregnancy and lactation, we arrive at the following average per capita requirements for the whole population:

energy: 2500 kcal/day
protein: 60 g/day

Allowing for possible losses in cooking and the low nutritional value of vegetable protein (if not properly balanced with respect to the required amino acids), 2600 kcal and 75 g of protein at the kitchen door can be considered a reasonable and realistic target for the year 2000. These are average figures for the whole of Pakistan, but if maldistribution still persists, substantial segments of the population will remain undernourished. However, these projections do anticipate significant overall improvements in national nutrition after 1977.

3 PRODUCTION REQUIRED FOR DIRECT HUMAN CONSUMPTION

In order to translate the nutritional requirements given in Section 2 into the production targets of specific commodities we look at how the food requirements have been

TABLE 3 Nutritional composition of various foods.

Commodity	Remarks	Energy content (kcal kg^{-1})	Protein content (% by weight)	
			Vegetable	Animal
Wheat flour	4/5 of field produce appears as edible flour	3600	11.5	
Rice (milled)	5/6 of field produce appears as milled grain	3600	7.5	
Maize		3500	8	
Other grain	Average values	3300	7	
Pulses	Average values	3400	22	
Vegetable oil		8800		
Refined sugar	Sugar cane processed yields 8.5% by weight of refined white sugar	3900		
Milk, fluid	1/5 is fed to calves or wasted	650		3.5
Milk, dried		6500		35
Beef/mutton (average cut)	1/5 of carcass weight is waste	2600		15
Fish	1/10 is waste	1300		18
Poultry meat	1/10 of dressed bird is waste	1300		12
Eggs	1/10 is waste	1400		11

SOURCES: McGraw-Hill (1977), PARC (1980), and Woolley (1977).

met in the recent past. Table 3 displays the nutritional content of the major food items consumed in Pakistan, as well as the losses that are inevitably incurred. Table 4 presents a breakdown of the food supply (per capita per day) for 1967–2000 in the convenient form of "percentage calorie vectors" and "percentage protein vectors"; e.g. for every 100 kcal consumed, 44 are contributed by wheat, 12 by rice, 15 by sugar, etc.

During 1967–77, for which available data have been analyzed, the calorie and protein vectors exhibited a remarkable stability despite a 28% increase in GNP per capita, and a 10% (9%) increase in the calorie (protein) intake per capita over the period. This has led us to respect the resilience of popular taste; hence the figures presented for the year 2000 in Table 4, except for the somewhat enhanced role of poultry products which is expected on other grounds. These values enable us to estimate the production levels of major commodities required *for direct human consumption* using a projected population of Pakistan of 139 million (World Bank 1979); those for other items such as pulses and coarse grains have been calculated by balancing the residual needs for vegetable protein, calories, etc. The results of this exercise are presented in Table 5; the requirements for animal feed and export are discussed in the following sections.

4 ANIMAL FEED REQUIREMENTS

4.1 Cattle and Sheep

Substantial increases in milk and meat production are expected over the next two decades, both to satisfy the domestic demand, and perhaps also to establish an export

TABLE 4 GNP and food supply per capita: Pakistan 1967–2000.

	1967	1970	1973	1977	Envisaged for the year 2000	Comments
GNP/cap (rupees, 1960)	490	526	567	625	1095	Trend extrapolated to the year 2000
Food supply/cap/day:						
Energy (kcal)	2045	2226	2205	2255	2600	See Section 2
calorie vector (%) wheat	42	44	47	45	45	See Section 3
calorie vector (%) rice	12	12	10	10	10	"
calorie vector (%) sugar	17	15	14	16	15	"
calorie vector (%) milk		8	8	8		See protein vector
calorie vector (%) others						
Protein (g)	56.9	60	60.7	62	75	See Section 2
protein vector (%) vegetable	74.5	76	77	75	74	See Section 3
protein vector (%) animal	25.5	24	23	25	26	"
animal protein vector (%) milk		62	61	60	57	"
animal protein vector (%) red meat		19.5	19	20	22	"
animal protein vector (%) fish		6	8	8	10	"
animal protein vector (%) poultry		1.6	2	2.4	6	"
animal protein vector (%) others						

SOURCES: Past data derived from FAO (1980), Agricultural Statistics of Pakistan (1978); projections by the author.

TABLE 5 Food supply for direct human consumption in the year 2000.

Commodity	Energy (10^{12} kcal)	Protein (10^3 t) Vegetable	Protein (10^3 t) Animal	Quantity needed for consumption (10^6 t)	Production requirement implied (10^6 t)
Wheat	59.4	1900		16.5 (flour)	20.6
Rice	13.2	275		3.7 (milled)	4.4
Maize (50% direct human)	2.1	50		0.6	1.2
Other grains (50% direct human)	1.3	30		0.4	0.8
Pulses	6.2	400		1.8	1.9
Sugar cane	19.8			5.0 (sugar equivalent)	60
Vegetable oil	10			1.2	
Milk (fluid equivalent)	10.7		580	16.5	20.6
Red meat	3.9		225	1.5	1.85 (carcass)
Fish	0.7		100	0.56	0.63
Poultry meat	0.2		20	0.17	0.19 (dressed)
Eggs	0.5		40	0.37	0.41

surplus. In fact, one might think of a country's cattle as a virtually "renewable" energy source on a local scale, e.g., exporting meat to buy oil! Indeed, this has quite favorable commercial energy economics (see Appendix), the secret being to let the ruminant do the value-adding. However, the quality of meat presently available in Pakistan would not be acceptable internationally, so that organized cattle farming needs to be developed with improved breeds. This new industry would take the usual penetration time and, with vigorous methods of persuasion and state initiative, Pakistan could expect an export potential of about 10% of domestic market by the year 2000.

To quantify these considerations, it is assumed that, in addition to the domestic requirement of 1.85×10^6 t carcass weight, 0.15×10^6 t could be exported, giving a total of 2.0×10^6 t of carcass to be produced annually. A breakdown of meat produced in 1977 (Agricultural Statistics of Pakistan 1978) shows that about 53% was from large animals (cattle, buffaloes) and 47% from small animals (sheep, goats); among the large animals, buffaloes and cattle contributed half of the meat each. The average weight of a carcass is about 11.5 kg for small animals, 82 kg for buffaloes and 114 kg for cattle, the lower figure for buffaloes being due to a tendency to slaughter young males. The annual offtake rate is about 50% of the total population of small animals, 10% for cattle, and 19% for buffaloes.

For small animals, no significant organized improvements are being made at present, nor planned for the future, so that no change in either average carcass weight or offtake rate is assumed. For large animals, however, there should be an increase in both indices as a result of better feeding and improved management. The following average figures are projected for the year 2000 in the light of present practices and existing interest in cattle breeding techniques.

	Average carcass weight (kg)	Offtake rate (%)
Buffaloes	100	30
Farm cattle (fattened)	200	100
Other cattle	140	15

It is further assumed that economic pressures will reduce the relative consumption of "small meat" from the present 47% to about 40% by the year 2000. With these assumptions in mind, the projected populations of small and large animals in the year 2000 are presented in Table 6.

It can be seen from Table 6 that the projected annual growth rate of buffaloes needed over the next 20 years is much higher than the rate achieved in 1971–76. Sustained effort is obviously required. In this report, however, we are concerned with the assessment of the necessary *physical* inputs, so we can assume that this effort will be made, and proceed to estimate the feed requirements of these animals.

TABLE 6 Actual and projected animal populations of Pakistan.

	Base year 1977 (10^6)	Year 2000 (10^6)	Projected annual growth rate (%)	Historical annual growth rate, 1971–76 (%)
Sheep and goats	48	130	4.4	8.6
Buffaloes	11	25	3.6	2.1
Farm cattle	0	1	–	–
Other cattle	15	17	0.5	0.3

SOURCE: Past data from Agricultural Statistics of Pakistan (1978); projections by the author.

An economical and manageable size for a cattle farm is about 500–1000 head (Williams *et al.* 1975), so about 3000–6000 such farms will need to be established by the year 2000, preferably located near a railway or road network for rapid transportation to ports or domestic consumption centers. In addition to hay, crop residues and other green fodder, the farm animals should be fed some fattening grain such as corn, preferably grown on the farms themselves. It is estimated (Williams *et al.* 1975) that cattle convert about 15% of the feed energy into meat. Using the calorific values of meat and maize, and assuming that corn grain supplies one-third of the total feed energy, an amount of 0.3×10^6 t of maize will be required as feed for farm cattle.

For off-farm sheep, cattle, and buffaloes, however, maize cropping, which requires both irrigation and fertilizers, may not be practicable. However, a new variety of grain called *triticale* (triticum = wheat + secale = rye) has been developed which has the grain qualities of wheat and the hardiness of rye. It can grow in dry areas and without much artificial fertilizer. While it may not yet be acceptable for human consumption, it is an excellent crop for pasture lands and provides a protein-rich grain supplement to hay and other fodder. Research on triticale is already under way in Pakistan (Naqvi 1980), and it should prove valuable in increasing the body weight (and so carcass weight) of sheep, cattle, and buffaloes reared on rangeland. It is assumed that the feed requirements of these animals will be met, as at present, by grazing and fodder grown on marginal land.

So far, the meat requirements have been discussed and attention is now turned to milk. Base year statistics (Agricultural Statistics of Pakistan 1978) indicate that 16% of the total cattle population and 33% of the total buffalo population is in milk, the average yield being 1630 kg yr^{-1} for cows. Figures for sheep and goats are not available, but from other data a whole population average of 10 kg yr^{-1} per animal may be inferred. The annual milk production from the animal populations shown in Table 6 would then be as follows:

Sheep/goats	1.3×10^6 t
Buffaloes	13.4×10^6 t
Cows	2.4×10^6 t
Total	17.1×10^6 t

This falls short of the anticipated milk demand by about 17%, so that organized dairy farming (with more productive buffaloes) and possibly some imports will also be needed. The maize feed of dairy animals is estimated at 0.9×10^6 t by using a figure of 11.5% for the conversion efficiency (Williams *et al.* 1975) from feed energy to milk calories, assuming that maize supplies 33% of the energy and that half of the milk shortfall will be met by imports. In total, therefore, 1.2×10^6 t of maize will have to be grown annually for animal feed by the year 2000.

4.2 Poultry

While ruminants can digest and convert roughage and cellulose, which are of no use to humans, poultry have to be fed grains and fish concentrates and thus, in some respects, compete with humans for food. However, they are more efficient converters of feed and, in any case, this is mostly obtained from broken grains and other unusable material inevitably produced during the milling of rice and grinding of wheat. The figures used in this report (see Table 3) are about 20% for wheat and 16% for rice, including about 5% for seed. Since there is always some waste which cannot be used for feed, it can be assumed that 8% of rice and 10% of wheat produced are potentially available for feed, of which roughly 75% may be allotted to poultry. Using the relevant production estimates from Table 5, it is expected that 1.6×10^6 t of "waste" from wheat and about 0.3×10^6 t from rice could be available for poultry feed; to this may be added 0.2×10^6 t from other grains, making a total of 2.1×10^6 t.

It is estimated (Holmes 1977, USNAS 1977) that broilers and layers require an amount of feed about 2.5 times the weight of dressed meat or eggs yielded. Since we have projected (Table 5) an annual requirement of 0.6×10^6 t of poultry produce by the year 2000, about 1.5×10^6 t of feed will be required, of which about 10% (0.15×10^6 t) could come from fish meal. Thus grain waste will be sufficient to meet poultry feed requirements.

4.3 Fish

The production of fish in 1977 was about 0.233×10^6 t of marine and 0.033×10^6 t of freshwater fish. The marine fish catch is very poor considering the length of coastline of over 1000 km. In contrast, another Asian country, Thailand, which has 3000 km of coastline, landed as much as 2.2×10^6 t of marine fish. Baluchistan, which has the major share of coastline, contributed less than a third of the total marine catch. Attention is now being given to the promotion of both freshwater and marine fisheries, the latter particularly along the Mekran coast. Considering the present low level of productivity, it should not be too difficult to raise the catch over the next two decades to the 0.8×10^6 t required for human consumption and fishmeal preparation. The finance required will be a small proportion of national resources, and the purchase of modern trawlers could easily be financed under an existing loan scheme of the Agricultural Development Bank of Pakistan. Surprisingly the share taken by fisheries *dropped* (Agricultural Statistics of Pakistan 1978) from 3.7% of the total credit granted in 1976–77 to 0.5% in 1977–78. Active promotion of the industry is therefore indicated, and there do not appear to be any physical limitations to growth.

Estimates of energy required for fishing vary widely (Leach 1975, Bardach 1980), depending upon country and the type of fishing, such as deep-sea or not, size of trawlers, etc. Assuming half the US average energy consumption per tonne of fish caught (Leach 1975) as nearly appropriate for Pakistan in the year 2000, we arrive at a requirement of 0.6×10^6 t of oil.

5 TOTAL PRODUCTION TARGET

In order to arrive at a total agricultural production target, we will now proceed to estimate the requirements of plant-derived material for industry and export. The major agricultural exports, by value, are rice and cotton; carpets are also agriculturally based but the requirements are assumed to be met by the sheep population. Sugar cane supplies industry, but that has been taken into account. The remaining items are rice (for export), cotton (for domestic industry and export), oilseeds, fruits, and vegetables.

5.1 Rice for Export

In 1977, the base year, 0.9×10^6 t of rice were exported, i.e. roughly 30% of total produced. With active export promotion, perhaps roughly the same percentage may be maintained, so that an annual export of about 1.8×10^6 t of rice by the year 2000 can be expected.

5.2 Cotton

The domestic requirement for textiles may be expected to increase rapidly, but the effect is likely to be offset by a decrease in exports as competition becomes more rigorous. Thus, it might not be prudent, even if it were possible, to plan for an increase in cotton production by more than 60% by the year 2000. Even that would require an annual growth rate higher than the average achieved in 1970–77. The target annual production is then 0.8×10^6 t of cotton lint by the year 2000.

5.3 Oilseeds

The principal oilseeds grown in Pakistan are cotton-seed, rape/mustard, ground nuts, etc. The quantities produced at present are not sufficient to meet domestic requirements, so that nearly 0.35×10^6 t of edible oil (a little more than half of which is soybean and the rest palm oil) have to be imported. Some substitution of palm oil could perhaps be made by sunflower oil, but not to any significant degree. It would be fruitful to make an effort to increase public acceptance of rape/mustard oil by necessary deodorization but without hydrogenation, and we therefore anticipate an increase in rape/mustard production from about 0.24×10^6 t in 1977 to 800,000 t in the year 2000. Having an oil content of 40%, this would then meet about 30% of the projected vegetable oil requirements. Other minor oilseeds will not be considered separately; their input requirements will be included by an *effective* increase in rapeseed production to 0.9×10^6 t.

5.4 Fruits and Vegetables

Fruits are "permanent" crops and do not require tilling, sowing, or fertilizers every year. They are also capable of obtaining their own water requirements from the ground although under Pakistan's conditions, the water needs to be supplemented by some irrigation. More orchards need to be planted in order to meet domestic demand and possibly to generate an export surplus. The area under fruit crops is therefore expected to double by the year 2000, i.e. an increase of 0.25×10^6 ha.

Vegetables occupy less than 0.15×10^6 ha of land, and are usually grown on any available ground in villages or around towns. They do require good land and a lot of care but do not contribute significantly to commercial energy input requirements.

Neither fruits nor vegetables are therefore considered as a separate category, so that any energy requirement is assumed to be included in a an aggregate increase of the final total.

5.5 Total Requirements

Direct human needs, animal feeds, industrial, and export needs are all added together and presented in Table 7. Note that since the feed requirements of cattle and poultry have been incorporated in agricultural crops, meat, milk, etc., they are no longer presented separately.

TABLE 7 Annual agricultural production of Pakistan (actual 1977 and targeted 2000).

Commodity	Production in base year, 1977 (10^3 t)	Production in year 2000 (10^3 t)	Annual growth rate (%)	
			Projected	Historical
Wheat	8750	21,000	3.9	4.0 (25-yr av.)
Rice	2840	6200	3.5	5.4 "
Maize	790	2600	5.3	2.8 "
Other grains	710	1000	1.4	2.4 "
Pulses	830	1900	3.6	1.2 (10-yr av.)
Sugar cane	30,000	60,000	3.0	3.0 "
Oilseeds (rape/mustard equivalent, excl. cotton seed	350	900	4.2	1.9 "
Cotton	500	800	2.1	1.0 "
Fish	267	1000	5.9	6.2 (8-yr av.)
Fruits and vegetables	1700	Not projected separately		

SOURCE: Base year production figures taken from Agricultural Statistics of Pakistan (1978); average for year 1976–77 and 1977–78 has been calculated where applicable. Projections are by the author. Historical growth rates derived from PARC (1980) and from Agricultural Statistics of Pakistan (1978).

In order to meet the production targets indicated in Table 7, there are three distinct ways to tackle the problem:

(i) to increase the physical size of the areas cultivated;
(ii) to increase the cropping intensity by bringing a greater proportion of the cultivated area under multi-cropping;
(iii) to increase the yield per unit area.

A glance at the production targets shows that reliance on alternative (i) alone is out of the question; this would require roughly three times the base year area, which is simply not available. Emphasis will therefore have to be placed upon the last two courses of action, i.e. to increase the effective *cropped* area and to improve yields through better farm management and higher inputs of water, fertilizer, pesticides, etc. Physical inputs are considered in detail below, but it must be stressed that the improvement of crop practices is equally important, including (a) more careful preparation of land; (b) the maintenance of recommended seeding densities; (c) timely applications of water and fertilizers; (d) regular weeding; (e) ensuring proper plant spacing, etc. These measures are a matter of training, care, attention, and somewhat increased labor, and could increase productivity levels even *without* additional commercial inputs. This message must be effectively carried down literally to the grass roots; without better agricultural practices, the 'green revolution' will not have the desired results and may even have a *negative* effect. For example, if a field has not been weeded, the fertilizers will provide nourishment to the weeds which would compete with the food crop more effectively than before!

With these few words on the importance of better farm management, we can now proceed to the main task of this report, i.e. the estimation of the physical inputs and their energy equivalents. We start with the consideration of land requirements.

6 LAND REQUIREMENTS

The evolution of land utilization in Pakistan over the six-year period 1971–77 is presented in Table 8. It can be seen that whle the total cultivated area increased only marginally, the area multi-cropped registered an average growth rate of 6% per year; this is the right trend and should be encouraged. The distribution of areas under different crops, and the changes needed over the next two decades, are discussed below.

TABLE 8 Evolution of land use in Pakistan, 1971–77.

	1971	1973	1975	1977	Average annual growth rate 1971–77 (%)
(1) Estimated total arable land (10^6 ha)	30.3	30.4	30.6	30.6	
(2) Actually under cultivation (10^6 ha)	19.1	19.3	19.7	19.9	1
(2a) Of which fallow (% of 2)	25	24	24	24	
(2b) Of which irrigated (% of 2)	68	69	68	69	
(3) Area sown more than once (10^6 ha)	2.3	3.0	2.8	3.2	6
(4) Total cropped area (2 – 2a + 3) (10^6 ha)	16.6	17.6	17.7	18.3	2

SOURCE: Agricultural Statistics of Pakistan (1978).

6.1 Wheat

The area under wheat increased from about 4.1×10^6 ha in 1950–55, to 6.3×10^6 ha in 1975–79 (PARC 1980), i.e. an increase of a little over 50% in 25 years. However, over the period 1977–2000, it is unrealistic to predict an equal increase in area because any new land available will naturally be less accessible and more difficult to bring under cultivation. One possible and logical step would be to bring some of the presently unirrigated land under irrigation in addition to opening up new areas. It is thus assumed that by the year 2000, the irrigated area will increase by 33% and that the unirrigated area will *decrease* by 25%, giving a net increase of only 1.2×10^6 ha under cultivation; the implications of this projection will now be discussed.

The 1977 yields of wheat reached 1700 kg ha^{-1} on irrigated and 640 kg ha^{-1} on unirrigated land. Although the high-yield varieties of wheat give best results with ample water, we can anticipate an increased yield on unirrigated land, say to 1000 kg ha^{-1}. The rest of the requirement will have to be met from high-yield varieties grown on irrigated land. The situation is summarized in Table 9.

TABLE 9 Wheat: area, total production, and yields in Pakistan.

	1977		2000		% increase	
	Irrigated	Unirrigated	Irrigated	Unirrigated	Irrigated	Unirrigated
Area (10^6 ha)	4.8	1.6	6.4	1.2	1.2	(–) 0.8
Total production (10^6 t)	8.1	1.0	19.8	1.2	4.0	0.8
Yield (kg ha^{-1})	1700	640	3100	1000	2600	2000

It can be seen that the average yield of irrigated land must increase to about 3100 kg ha^{-1} by the year 2000. This is by no means an unattainable target (the *present* figures for Mexico, France, and the UK being 3500, 5000, and 5100 kg ha^{-1} respectively; FAO 1979), but will doubtless require better land management and higher inputs of fertilizers, etc. Much higher productivities have been achieved in 55 demonstration farms (Muhammad 1978); the national average yield (duly weighted with the area contributing to wheat in each district) obtained was 4165 kg ha^{-1} on irrigated land (with application of 135 kg ha^{-1} of nitrogen and 67.4 kg ha^{-1} of phosphate) and 2305 kg ha^{-1} on unirrigated land (with application of 55.6 kg ha^{-1} of nitrogen and of phosphate). The yields achieved on demonstration farms are often much higher than national averages, and serve to illustrate the productivity *potential* of the land. The yields envisaged here, both for irrigated and unirrigated land, are therefore well within the domain of feasibility, provided adequate inputs, particularly of fertilizers, are supplied. Other inputs will be discussed separately below.

6.2 Rice

The production target for rice in the year 2000 is 6.2×10^6 t as compared with 2.9×10^6 t in 1977. The main varieties grown are the aromatic Basmati and the high-yield IRRI, the former being the favored export variety. Therefore, while the production of Basmati, even with its lower yield potential, must continue to be encouraged, efforts should also be made to extent IRRI almost exclusively to other areas. It should therefore be possible to meet the target without a large increase in crop area and with modest increases in the yield of non-IRRI varieties. This rather low target for rice is assumed

TABLE 10 Rice production in Pakistan.

	Base year, 1977[a]				Year 2000				% Annual increase of totals
	Basmati	IRRI	Other	Total	Basmati	IRRI	Other	Total	
Area cropped (10^6 ha)	0.52	0.76	0.54	1.82	0.8	1.5	0.12	2.42	1.2
Total produced (10^6 t)	0.61	1.5	0.74	2.85	1.4	4.6	0.2	6.2	3.4
Yield (kg ha^{-1})	1200	2000	1400	1570	1700	3050	1700	2560	2.2

[a]Average of 1976–77 and 1977–78.
SOURCE: Agricultural Statistics of Pakistan (1978).

because it is, and is likely to remain, a crop of secondary importance relative to wheat. Table 10 presents the projected area increases required to meet the demand. It is hoped that a doubling of the area under IRRI will be accompanied by a 50% increase in that producing Basmati, with a reduction in the cropping of other varieties. Marginal increases in yields per hectare of non-IRRI rice are expected; the yield of IRRI will need to be increased by a little more than 50% to 3050 kg ha^{-1} using more and better applied fertilizers. For comparison, the average rice yield in Japan is over 6000 kg ha^{-1}, and in the US and Egypt about 5000 kg ha^{-1}.

The total increase in cropped area should be 0.6×10^6 ha, of which half may be assumed to be double-cropped with wheat so that only 0.3×10^6 ha of virgin land would need to be brought under cultivation.

6.3 Maize and Other Grains

A substantial increase in maize production over base year production is anticipated, mainly due to its use as fattening feed for farm cattle. The production requirement can be met by increasing the irrigated area to 0.7×10^6 ha with an average yield of 3400 kg ha^{-1} (the corresponding figure in the US in the late 1970s being around 5000 kg ha^{-1}). The unirrigated area may be maintained at its present level, but yields should be increased from about 750 to 1100 kg ha^{-1} through better techniques and more extensive use of fertilizers. Since maize needs a lot of nutrition, it is not advisable to double-crop it with another major crop, but preferably with legumes, partly for human consumption and partly to be ploughed under as green manure.

The anticipated increase in production of other minor grains is not great, and this could be met by the acquisition of an additional $0.1–0.2 \times 10^6$ ha of semi-arid land, possibly in Baluchistan. No appreciable commercial energy inputs will be required, except perhaps for the installation of some scattered tube-wells.

6.4 Sugar Cane

Over the ten years 1967–77, sugar cane production increased at an average annual rate of 3%, solely due to an increase in the area cropped. This trend cannot continue indefinitely, however, but the yield should also be increased. It is therefore assumed that by the year 2000 the yield will improve by about 50% to 55 t ha^{-1}, which is roughly the present Indian production level, but far below that of Egypt or the US. The total cultivated area required will then be 0.95×10^6 ha, i.e. just 0.15×10^6 ha more than in 1977.

6.5 Cotton

Here again, there is considerable scope for an increase in yield and we shall assume an increase of 60% over the projection period, so that the entire additional demand could be met without any further increase in area. The target cotton lint yield is 430 kg ha^{-1}, compared with Egypt's 680 kg ha^{-1} and Mexico's 900 kg ha^{-1}, figures achieved in the 1970s.

6.6 Fruit Orchards

An increase of about 0.25×10^6 ha under fruit orchards is required, which could be partly irrigated and partly rain-fed.

6.7 Overall Land Requirements

Pulses and rapeseed would mostly be double-cropped with major crops and so would not contribute to additional land requirements. Water and fertilizers would be needed, but to a much lesser extent than for the major crops; e.g. the optimum water requirement for rapeseed is about 0.3 ha-m ha^{-1} and pulses would need little, if any, nitrogenous fertilizer. The total additional land requirements are summarized in Table 11.

From Table 11 it can be seen that a rather modest increase in cultivated area will be sufficient to meet the production targets, provided water, fertilizer, etc., are supplied in adequate quantities for increasing the specific yields. The energy requirements for clearing this land, spread over 23 years, will be a small fraction of the total energy spent

TABLE 11 Land requirements for major crops (10^6 ha).

Crops	Cropped area in base year, 1977		Additional area by year 2000		
			Virgin land		Multi-cropped (irrigated)
	Irrigated	Unirrigated	Irrigated	Unirrigated	
Wheat	4.8	1.6	1.6	(–)0.4	
Rice	1.8	0.03	0.3		0.3
Maize	0.44	0.2	0.26		
Coarse grains	1.3			0.2	
Sugar cane	0.8		0.15		
Cotton	1.8				
Pulses and oilseeds	2.0				1.0
Fruits	0.25		0.1	0.15	
Total (major crops)	16.0		2.4	~0	1.3

in tilling, etc., during that period and is assumed to be included in the final aggregate increase. With regard to investment, the major share will be spent on the establishment of a water supply infrastructure, such as canals and tube-wells. At present, about 60% of the water used in farming comes from canals and the rest from wells. Since no more large-scale dams are planned, this proportion is likely to change in favor of tube-wells and the new land opened will probably depend more upon groundwater than canals. Let us assume that, out of the 2.4×10^6 ha of virgin land, 1.8×10^6 ha are irrigated by tube-wells and 0.6×10^6 ha by canals. The building of small dams and digging of canals are labor-intensive activities requiring comparatively little capital, so we can focus on the tube-well investment. Agricultural tube-wells have a delivering capacity of about 0.03 $m^3 s^{-1}$ and work for about 1000 h per crop season. Taking an average of 1 ha-m ha^{-1} of water for all crops, we arrive at a requirement of one tube-well for every 11 ha, or a net increase of about 165,000 tube-wells by the year 2000. This implies an average annual increase of only 3% compared to an eight-year average (1969–77) of more than 8% per year (Agricultural Statistics of Pakistan 1978). Thus the investment required is well within national capability.

7 WATER REQUIREMENTS

Water and fertilizers are two major components of commercial inputs to agricultural intensification. In this section, we explore the implications of supplying recommended volumes of water to all important crops, as given in Table 12.

TABLE 12 Recommended water requirements of important crops in Pakistan.

Crop	Season	Water requirement (m)
Wheat	Rabi (spring harvest)	~0.5
Rice	Kharif (autumn harvest)	1.3–1.7
Sugar cane	Kharif	2–2.2
Cotton	Kharif	0.5–0.7
Maize	Kharif	0.5–0.7
Rapeseed and mustard	Rabi	~0.3

SOURCE: PARC (1980).

Calculation of the total water requirements in the two main seasons in Pakistan is now a matter of arithmetic, including a margin to cover losses and also crops not accounted for explicitly (including fruits and vegetables), although estimating this margin requires some care. The crops not included are pulses, fruits, and vegetables, since none of these requires large amounts of water. Together they account for about 30% of the cropped area and may be assumed to need about 0.3 m of water, divided roughly equally between the Kharif and Rabi seasons (i.e., $12 \times 10^9 m^3$ per season). Since evaporation in the fields is a surface phenomenon, it will be proportional to the area rather than the volume of water. In order to estimate the energy requirements of supplying the water, we have to make certain assumptions about the relative contributions of canals and groundwater, motor and pump efficiencies, etc., as follows.

(i) In the Kharif season there will be, as at present, considerably more canal water available, and the ratio of Kharif:Rabi water supply at the farm gate will be maintained near the present value of 3:2.

(ii) With increasing rural electrification, more electric- than diesel-operated tube-wells could be installed and the electric-to-diesel ratio will rise from the base year value of 5:9 to near equality (1:1). Moreover, electric pumps do somewhat more work than diesel pumps.

(iii) Surface irrigation will also require energy where pumping is involved, but the amount will be negligible in comparison with tube-well requirements.

(iv) About 30,000 kcal of useful energy are expended in lifting 1 ha-m of water through 1 m, allowing for pipe friction and the discharge velocity of water. The conversion efficiency from final to useful energy is taken as 65% for electric pump sets and 20% for diesel ones; these values are fairly typical.

(v) The water table is assumed to be at an average depth of 6 m; this value, inferred from 1977 energy consumption data, also seems reasonable from other sources. This leads to an oil consumption in pumping of 0.9×10^6 kcal ha-m^{-1}, which is comparable with estimates of 2.1×10^6 kcal ha-m^{-1} (Revelle 1976) from India where the water table is possibly much deeper.

(vi) The energy used by drainage tube-wells (in reclaiming land in waterlogged and saline areas) is considerable. The striking difference in load characteristics between drainage and irrigation tube-wells can be seen in electricity consumption statistics (WAPDA 1979, Energy Yearbook 1979). In 1977 drainage tube-wells consumed 120 MWyr of electricity while other electric (irrigation) pumps used only half as much. The load imposed by drainage tube-wells is expected *ad hoc* to double by the year 2000.

Based on the above assumptions, the final energy requirements for 1977 and 2000 are presented in Table 13. We see that energy requirements for irrigation are not high enough to necessitate conservation measures on that account alone, but there are other effects that ought to be considered. For example, indiscriminate irrigation practices

TABLE 13 Final energy demand for irrigation and drainage.

	Base year 1977			Projections for 2000		
	Kharif	Rabi	Total for year	Kharif	Rabi	Total for year
Total water at farm gate (10^6 ha-m)	6.2	4.6	10.8	10.5	7.5	18
from canals	4.4	2.8	7.2	5.4	3.6	9
diesel tube-wells	1.1	1.1	2.2	2.4	1.8	4.2
electric tube-wells	0.7	0.7	1.4	2.7	2.1	4.8
Energy consumed by irrigation (TW)						
diesel (10^3 toe)	98	98	196	225	175	400
electricity (MWyr)	31	31	62	110	90	200
Energy consumed by drainage (TW)						
electricity (MWyr)			118			250
Total electricity in agriculture (MWyr)			180			450

(especially in fields with inadequate drainage) could lead to a significant raising of the local water table, resulting in waterlogging. Also, excessive evaporation could raise the soil salinity. These two problems are already being faced in Pakistan today, so that water economy measures such as root irrigation (using plastic pipes) or sprinkler irrigation should be considered in future. It has been estimated by Gilley and Watts (1979) that irrigation efficiency improvements of 50% and above could be achieved through run-off re-use, sprinkler or trickler systems.

8 MAN- AND MACHINE-POWER

Much of the farming work in Pakistan is still labor-intensive with the aid of animals, usually bullocks; only 2×10^6 ha, i.e., about 10% of total cultivated area, had been tractorized in 1977. There are two schools of thought regarding farm mechanization in developing countries: one for and the other against.

The "pro" school maintains that farm machines (a) help in the rapid preparation of land for multi-cropping; (b) enable vigorous turning of the soil to kill weeds, air the soil and to improve porosity; (c) reduce the number of animals competing for fodder, resulting in better-nourished cattle; (d) improve water availability; and (e) release farm labor to more productive employment off the field.

The "con" group, on the other hand, disputes the validity or positive aspects of most of these points and emphasizes the negative consequences; e.g. that fewer animals would also result in less organic material for the soil, etc. While the controversy is unlikely to be resolved in the near future, it is axiomatic that what people actually do or have done over a sufficiently long period must essentially be profitable to them. Since there has been a definite trend towards tractorization in Pakistan, it must be advantageous to farmers in some way, and the process is likely to continue unless the state decides that it is against broader societal interests. Furthermore, the trend shown in Figure 1

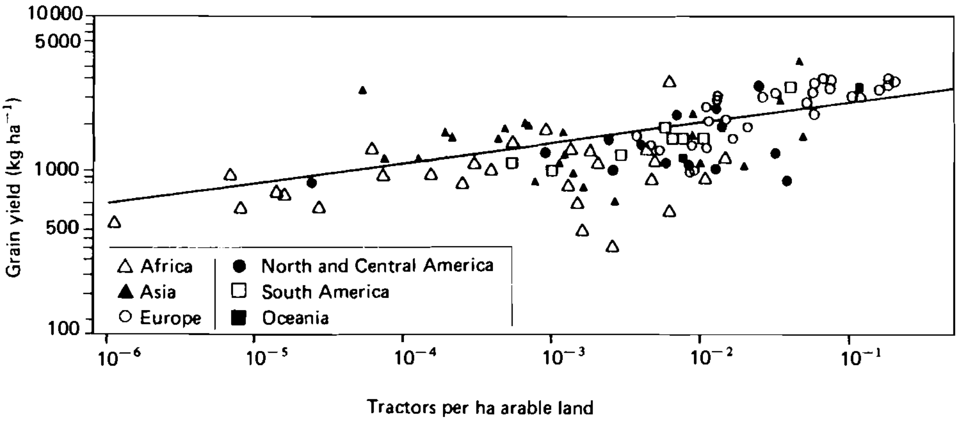


FIGURE 1 Yield of cereals per ha versus tractor use per ha of arable land (1970), using five-year averages of 107 countries. Source: Heumann *et al.* (1980).

does indicate an interesting correlation between productivity and the number of tractors per hectare, although of course the latter cannot be regarded as the sole, or even the main explanatory variable.

Since the issue brooks more than one opinion, we have explored three alternative futures:

Future A (high mechanization): Approximately 75% of the area under major crops (wheat, rice, sugar cane, and cotton) is expected to be mechanized by the year 2000, both for ploughing and harvesting; 50% of the remaining cropped area will be mechanized for tilling only. This can be assumed to be the upper limit because 33% of the total cultivated area is under farms of 5 ha or less whose owners are unlikely to opt for mechanization even under cooperative schemes.

Future B (low mechanization): 25% of the area under major crops and 20% of the remainder is mechanized. This would appear to be the lower limit since 10% of total cultivated area was already tractorized in 1977.

Future C (low mechanization, low tillage): The same degree of mechanization is projected as in Future B, but with 33% of the non-mechanized area cultivated with low-tillage techniques. Low tillage has the additional advantages of reducing soil erosion and damage to the biological components of the soil.

In order to assess the fuel requirements of each of these alternatives, we need estimates of useful energy requirements for farmwork (excluding irrigation, which has already been discussed); these are presented in Table 14, based on data collected by the Pakistan Agricultural Research Council (1980) for the average number of man- and bullock-hours needed for different types of work.

TABLE 14 Estimated average effort required per hectare for different farm operations.

Operation	Number of men	Pairs of bullocks	Hours worked	Total energy expenditure (10^3 kcal)[a]
Ploughing, planting, leveling	1	1	22	19.5
Sowing of wheat	1	1	5	4.4
Harvesting of wheat	4	–	12	1.2
Threshing of wheat	3	3	15	40
Winnowing of wheat	4	–	15	1.5
Sowing of rice	4	–	20	2.0
Harvesting of rice	5	–	20	2.0
Threshing of rice	4	–	12	1.2
Hoeing of sugar cane	4	–	20	2.0
Sowing of sugar cane	9	1	15	16
Cutting and stripping of sugar cane	25	–	32	20
Sowing of cotton	1	1	5	4.4
Interculture of cotton	4	–	20	2.0
Picking of cotton	5	–	10	1.0
Fertilizer spreading	1	–	3	0.15
Manure hauling and loading	2	1	5	4.6
Manure spreading	2	–	5	0.25

[a]Based on 25 kcal h^{-1} for humans and 430 kcal h^{-1} for bullocks as inferred by Revelle (1976).

For converting the above requirements into final energy inputs, the following factors need to be taken into account.

(1) With tractors, deeper tilling is possible and so the useful energy requirement is greatly increased, perhaps by a factor of 4.
(2) The actual useful energy available at the implement in contact with the ground is assumed to be 20% of the final energy input, which is typical of oil-powered machines.
(3) For harvesting and threshing, the increased yields required in the year 2000 need to be taken into account; the figures per hectare are multiplied by a factor of 2.
(4) The efficiency of harvesters/threshers is also assumed to be 20%, as in the case of tractors.

The factors assumed in (1) and (3) above may appear *ad hoc*, but they lead to a figure of 8×10^5 kcal of fuel energy per hectare of wheat cultivated, which is remarkably close to the 9×10^5 kcal ha^{-1} derived by Pimentel (1979) from US Department of Agriculture data. Thus the useful energy considerations correlate with actual energy consumption data from a highly mechanized country.

8.1 Final Energy Requirements for the Three Futures

The final energy requirements* of farming in the year 2000 for the three alternative scenarios are presented in Table 15, which also includes 1977 data for comparison.

TABLE 15 Final energy demand for farmwork excluding irrigation.

	Cropped area (10^6 ha)		Final energy required for tilling/harvesting (10^{12} kcal)			
	1977	2000	1977	2000		
				Future A	Future B	Future C
Wheat	6.4	7.6		4.6	1.5	1.5
Rice	1.8	2.4		0.9	0.3	0.3
Sugar cane	0.8	0.95		0.3	0.1	0.1
Cotton	1.8	2.8		1.1	0.4	0.4
Others (tilling only)	6.5	8.2		1.6	0.7	0.7
Total	18.3	22	0.85 (0.08×10^6 toe)	8.5 (0.8×10^6 toe)	3.0 (0.28×10^6 toe)	3.0
Additional pesticides[a]						1.4
Total (Future C)						4.4 (0.41×10^6 toe)

[a]Calculated @ 10 kg of pesticide for each hectare under low-tillage techniques and 24,000 kcal kg^{-1} for pesticides (Leach and Slesser 1976).

*A word is in order here about the omission of the energy requirements for the *production* of farm machinery which is usually included by authors in advanced countries (see, e.g., Pimentel 1979). The estimates are well known, but we do not envisage significant domestic production of tractors, etc., over the next two decades. Some threshers may be produced but the energy needed for that would be too small to change the picture.

Thus, we see that, solely on commercial energy considerations, the introduction of low-tillage practices will not be particularly advantageous unless a less costly way to control weeds than using pesticides is developed. One possible way is to focus on the genetic or hormonal control of weeds (Marchetti 1979). This is not likely to have an impact over the next two decades, however, so Future C does not appear to be feasible.

8.2 Financial Requirements

The larger tractors cost about 60,000 rupees (1977), and they can serve about 30–40 ha. The approximate number of tractors required in the year 2000 would thus be 450,000 for Future A and 160,000 for Futures B and C. In 1977 about 60,000 tractors were in use, so there will need to be a net increase of approximately 9% per year for Future A, and 4.4% for Futures B and C. Both figures are within the limits of possibility.

For estimating the total finance needed, we may assume that the working life of a tractor is 12 years. The total cost over the 23-year period (tractor prices are not likely to increase in real terms; the prices are assumed constant in 1977 rupees), will be 37 billion (10^9) Rs (1977) in Future A and 16 billion Rs in the other cases. Assuming a modest 4% annual investment growth rate in farm machinery, the 1977 commitment required to meet the cumulative figure is about one billion Rs (1977) for Future A, and 450 billion Rs for Futures B and C. These figures are to be compared with the loans of 325 million Rs granted in 1977–78 to farmers by the Agricultural Development Bank of Pakistan for the purchase of tractors, power tillers and attachments (Agricultural Statistics of Pakistan 1978); commercial banks give about two to three times as much. Thus, for Futures B and C, there do not appear to be any financial difficulties in implementation, but Future A may turn out to be resource-constrained.

9 NUTRIENT REQUIREMENTS

The significant increases in average yields discussed in Section 6 will not be possible without appropriate application of macronutrients such as nitrogen, phosphorus, and potassium. Nitrogen, the most important, will be discussed in detail.

9.1 Nitrogen

The dependence of crop yields on nitrogen application has been widely studied and reported (Hardy and Havelka 1975, Vohra and Robinson 1977, USNAS 1977, I Singh 1979). While there are differences in detail, two overall trends are clear.

(i) Beyond a certain value (between 70–80 kg ha^{-1} nitrogen applied), the marginal utility of fertilizer application begins to decrease.

(ii) Up to that value, the relationship is almost linear despite large variations in climate, soil, etc. Typical curves, adapted from the literature, are reproduced in Figure 2; the actual yields vary from crop to crop and from region to region, and those shown here are only indicative.

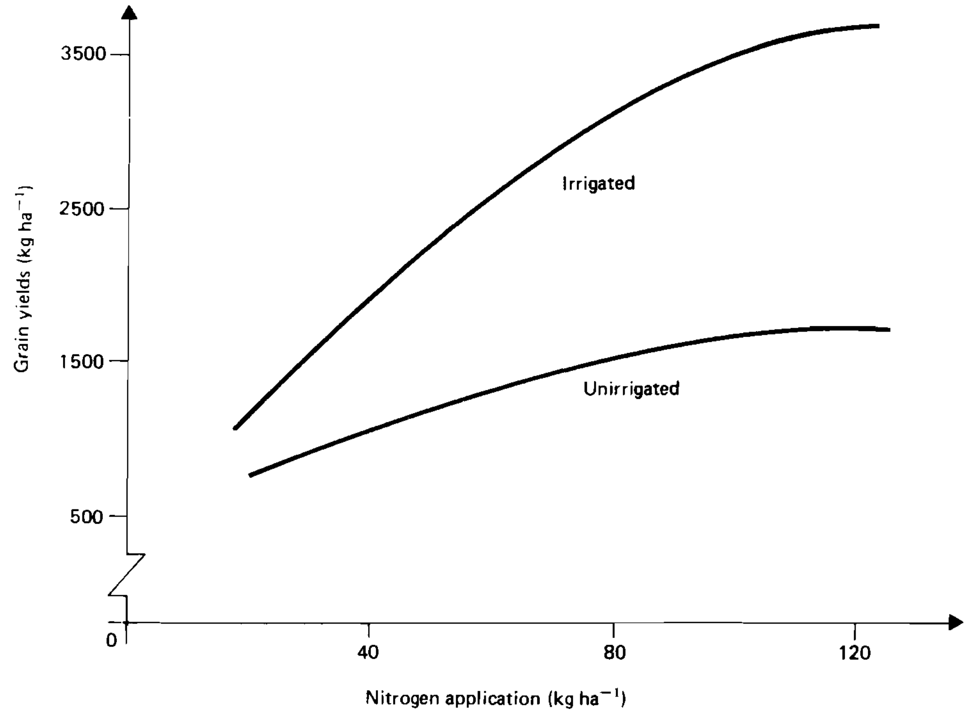


FIGURE 2 Typical response curves of high-yield varieties to nitrogen application.

The general trends depicted in Figure 2 are of little use to the farmer who needs to be told the specific needs of his crop under given conditions, but they are useful in the overall assessment of fertilizer requirements of a country or a region. The planned yield of wheat is 3100 kg ha^{-1}, of rice 3050 kg ha^{-1} and of maize 3400 kg ha^{-1}, but these figures are in the region of the upper right-hand corner of Figure 2, where data are least reliable. A reasonable estimate of fertilizers required is nevertheless 80–110 kg ha^{-1} under well irrigated conditions. This figure can be compared with the Ziauddin experiments reported by Muhammad (1978) in which an application of 135 kg ha^{-1} of nitrogen led to average wheat yields of over 4100 kg ha^{-1}. The total nitrogen need can therefore be estimated by taking an average value of 100 kg ha^{-1} for irrigated, and 50 kg ha^{-1} for unirrigated areas. Since the amount of nitrogen actually taken up by a plant is only 30–40% of that applied externally, the need for fertilizer could be significantly reduced if clear instructions are given to the farmers as to *when* and *how* to apply it. These figures are therefore somewhat overestimated and serve only to establish an upper bound to the annual nitrogen nutrient required by the year 2000. The various alternatives will be discussed below.

Using the above data, and assuming 16×10^6 ha irrigated and 6×10^6 ha unirrigated, the total nitrogen nutrient requirement works out to 1.9×10^6 t yr^{-1} by the year 2000. The consumption of industrially produced nitrogen in 1977 was about 0.6×10^6 t, of which nearly 0.35×10^6 t was produced within Pakistan; thus an average annual compound growth rate of 5.1% in consumption* and 7.6% in production can be expected.

Two scenarios will now be considered for meeting these estimated requirements.

Future D: The entire nutrient requirement will be met by chemical fertilizers.

Future E: The nutrient requirement will be met to the greatest extent feasible by manure/crop residues and only the balance by chemical fertilizers. As a variant of this future, the introduction of biogas plants will also be discussed.

Future D

We may assume that none of the plants producing fertilizers in the base year will still be operating in the year 2000. However, a number of new plants are nearing completion, under construction or firmly committed; their total capacity is 1.1×10^6 t of nitrogen nutrient per year. Assuming an average operating level of 80%, the annual production by these plants would be 0.88×10^6 t, leaving a shortfall of about 10^6 t. An additional annual capacity of about 1.2×10^6 t of nitrogen nutrient is thus required to meet the expected demand of 1.9×10^6 t yr^{-1}.

The average economical size of a natural gas-based fertilizer plant is 1700 t per day of urea, which translates into 0.29×10^6 t of nitrogen per year. Four such plants would thus need to be constructed between 1985 and 2000; at an estimated outlay of about 2.5 billion Rs (1977) per plant, this would mean an investment of 10 billion Rs over 15 years. This is a sizable amount, and is by no means a negligible fraction of Pakistan's investment resources (the total industrial investment in 1976–77 was little over 6 billion Rs). Such an investment may be unnecessary, as will be seen in the discussion of Future E, but could possibly be justified, without reference to domestic agriculture, as an export-oriented industry.

We will now proceed to calculate the energy input required for the production of 1.9×10^6 t of nitrogen nutrient; estimates vary from about 0.013 to 0.019 kcal kg^{-1} of nitrogen produced. From data available for Pakistan, a value near the upper end of the range is considered appropriate and, accordingly, the calculations are based on a mean value of 0.018 kcal kg^{-1}. The energy requirement for 1.9×10^6 t of nitrogen is 34.2×10^{12} kcal, or 3.2×10^6 t of oil-equivalent (toe), or (since most of the industrial feedstock and fuel needs are met by natural gas) $3.8 \times 10^9 m^3$ of gas. For comparison, the total consumption of natural gas in Pakistan was about $6 \times 10^9 m^3$ in 1977.

Future E

While discussing the nitrogen requirements of crops, alternatives to chemically synthesized urea or other compounds should also be considered and evaluated. Two of these are considered below.

Biological fixation of nitrogen: The most important nitrogen-fixing system is the *Rhizobium*–legume symbiosis in which the *Rhizobium* bacteria occur in the root nodules of leguminous plants such as pulses commonly grown in subtropical countries including

---

*The Fertilizer Board of Pakistan has projected an annual consumption of over 0.9×10^6 t by 1982–83, implying a much faster growth rate of around 9% per year in the short term.

Pakistan. The plant provides an environment for the bacteria which in return fix atmospheric nitrogen. It is estimated (Hardy and Havelka 1975) that on a global scale, *Rhizobium*–legume symbiosis contributes 40 X 10^6 t of nitrogen annually to grain legumes, as well as a major part of the 40 X 10^6 t of nitrogen fixed in permanent meadows; these quantities are the same as the 40 X 10^6 t of fertilizer nitrogen produced by man in 1974. Active research (Hardy and Havelka 1975, Nutman 1976) is underway – so far with little success – to establish an associative symbiotic relationship with non-leguminous plants, particularly cereal grains. The breakthrough, if and when it comes, will bring about a second "green revolution" in agriculture, but until then we must continue to rely upon externally applied nitrogen, except for the technique of green manuring in which legumes may be grown preceding or following a cereal grain crop and partly cut into the soil.

Animal and crop waste: Both animal and crop wastes are rich in nitrogen and are traditionally composted to make manure. However, crop residues such as rice stalks and bagasse also serve as fodder for farm animals and, since we anticipate a substantial increase in cattle and sheep numbers to raise the protein content of human food, crop residues would be better used as fodder, and only animal waste considered as a soil fertilizer. Table 16 lists estimates of daily manure production by major farm animals and their nitrogen and energy content.

TABLE 16 Quantity and nutrient content of manure produced by farm animals.

Animal	Daily manure production (kg)		Nitrogen (% of dry matter)	Phosphorus (% of dry matter)	Calorific value (kcal kg^{-1})	Annual nitrogen production (kg yr^{-1})
	Raw	Dry matter equivalent				
Beef cattle	13–29	2–5	3.5	1.0	2300–4700	25–64
Dairy cattle	35–60	5–6	2.7	0.5	4500	50–60
Sheep	2	0.7	4.0	0.6	4250	10
Horses	20	8.0	1.7	0.3	3900	50
Poultry	0.1–0.2	0.02–0.05	2.2–3.4	1.0	2700–3500	0.16–0.6

SOURCE: Vohra and Robinson (1977); adapted.

In order to estimate the amount of nitrogen nutrient available from animal waste, we can discount poultry manure which will be used for growing vegetables, etc., around poultry farms and villages. We may also make the following assumptions.

(i) Only 66% of manure is collected for systematic use, half of which is used as fuel and half as fertilizer;
(ii) Buffaloes produce more dung than cattle, so we can assume an average of 50 kg of nitrogen per year from large animals, and 10 kg yr^{-1} from sheep and goats (these figures are likely to be underestimates).

With these assumptions, and using the animal populations projected in Table 16, we arrive at a manure-nitrogen availability of 0.8 X 10^6 t yr^{-1}, i.e., almost the shortfall estimated if no additional fertilizer plants are commissioned after 1982! Thus, in this scenario, at most only one more factory will need to be built. The energy requirement will also be reduced from 3.8 to 2.1 $\times 10^9 m^3$ of gas. It may be further noted that these substantial investment and energy savings result from assuming that the existing pattern of dung consumption will continue, i.e. roughly half will be burned as dung-cakes and the other half used as fertilizer. Also, if biogas technology penetrates the market to any significant degree, even larger energy savings may be made.

We will now discuss the prospects for biogas technology. It is generally known (Van Buren 1979) that the slurry from a biogas plant is a better fertilizer than unfermented manure used directly. There is also an additional bonus of improved hygiene, and the biogas itself, which may be used as fuel for cooking, lighting, etc. The construction and principles involved in the operation of a biogas plant are also rather simple, so it is considered an "appropriate technology" for rural areas in less developed countries. We feel, however, that the introduction of biogas plants in Pakistan may be slow for various cultural, traditional, and even technological reasons, as listed below.

(i) The fermentation compartment of a biogas plant requires frequent inspection and maintenance, in the course of which persons have to climb inside the pit. It is hard to find men willing to do the job because of cultural shyness, since manure collection and dung-cake making is traditionally women's work, and even they do not find it pleasant. Similarly, the slurry has to be stirred frequently which again needs to be done by men.

(ii) The fermentation has to be anaerobic, so the compartment must be kept airtight, and requires careful management.

(iii) The production of methane proceeds properly only within certain ranges of temperature and pH; proper understanding of the methods and corrective measures that need to be made will take a long time to learn.

There are however better prospects for larger, quasi-commercial biogas plants associated with the organized cattle farms advocated in this report. These could be partially mechanized, thus reducing the need for manual handling of the waste. Even if our misgivings about biogas acceptability turn out to be unfounded, there would nevertheless still be *more* organic nutrient available, resulting in greater savings of synthetic urea.

9.2 Phosphorus and Potassium

The nitrogen-to-phosphate consumption ratio gradually declined from about 40:1 in the mid-1960s to about 4:1 in the late 1970s, and may fall further to about 2:1 by the year 2000, so we estimate a phosphate requirement of about $0.9 \times 10^6 t\ yr^{-1}$ by the turn of the century, as compared with the 1977 consumption of about 0.13×10^6 t. The production of phosphate is much less energy-intensive than nitrogen, requiring about 3200 kcal kg^{-1} (Leach and Slesser 1976). At present, considerable amounts of phosphate are imported and no significant expansion in capacity is planned for the early 1980s. For energy calculations, however, we can assume that by the year 2000, about 75% of all phosphorus requirements will be met domestically. If so, the annual energy needed would be about 0.2×10^6 toe.

The potash requirements of different soil types vary considerably, but are generally an order of magnitude less than that of phosphate. It does not therefore figure significantly as an input requirement.

The total energy need for fertilizers in the two scenarios may now be summarized as follows:

Future D: 3.4 X 10^6 toe/yr;
Future E: 2.0 X 10^6 toe/yr (assuming no penetration of biogas technology).

10 OTHER INPUT REQUIREMENTS

We now turn to the consideration of the energy equivalents of other inputs, i.e. seeds and pesticides, and crop drying and transportation.

10.1 Seeds and Pesticides

The requirements of seeds and pesticides vary with different crops and environments. The data presented in Table 17 reflect the average seed rates in Pakistan, and the desired pesticide application rates for different crops. The total energy requirements for seeds and pesticides may be worked out at the average rate of 500 Mcal ha^{-1} for grains, 1300 for sugar cane and 300 for cotton. The total energy required is 9 X 10^{12} kcal, or about 0.8 X 10^6 toe.

TABLE 17 Seed rates and pesticide applications for different crops.

Crop	Seed rate ($kg\ ha^{-1}$)	Equivalent energy[a] (10^3 kcal ha^{-1})	Pesticides ($kg\ ha^{-1}$)	Equivalent energy[b] (10^3 kcal ha^{-1})
Wheat	70–75	350–375	–	–
Rice	10–12	50–60	15–20	360–480
Maize	30–35	150–175	20	480
Sugar cane (2 rattoons)	2300–3000	700–900	20	480
Cotton[c]	7–9	40–45	10	240

[a]The energy equivalent of seed was derived from the calorific value and adding 50% for the extra effort involved in producing seed.
[b]Pesticides are evaluated at 24,000 kcal kg^{-1} (Leach and Slesser 1976).
[c]Energy equivalent of cotton is calculated at 25% oil content.

10.2 Crop Drying and Transportation

Data in sufficient detail are not available to make a bottom-up estimate, but for comparison, we can look at the fractional energy consumption of a number of crops in the US for which estimates have been made (Pimentel 1979). The percentage of energy used in crop drying and transportation are 2.8% for wheat, 8% for rice and 3.6% for oats. The commercial energy used in crop drying and transportation is not expected to be more than 3% of the total used in agriculture because (i) due to the warmer climate of Pakistan, the moisture content of grains will be lower than in the US; (ii) solar drying will continue to be significant; and (iii) transportation distances are substantially shorter than in the US.

11 CONCLUDING REMARKS

The objectives of this study have been:

(1) to define the ultimate role of the agricultural system in Pakistan;
(2) to study the environment and constraints on the system;
(3) to translate the objectives into concrete production targets for specific crops for the year 2000;
(4) to identify the physical input requirements for meeting the set targets; and
(5) to evaluate the energy equivalents of the inputs.

The main results and conclusions are as follows. The total quantities of cereal grains, milk, meat, poultry, etc., required to provide adequate nutrition for the projected population of Pakistan of 139 million by the year 2000, are estimated and presented in Table 5. Since animals obtain their nutrition from vegetation, human food needs (both vegetables and animal origin, excluding fish) may be expressed in terms of agricultural production. Other non-food crops such as cotton are also needed, and some produce has to be exported to earn foreign exchange. These requirements are displayed in Table 7.

The physical input requirements are then analyzed: land, water, farm machinery, macronutrients, seeds, pesticides, crop drying and transportation. Energy requirements and, where appropriate, the financial implications of the various inputs are estimated. The report concludes with energy input estimates for seeds, pesticides, crop drying, and transportation; the possibility of off-farm employment for villagers and small-town dwellers is also briefly discussed.

The perception of the future is aided by a scenario approach, in which three possible development paths for farm mechanization (A, B, C), and two other paths for the supply of macronutrients (D, E) are considered. Alternative C, which envisages significant penetration of low-tillage technology, is not considered likely to be realized. The various different combinations of the other alternatives are listed in Table 18, and the energy implications are presented in Table 19.

It is evident from Table 19 that the largest amounts of commercial energy are expected to be used in fertilizer production, drainage and irrigation, tractors, seeds, and pesticides, roughly in that order. The greatest energy savings are accordingly expected if Pakistan restricts the use of man-made fertilizers and conserves water resources. As discussed in the text, both of these measures are possible and are indeed to be recommended for reasons other than commercial energy saving: water conservation to prevent waterlogging, and urea economy to enhance the organic quality of the soil. The adage "waste not, want not" is particularly relevant to these two vital inputs to agriculture. With regard to farm mechanization, energy considerations alone do not seem to disfavor strongly high tractorization, but other socioeconomic factors will probably steer the country closer to the low-mechanization future rather than towards the high one.

From the information presented, we may also derive energy ratios, i.e., the ratio of metabolizable energy produced by the whole agricultural system to the energy provided

TABLE 18 Characteristics of possible evolution paths of Pakistan's agricultural system.

Parameter	Base year, 1977	Year 2000			
		Future AD	Future AE	Future BD	Future BE
(1) Area cropped per year	18.3×10^6 ha	22×10^6 ha			
(2) Irrigation (the per hectare figures pertain to irrigated area only)	10.8×10^6 ha-m of water available at farmgate (~0.8 ha-m ha^{-1} yr^{-1})	Farm-gate availability of water increases to 18×10^6 ha-m yr^{-1} (~1.1 ha-m ha^{-1} yr^{-1})			
(3) Farm mechanization (the per hectare figures refer to entire cultivated area	60,000 tractors (3.3×10^{-3} tractors/ha)	3/4 of area under major crops mechanized; 1/2 of other area under tractors (20×10^{-3} tractors/ha)		1/4 of area under major crops mechanized; 1/5 of other area under tractors (7×10^{-3} tractors/ha)	
(4) Supply of nitrogen from chemical fertilizers (per hectare figures pertain to total cropped area)	0.6×10^6 t nutrient (32.5 kg ha^{-1} yr^{-1})	1.9×10^6 t (86 kg ha^{-1} yr^{-1})	1.1×10^6 t (50 kg ha^{-1} yr^{-1})	1.9×10^6 t (86 kg ha^{-1} yr^{-1})	1.1×10^6 t (50 kg ha^{-1} yr^{-1})
(5) P:N ratio	1:4	1:2	1:2	1:2	1:2

TABLE 19 Evolution of commercial energy use in agriculture.

		Year 2000			
	Base year, 1977	Future AD (high mech, high urea)	Future AE (high mech, low urea)	Future BD (low mech, high urea)	Future BE (low mech, low urea)
(1) Drainage tube-wells					
electricity (MWyr)	118	250	250	250	250
(2) Irrigation tube-wells					
electricity (MWyr)	62	200	200	200	200
diesel (10^3 toe)	196	400	400	400	400
(3) Farm machines					
diesel (10^3 toe)	80	800	800	280	280
(4) Chemical fertilizers					
mainly gas (10^3 toe)	650	3400	2000	3400	2000
(5) Seeds and pesticides (10^3 toe)	300[a]	800	800	800	800
(6) Other requirements (10^3 toe)[b]	75	300	250	250	200
(7) Total non-animal energy					
electricity (MWyr)	180	450	450	450	450
gas and oil (10^6 toe)	1.0	5.3	3.9	4.7	3.3
latent (10^6 toe)[c]	0.3	0.4	0.4	0.4	0.4
(8) Commercial energy use[d]					
(10^6 kcal ha^{-1})	~1.0	3.2	2.5	3.0	2.3
(9) Persons supported per hectare	4.0	6.3	6.3	6.3	6.3

[a] Seeds only; pesticides estimate included in "other requirements".
[b] Other requirements include transportation, crop drying, fishing, etc.; estimated figures.
[c] Energy latent in seeds.
[d] Electricity converted to thermal equivalent at 35% efficiency.

by man*. The ratios in Pakistan are presented in Table 20 and compared with other countries; if one also includes the human and animal energy expended, the ratios for Pakistan will decrease by 10–15%, assuming that about 65% of the annual effort exerted by farm labor contributes to agriculture and that the farm-related work of draft cattle averages 6 hours daily all year round.

TABLE 20 Energy output–input ratios for the total agricultural system.

China	1930	40	
Pakistan	1977	3.3	Commercial energy input only
Pakistan	2000 (high-energy future AD)	1.6	Commercial energy input only
Pakistan	2000 (low-energy future BE)	2.6	Commercial energy input only
US	1940	2.26	
US	1970	0.87	
UK	1950	0.41	
UK	1970	0.34	

SOURCES: Marchetti (1979), Steinhart and Steinhart (1974), Leach (1976), present work.

The difference between the energy ratios in the US and UK is due to the land scarcity in the latter, necessitating greater intensification of agriculture, and also the harsher climate. The higher ratios for Pakistan reflect the lower intensity of commercial energy inputs as well as the lower consumption of animal products: the conversion of plants to animal food may cost a factor of up to 20 in energy depending upon the type of animal product (milk, eggs, or meat) and the method of raising animals (grass-fed, feed-lot, etc.).

Let us now view agricultural energy use in the national context. In another study by the author (unpublished), it has been estimated that the final electricity demand of Pakistan in the year 2000 will lie between 2.7 and 3.3 GWyr, while all other forms of commercial energy will be $17–20 \times 10^6$ toe. Thus, if agriculture in Pakistan develops along the high-energy road, in 2000 it will account for about 15% of total electricity consumption and about 28% of all other forms of commercial energy; for the low-energy path, the respective figures will be 15% and 18%. For comparison, in 1977 agriculture used a little over 20% of the electricity and 12% of other forms of commercial energy. Thus, agriculture's share of the total electricity demand will decline, while its share of fossil fuels used is expected to register a sharp increase, mainly on account of agrochemicals produced domestically.

The above figures underscore the importance of analyzing agricultural energy requirements in a developing country with a largely agrarian economy; the situation is different in advanced industrialized countries, where agriculture typically accounts for only about 5% of the total commercial energy use. Thus, for Pakistan, it is logical to look for methods of saving energy in agriculture-related activities, just as in other sectors such as transportation, domestic consumption, etc. This should however be done in ways that do not compromise productivity; possible measures are indicated in Sections 7 and 9 of this report. If competition does develop among different energy consumers, it is obvious that agriculture deserves first consideration; indeed, something would be basically wrong

*Note that energy ratios greater than unity are possible because solar energy, freely available to man, is not included in the input.

with a nation's priorities if it cut down on supplies of electricity and motor fuel to tube-wells and allowed, for example, office air-conditioners and automobile fleets to run unrestrained.

Finally, we would like to stress an obvious point: that the provision of energy and other inputs does not necessarily guarantee that production targets will be met. Farmers must be educated and encouraged to adopt improved cultivation practices. A major effort to translate available technical knowledge into practical information, and the effective dissemination of that information needs to be undertaken seriously and urgently.

ACKNOWLEDGMENTS

I have benefited from conversations with Professor W. Häfele and colleagues in the Energy Program. Dr. A. Muhammad and Mr. A.H. Qureshi have provided valuable research material. I am also indebted to Dr. C. Marchetti, Dr. A. Muhammad, Dr. K.S. Parikh, Mr. A. Husain, Dr. J. Parikh and Dr. A.M. Khan for their comments on the first draft of the paper. Whatever deficiencies remain, reflect the author's limitations.

Finally, I wish to thank Professors R. Levien and W. Häfele for the warm hospitality of IIASA.

REFERENCES

Agricultural Statistics of Pakistan 1978 (Food and Agriculture Division, Government of Pakistan, 1979).

Bardach, J.E. (1980) Economic Energy Use in Fish Production, P-80-2. East–West Centre, Honolulu, Hawaii.

van Buren, A. (Ed.) (1979) A Chinese Biogas Manual. London: Intermediate Technology Publications.

Burton, B.T. (1976) Human Nutrition. New York: McGraw-Hill.

Cleland, A.C. and M.D. Earle (1980) Energy use in the Food Manufacturing Industry. New Zealand Energy Research and Development Committee Report No. 54.

Energy Year Book 1979 (1980) Directorate General of Energy Resources, Pakistan.

FAO Production Yearbook 1979, Vol. 33 (1980) Rome: United Nations.

Government of Pakistan, Energy Year Book 1979. Directorate General of Energy Resources.

Hardy, R.W.F. and U.D. Havelka (1975) Nitrogen fixation research: A key to world food? Science 188: 633–43.

Heumann, Gisela, Weber, A., *et al.* (1980) Die Schleppermachfrage in einzelner Regionen der Welt. Agrarwirtschaft 29:129–41.

Holmes, W. (1977) Choosing between animals, in: Agricultural Efficiency. London: Royal Society.

Leach, G. (1976) Energy and Food Production. Guildford: IPC Science and Technology Press.

Leach, G. (1978) The energy costs of food production, in: F. Steele and A. Bourne (Eds.) The Man/Food Equation. New York: Academic Press.

Leach, G. and M. Slesser (1976) Energy Requirement of Network Inputs. Glasgow: University of Strathclyde.

Marchetti, C. (1979) On Energy and Agriculture: From Hunting–Gathering to Landless Farming. RR-79-10. Laxenburg, Austria: International Institute for Applied Systems Analysis.

McGraw-Hill Encyclopedia of Food, Agriculture and Nutrition (1977). New York: McGraw-Hill.

Muhammad, A. *et al.* (1976) Seed Protein Improvement in Wheat by Mutation Breeding. Vienna: IAEA.

Muhammad, A. (1978) Wheat Production in Pakistan. Pakistan Agricultural Research Council.

Naqvi, M. (1980) personal communication, 1980.

Nutman, P.S. (Ed.) (1976) Symbiotic Nitrogen Fixation in Plants. London: Cambridge University Press.
Pakistan Agricultural Research Council (PARC) (1980) communicated by A. Muhammad, Chairman.
Pimentel, D. (1979) Energy and Agriculture, in: Biswas and Biswas (Eds.) Food, Climate and Man. New York: Wiley.
Revelle, R. (1976) Energy use in rural India. Science 192:969–75.
Singh, I. (1979) Small Farmers and Landless in South Asia. World Bank Staff Working Paper No. 320.
Steinhart, J.S. and C.E. Steinhart (1974) Science 184:307.
US National Academy of Sciences (1975) Agricultural Production Efficiency. Washington, DC: NAS.
Vohra, P.V. and D.W. Robinson (1977) Feed, fuel and fertilizer, in: R.A. Fazzolare and C.B. Smith (Eds.) Energy Use Management. Oxford: Pergamon.
WAPDA Power Market Survey and Forecast of System Loads (1979). Pakistan Water and Power Development Authority.
Williams, D.W. *et al.* (1975) Energy Utilization on Beef Feedlots and Dairy Farms, in: W.J. Jewell (Ed.) Energy, Agriculture and Waste Management. Ann Arbor Publishers.
World Bank (1979) World Development Report. Washington, DC.
Woolley, D.G. (1977) Food-crop production, limitation and potential, in: E.R. Duncan (Ed.) Dimensions of World Food Problems. Iowa State University Press.

APPENDIX: ENERGY ECONOMICS OF ORGANIZED CATTLE FARMING

We estimate here the total commercial energy inputs required to deliver one ton of frozen beef to the port of exit in the year 2000. The major components that make up the total are: (i) energy embodied in the feed; (ii) energy required in processing and cold storage; (iii) transport fuel; and (iv) refrigeration during transport.

Feed Energy

Apart from non-energy-intensive fodder such as hay, it has been estimated in the text that 0.8×10^6 t of maize will be required to produce 0.3×10^6 t of export-quality beef, i.e., about 2.7 t of maize per tonne of beef. The commercial energy input per hectare will be

N-fertilizer: 100 kg ha^{-1} N @ 18 Mcal kg^{-1} N = 18×10^5 kcal ha^{-1}
Water (0.6 ha-m ha^{-1}): = 6×10^5 kcal ha^{-1}
Tilling and harvesting: = 6×10^5 kcal ha^{-1}

Assuming maize yield to be 3.4 t ha^{-1} (see text), the commercial energy required to produce 2.7 t of maize will be about 2.4×10^6 kcal.

Processing and Cold Storage

Estimates for this activity are based on the US and New Zealand figures given in Cleland and Earle (1980). In order not to err on the low side, the higher figures are taken for both electricity and fuel requirements. Converting to thermal requirements, one arrives at a figure of 1.8×10^6 kcal per tonne of carcass.

Transport Fuel

Although the cattle farms will be preferentially located near to ports, we again take an upper bound and assume that the average distance traveled by a carcass is 1000 km, of which 200 km is by truck and 800 km by train. Using internationally accepted averages, raised somewhat to take account of adverse road and vehicle maintenance conditions in Pakistan, one obtains a value of about 0.4×10^6 kcal per tonne of meat.

Refrigeration During Transport

Since the fuel requirements for meat processing are for hot water in scalding and cleaning, we need take only the electricity figure, which is itself likely to be an overestimate because the transit time will in general be shorter than the storage period. The energy then works out to be 10^6 kcal per tonne of meat.

Energy Balance

Adding all these figures, we arrive at a total of 5.6×10^6 kcal of secondary commercial energy (or, say, 6×10^6 kcal of primary) sequestered in delivering one tonne of beef carcass to the port of Karachi. In making each estimate we have tried to err on the high side. We have also not taken account of the dung which could be used to produce biogas and also to reduce the chemical fertilizer requirements. On the other hand, we have not accounted for the energy required in breeding and raising stock or the energy embodied in refrigerated trucks and wagons. The figure should therefore be approximately of the right order. As is made clear, the conclusion will not be materially affected even if the error is as much as 100%.

Now, if we further assume that the farm is not allowed any indigenous energy supply (i.e., it must compensate in thermal units for the gas and electricity used), then 4.1 barrels of oil must be imported in order to be able to export one tonne of beef. At 1979 beef prices and 1980 oil prices, one tonne of beef could buy about 50 barrels of oil. Thus there is a huge margin of "energy profit". The export of 0.3×10^6 t of beef envisaged in the text could earn 1.8×10^6 t of oil, which would be more than sufficient to meet the diesel requirements of the entire agricultural system of Pakistan, even in the high-mechanization scenario.

Incidentally, this example highlights the fact that in order to increase the total national wealth and individual productivity in a developing country, it is not absolutely necessary (contrary to popular belief) to veer away from agriculture towards manufacturing. What is important is to enhance the *value-adding capability* of each sector in that country.

LONG-TERM PROSPECTS FOR AGRICULTURAL DEVELOPMENT IN THE EUROPEAN CMEA COUNTRIES, INCLUDING THE SOVIET UNION

Csaba Csáki
International Institute for Applied Systems Analysis, Laxenburg, Austria, and Karl Marx University for Economic Sciences, Budapest, Hungary

SUMMARY

The current status and the development potential of agriculture in the European member countries of the CMEA, particularly the Soviet Union, have been much discussed. In this report the principal supply and demand trends, agricultural policy in the CMEA countries, and expected future developments, are analyzed. In Sections 2–5 of the report the agricultural status in each country is discussed. Government policies on agricultural development are based on a mathematical model. The so-called CMEA Agricultural Model is an element of the model system of the Food and Agriculture Program at IIASA. The model is actually a descriptive, recursive simulation model, which is structured according to two submodels – smaller CMEA countries and the Soviet Union – with similar structures. Section 6 of the report describes the CMEA Agricultural Model and the two basic scenarios and additional variants computed by the model. Section 7 of the report is devoted to an analysis of future trends. The projections are made at the CMEA level – country-specific analysis was not the aim of this study. The work was initiated and supported by the Food and Agriculture Organization of the United Nations, and was used as an explanatory and background analysis for the Agriculture: Toward 2000 *project of the FAO.*

1 INTRODUCTION

The status and development potential of agriculture in the European member countries of the CMEA, particularly the Soviet Union, have often been the subject of discussion in both the Eastern and Western hemispheres. This concern is not surprising, since the CMEA and the Soviet Union can be regarded as countries disposing of about 25% of the world's agricultural resources. In 1978 they produced 35.5% of the wheat, 8.1% of the corn, 46% of the sugar beet, and 50.8% of the world's potatoes, as well as 11.1% of the cattle, 18.9% of the pigs, and 18.4% of the sheep.

Within the framework of IIASA's Food and Agriculture Program (FAP) a consistent set of models describing national food and agricultural systems has been developed for both market and centrally planned economies. The FAP research is much more than a methodological exercise; the models also offer opportunities for actual policy analyses and long-range projections. In this report just one example of these uses is presented. The work detailed here was initiated and supported by the Food and Agriculture Organization (FAO) of the United Nations.

The purpose of the study was to give explanatory and background analyses for the *Agriculture: Toward 2000 (AT 2000)* project, using the CMEA Agricultural Model developed within the framework of the FAP of IIASA. It must be emphasized at this point that the approach of the study was determined by the above circumstances; the aim was to elaborate a CMEA-level, long-range perspective that fitted the global analysis of *AT 2000*, and not to carry out detailed country-by-country analyses or to discuss country-specific problems. In this report, the agricultural situation in the European CMEA countries is assessed, and then the methodology of the projections is outlined. Based on several runs of IIASA's CMEA Agricultural Model, projections are elaborated for the year 2000, and these are discussed.

This report and the CMEA Agricultural Model are based on a broad range of source material, such as the official statistics published by the CMEA countries and by the Secretariat of the CMEA, the data banks of the FAO and IIASA, and analyses carried out by the OECD and by the Research Institute for Agricultural Economics in Budapest*. Corresponding to the objectives of *AT 2000*, answers are sought to the following questions: What kinds of long-term demand exist in the CMEA countries at the international market level? How do domestic development alternatives influence agricultural exports and imports of these countries? What concrete requirements should be taken into consideration in respect of those products that are important for the developing countries? Although the European member countries of the CMEA and the Soviet Union are treated as one aggregate region, in some parts of the analysis, especially in the assessment of the present situation, the smaller member countries (Bulgaria, Czechoslovakia, GDR, Romania, Poland, and Hungary) are treated together, and the Soviet Union (including its Asian territories) is treated separately. The projections for the year 2000 are made at CMEA level.

2 THE STATUS OF AGRICULTURE

2.1 Natural and Material Conditions for Agriculture

Considerable changes have recently taken place in agriculture in the CMEA countries, which have reduced the dependence on natural and climatic conditions but, as demonstrated by the results of recent years, these environmental factors are still significant. This analysis of agriculture in the smaller CMEA countries and the Soviet Union

*The author is especially grateful to Dr. Janos Nagy at the Research Institute for Agricultural Economics for providing data for the assessment of the present situation. The parameter estimation and computer programming of the CMEA Agricultural Model were done by Günther Fischer, Laszlo Zeöld, and Bozena Lopuch at IIASA. Many thanks are also due to Bonnie Riley for typing and grammatical correction, and Valerie Jones for editing the material.

begins with a brief outline of its development, as well as the natural and material conditions that underlie it.

The smaller CMEA countries are situated in the central part of Europe, where natural conditions for agriculture can generally be described as favorable. The climate is continental in character; mean annual temperatures lie in the range 8–11 °C, and the average precipitation ranges from 600 to 1000 mm yr^{-1}. In the north the climate is cooler and wetter, while continental influences dominate in the south, and the risk of drought is greater.

Throughout the CMEA the proportion of the total land under cultivation (i.e. under arable farming, permanent crops, pastures, and meadows) is high, as shown in Table 1, exceeding 60% in Hungary, Poland, and Romania. Opportunities to increase this

TABLE 1 The proportion of land under cultivation in the smaller CMEA countries, 1960–78 (%).

	1960	1978
Bulgaria	51.1	56.0
Hungary	76.8	72.0
GDR	57.3	58.1
Poland	65.2	60.9
Romania	61.1	63.0
Czechoslovakia	57.2	54.3

SOURCE: Statistical Yearbooks of the CMEA.

area are restricted, however, and frequently there are substantial losses of farmland to other activities such as industry or road construction, and because of the withdrawal of certain unproductive areas from cultivation. In Poland, where much of the land is privately owned, inheritance practices have caused excessive subdivision of farms, which is very uneconomical.

Compared with other countries, the amount of agricultural land per capita in the CMEA is also high (see Table 2). Arable farming is the largest sector, accounting for 65.1%

TABLE 2 The supply of agricultural and arable land per capita in the smaller CMEA countries, 1960–78 (ha).

	Total agricultural land per capita		Arable land per capita	
	1960	1978	1960	1978
Bulgaria	0.72	0.69	0.54	0.49
Hungary	0.72	0.63	0.54	0.50
GDR	0.37	0.37	0.28	0.30
Poland	0.69	0.54	0.54	0.42
Romania	0.79	0.68	0.53	0.47
Czechoslovakia	0.54	0.46	0.37	0.34

SOURCE: Statistical Yearbooks of the CMEA.

of the land under cultivation in Romania in 1975, and as much as 76.6% in Poland (see Table 3). The agricultural land area is likely to be reduced throughout the CMEA, and there has been a general trend towards an increase in the amount of permanent tree crops, especially in Romania and Poland. Apart from this development, however, further modifications to the overall structure of agriculture in the region are not likely.

TABLE 3 The cultivation structure of agricultural land in the smaller CMEA countries, 1960–75.

	Arable land (%)	Plantations (%)	Meadows (%)	Pasture (%)	Total agricultural land (10^3 ha)
Bulgaria					
1960	75.44	6.08	4.53	13.95	5672
1975	66.44	6.41	4.98	20.40	5955
Hungary					
1960	75.86	5.02	6.93	13.20	7141
1975	75.72	5.50	5.70	13.13	6770
GDR					
1960	75.70	3.20	13.60	7.60	7420
1975	74.65	3.78	11.60	10.00	6295
Poland					
1960	78.20	1.30	11.70	8.77	20,403
1975	76.60	1.93	13.25	8.22	19,209
Romania					
1960	67.50	3.60	9.53	19.30	14,547
1975	65.10	5.10	9.45	20.30	14,946
Czechoslovakia					
1960	69.90	4.09	14.73	22.20	7327
1975	69.54	5.08	12.86	11.93	7004

SOURCE: Calculations made on the basis of data in the Statistical Yearbook of the CMEA, 1977.

As shown in Table 4, there has been a considerable reduction in the agricultural labor force in recent years in the smaller CMEA countries, with the exception of Poland, although productivity has nevertheless been increased. This has been due to the introduction of mechanization, and the numbers of tractors and combine harvesters have increased substantially everywhere (see Table 5).

TABLE 4 Share of agriculture and forestry in total employment in the CMEA, 1950–78 (%).

	1950	1978
Bulgaria	79.5	35.7
Hungary	52.0	17.3
GDR	27.3	10.2
Poland	54.0	32.0
Romania	74.3	49.0
Czechoslovakia	38.6	11.4
Soviet Union	47.6	18.1

SOURCE: *Thirty Years of the CMEA*. Hungarian Central Statistical Bureau, 1979.

TABLE 5 Increases in tractors and combine harvesters in the CMEA countries (in thousands of tractor units*).

	No. of tractors (in kind)			Combine harvesters	
	1960	1975	1977	1960	1975
Bulgaria	25.8	64.7	65.0	7.5	10.3
Hungary	41.0	62.1	69.8	4.2	14.3
GDR	71.0	140.0	137.0	6.4	11.2
Poland	62.8**	411.0	482.0	3.1	21.1
Romania	44.2	120.0	139.0	17.6	38.1
Czechoslovakia	74.9	142.0	140.0	6.3	19.9

*1 tractor unit = 15 hp traction capacity.
**Excluding garden tractors.
SOURCE: Data calculated from the CMEA Yearbook, 1977.

The increase in the number of tractors was greatest in Poland and Romania in 1960–77, while that of combine harvesters was greatest in Poland and Hungary. During this period, the number of tractors almost trebled, and the total motor capacity grew to more than four times that of 1960.

The use of fertilizers increased dramatically in 1960–80, but the level of use is still not very high in some countries (see Table 6). Despite the substantial increase in fertilizer use, however, there are still regional disparities, although these have been diminishing since 1960. For example, in 1960 about 23.8 times as much fertilizer per hectare was used in GDR as in Romania, and by 1980 this figure had been reduced to only 2.4 times as much.

Considerable efforts have been made to extend irrigation and to improve soil fertility, but the irrigated land area is still only a relatively small proportion of the total (20.7% in Bulgaria, 8.3% in Hungary, 10.2% in the GDR, 3.3% in Poland, 6% in Romania, and 4.6% in Czechoslovakia).

The material and technological inputs to agriculture in the smaller CMEA countries have now reached levels whereby continually high yields can be achieved. A similar situation has also been reached in the USSR, but both natural and material–technical conditions are rather different.

TABLE 6 Fertilizer use in the smaller CMEA countries, 1960–80 (in kg of active ingredients per hectare).

	1960	1975	1980
Bulgaria	36.1	166.0	187.0
Hungary	29.4	276.0	303.0
GDR	188.0	370.0	360.0
Poland	48.6	236.0	245.0
Romania	7.9	114.0	151.0
Czechoslovakia	94.6	305.0	341.0

SOURCE: CMEA Yearbooks.

Although the USSR is the largest country in the world, only 553 × 10^6 ha were under some kind of agricultural use in 1978, out of a total of 2240 × 10^6 ha, a significant part of which experiences extreme climatic conditions similar to those in the northern states of the USA and the Canadian Prairies. The farmlands are generally located in relatively high latitudes, and only the southernmost zones extend as far south as 35–40° N – the latitude of San Francisco. Almost all extremes of climate are experienced in this vast country, such as severe cold, widely fluctuating precipitation levels or a high risk of drought, relatively short growing seasons, each of which is a fundamental constraint. A significant part of the country is not cultivated at all because of one or more of these factors, and it is unlikely that any form of agricultural activity, particularly arable farming, will be extended into the more remote areas. Efforts were made in the late 1950s and 1960s to extend farming into these marginal areas, and the total arable area in 1978 accounted for about 40% of the total agricultural area in the USSR. The extension of the area under grain crops in 1950–75 is shown in Table 7. In 1978 the total arable area amounted to 231 × 10^6 ha, or 0.86 per capita. The increase in the arable area cannot keep pace with the population growth, so that further per capita decreases can be expected.

TABLE 7 Development of arable farming in the USSR, 1950–78 (10^6 ha).

	Arable area, total	Under cereals	Fallow
1950	203.0	115.6	32.0
1963	218.5	130.0	7.4
1964	212.8	133.3	6.3
1965	209.1	128.0	14.7
1966	206.8	124.8	16.8
1967	206.9	122.2	17.7
1968	207.0	121.5	18.2
1969	208.6	122.7	16.9
1970	206.7	119.3	18.4
1971	207.3	117.9	18.8
1972	210.7	120.1	16.2
1973	215.0	126.7	13.5
1974	216.5	127.2	12.7
1975	218.0	128.5	10.8
1978	231.0	133.3	–

SOURCE: *Narodnoe Chozyaistovo SSSR* (vol. 1960–73), SSSR v tsifrakh, 1974; *Sel'skoe Chozyaistvo SSSR*, 1971; N. Gusev (1975) *Ekonomika Sel'skovo Chozyaistva*, No. 2, Feb, p1, and Statistical Yearbooks of the CMEA.

Irrigation and soil improvement have become increasingly important factors in raising Soviet agricultural production levels. The total area irrigated was 15.15 × 10^6 ha in 1976, of which about 12 × 10^6 ha were harvested. About 6.3% of the cultivated area was irrigated in 1975, compared with 4.9% in 1970.

The levels of technological and other inputs to Soviet agriculture have been lower than in Western Europe and North America, but these are improving rapidly. The major characteristics of mechanization and fertilizer use are outlined in Table 8. In 1979 in the

TABLE 8 Mechanization and fertilizer use in the USSR, 1965–76.

	1965	1970	1975	1976
Total agricultural hp (10^6 hp)	228.8	318.9	454.9	486.9
Number of tractors (10^3 tractor units)	1613	1977	2336	2402
Number of combine harvesters (10^3 tractor units)	520	623	680	605
Number of motor trucks (10^3 tractor units)	945	1136	1396	1442
Fertilizers used (10^3 t active ingredients)	6303	10,360	17,665	18,255

SOURCE: Statistical Yearbook of the USSR, 1977.

USSR the density of tractors was 90 ha/tractor while the same indicator in the US was 44 ha/tractor, and in the EEC the average was 11 ha/tractor. At this time, high-performance Soviet combine harvesters were introduced, although in comparison with other developed countries their numbers are relatively low, and there are problems with the provision of maintenance facilities and the lack of an adequate infrastructure such as access roads, etc. The fertilizer used in 1980 was 81 kg ha^{-1} (active ingredients) compared to 106 kg in the US and 306 kg (on average) in the EEC.

2.2 The Development of Agricultural Production

As a result of technological improvements to agriculture (such as irrigation, fertilizers, machinery, etc), the output of the smaller CMEA countries grew more rapidly during the 1970s than the world average. Table 9 presents the relevant data, showing that the annual growth over two decades was between 2.5 and 3.5%. The only exception was Romania, where output increased by 5.8% per annum during 1961–78. The growth of agriculture was relatively fast in the late 1960s and early 1970s, but slowed down toward the end of that decade. Of course, in the actual growth rates there are substantial variations between countries.

TABLE 9 Annual growth of agricultural production in the CMEA countries, 1966–78 (%).

	1966–70	1971–75	1976–78	1976–78
	Annual growth in the given period on the basis of the previous five years			For the whole period 1964–65
Bulgaria	4.7	2.3	2.8	3.3
Hungary	3.0	3.5	4.1	3.5
GDR	3.7	2.1	1.9	2.6
Poland	3.0	3.2	1.0	2.4
Romania	4.2	4.8	7.4	5.8
Czechoslovakia	3.5	2.8	2.5	2.9
USSR	4.1	2.5	2.6	3.1

SOURCE: *Thirty Years of the CMEA*. Hungarian Central Statistical Bureau, 1979.

In general, the percentage rate of increase in animal husbandry was greater than that in crop growing in the 1970s, resulting in a reversal of the relative importance of the two sectors. The relative position of animal husbandry increased everywhere in the CMEA; for example, in 1971–75 its share increased from 34.5 to 57.7% in Bulgaria, and from 38.2 to 54.8% in Romania.

The improvements achieved in total production and in the yields of some crops up to 1980 are summarized in Tables 10 and 11; cereal grain yields increased significantly in all countries, particularly in Hungary and Czechoslovakia. Wheat output increased most of all, while that of rye declined further, yielding its place to wheat, barley, and corn. Vegetable, fruit, and sugarbeet production showed slower rates of increase, and the output of potatoes was considerably reduced in most countries, mainly because of the changing role of the potato in diets.

TABLE 10 Average annual gross production of major crops in the smaller CMEA countries, 1961–80 (10^6 t).

	Bulgaria	Hungary	GDR	Poland	Romania	Czechoslovakia
Grain						
1961–65	4.86	8.90	5.97	15.43	11.10	5.66
1971–75	7.46	11.52	8.76	21.24	14.98	9.44
1976–80	9.80	–	9.70	26.40	21.40	10.60
Index 1976–80 (1971–75 = 100)	131.30	–	110.70	124.30	133.60	112.30
Sugarbeet						
1961–65	1.44	3.09	5.40	11.44	2.64	6.30
1971–75	1.71	3.09	5.50	12.70	4.76	6.90
1976–80	2.44	–	7.50	21.10	7.32	9.00
Index 1976–80 (1971–75 = 100)	142.90	–	137.20	152.80	153.80	131.10
Potatoes						
1961–65	0.40	1.99	12.10	43.70	2.60	5.63
1971–75	0.35	1.57	10.80	47.10	3.40	4.60
1976–80	0.37	1.00	14.20	49.80	–	4.00
Index 1976–80 (1971–75 = 100)	105.30	–	131.60	105.80	–	97.50
Vegetables						
1961–65	0.89	0.79	0.89	1.08	1.30	0.81
1971–75	1.56	1.63	1.14	3.76	2.60	1.80
1976–80	2.24	–	1.55	5.10	–	–
Index 1976–80 (1971–75 = 100)	142.00	–	135.80	135.50	–	–
Fruit						
1961–65	1.90	1.60	0.55	0.74	1.82	0.44
1971–75	2.13	2.20	0.57	1.15	2.30	0.52
1976–80	1.29	–	0.60	2.40	–	–
Index 1976–80 (1971–75 = 100)	60.40	–	105.10	205.80	–	–

TABLE 11 Development of yields of the major crops in the smaller CMEA countries, 1961–80 (100 kg ha^{-1}, annual averages).

	Bulgaria	Hungary	GDR	Poland	Romania	Czechoslovakia
Grain and leguminous crops						
1961–65	19.0	20.3	25.3	17.0	15.9	21.8
1971–75	33.1	35.0	35.7	25.1	24.1	33.9
1980	39.7	47.6	43.9	26.0	28.4	45.1
Corn						
1961–65	25.1	26.1	19.8	23.5	17.7	26.3
1971–75	39.7	41.7	31.2	42.6	26.8	44.1
1980	37.7	53.2	30.0	35.4	33.9	49.3
Sugarbeet						
1961–65	205.0	246.0	243.0	267.0	149.0	270.0
1971–75	293.0	330.0	277.0	307.0	221.0	346.0
1980	273.5	376.4	277.7	226.0	234.0	331.0
Potatoes						
1961–65	85.5	79.1	166.0	154.0	85.1	114.0
1971–75	118.0	117.0	171.0	177.0	114.0	153.0
1980	84.4	149.6	180.4	113.0	141.0	136.0

SOURCE: Yearbooks of the CMEA.

Grain yields were similar in Bulgaria, Hungary, the GDR, and Czechoslovakia, but significantly lower in Poland and Romania. Corn and sugarbeet yields were highest in Czechoslovakia, and potato yields were highest in Poland and the GDR. When comparing gross production figures with yields it is clear that increasing specific yields is the best method of raising output levels.

The development of livestock rearing in each of the CMEA countries is outlined in Table 12, and Table 13 presents data for the output of various animal products.

In most of the CMEA countries about 20% of the meat produced was beef, but around 30% in Czechoslovakia and Poland. Pork was the most important meat, however, exceeding 50% of the total produced in all countries, but as high as 60% in Hungary, the GDR, and Poland. Poultry meat production in the late 1970s exceeded that of beef in Bulgaria, Hungary, and Romania. The share of mutton and goat meat was significant only in Bulgaria and Romania. As well as adding to the meat produced, cattle rearing has contributed to increased milk production, particularly in Bulgaria, Poland, and Romania, and as a result of improved poultry breeding methods, egg production has also increased.

The output of the agricultural sector has increased in all CMEA countries. In the USSR over the period 1952–70, for example, the increase was much greater than in other parts of the world (see Tables 14 and 15). The production of vegetables and fruits such as grapes has been outstanding, but that of animal products was only moderate. No significant changes took place in the crop structure, and grains and leguminous crops continued to occupy about 60% of the total cultivated area. Of all livestock, pigs have become particularly important (in 1980 there were 116×10^6 cattle, 73×10^6 pigs, and 141×10^6 sheep).

TABLE 12 Development of livestock rearing in the smaller CMEA countries, 1960–80.

	Bulgaria	Hungary	GDR	Poland	Romania	Czechoslovakia
Cattle (10^3)						
1960	1642	1965	4675	8695	4530	4387
1975	1725	1904	5532	12,764	6126	4555
1980	1843	1918	5723	11,335	6485	5002
Index 1980 (1960 = 100)	112.1	97.6	122.4	130.4	143.2	114.0
Pigs (10^3)						
1960	2553	6388	8316	12,615	4300	5962
1975	3889	6953	11,501	21,647	8813	6683
1980	3806	8330	12,871	18,728	11,542	7894
Index 1980 (1960 = 100)	149.1	130.4	154.7	148.5	268.4	132.4
Sheep (10^3)						
1960	9933	2250	2015	3662	11,500	646
1975	10,014	2039	1883	3178	13,865	805
1980	10,468	3090	2036	3486	15,873	903
Index 1980 (1960 = 100)	105.3	137.3	101.0	95.1	138.0	139.8
Poultry (10^6)						
1960	23.4	39.6	36.9	71.9	38.0	28.2
1975	38.1	56.1	47.1	99.8	78.6	40.1
1980	39.9	61.3	32.3	79.3	87.5	45.3
Index 1980 (1960 = 100)	170.5	154.8	187.5	110.3	230.2	160.1

SOURCE: Based on Yearbooks of the CMEA.

TABLE 13 Development of animal products in the smaller CMEA countries, 1960–75 (10^6 t at slaughter).

	Bulgaria	Hungary	GDR	Poland	Romania	Czechoslovakia
Total meat						
1960	307	916	1021	1751	561	802
1975	657	1422	1718	3062	1328	1349
Index 1975 (1960 = 100)	214	174	168	175	237	168
Beef						
1960	44	151	232	396	169	240
1975	112	229	417	870	260	431
% of total meat production 1975	17.0	16.1	24.2	28.4	19.6	31.9
Pork						
1960	162	499	687	1215	276	483
1975	329	892	1132	1852	724	738
% of total meat production 1975	50.0	62.7	65.8	60.5	54.5	54.7

TABLE 13 *Continued.*

	Bulgaria	Hungary	GDR	Poland	Romania	Czechoslovakia
Mutton and goat meat						
1960	60.5	9.7	30.9	35.5	54.3	9.7
1975	90.4	16.7	13.9	25.9	71.4	6.7
% of total meat production 1975	13.7	1.1	0.8	0.8	5.4	0.4
Poultry						
1960	36.3	122	57.5	68.3	61.3	45.8
1975	123	280	127	254	273	134
% of total meat production 1975	18.7	19.7	7.4	8.3	20.5	9.9
Other animal products						
Milk (t)						
1960	1115	1652	5780	16,395	3343	4093
1975	1803	1835	7417	21,658	4581	5562
Index 1975 (1960 = 100)	161.0	111.0	128.0	129.5	137.0	135.8
Eggs (10^6)						
1960	1202	1848	3512	5589	2179	2267
1975	1817	4001	5047	8013	4973	4499
Index 1975 (1960 = 100)	151.0	216.5	143.7	143.3	228.0	198.0

SOURCE: Statistical Yearbooks of the CMEA, 1976, 1977.

TABLE 14 Development of agricultural production in the USSR, 1961–80 (average annual figures).

	Gross agricultural production (10^9 roubles)	Cereals (10^6 t)	Meat (10^6 t)	Milk (10^6 t)	Cotton (10^6 t)
1961–65	66.5	130.5	7.9	51.7	5.0
1966–70	80.5	167.6	11.6	80.6	6.1
1971–75	92.0	180.2	14.1	87.5	7.7
1976–80	–	220.0	15.4	95.3	–
Index 1971–75 (1966–70 = 100)	113.0	107.4	121.6	108.6	126.2
Index 1971–75 (1961–65 = 100)	136.8	138.1	178.4	169.2	154.0
Index 1976–80 (1971–75 = 100)	–	121.0	110.0	109.0	–

SOURCE: "Guidelines for Soviet Economic Development", *Soviet Life*, March 1976, p2. Figure for 1975 grain output from *Pravda*, 1 February 1976.

The relatively moderate and widely fluctuating crop yields achieved in the USSR up to 1975, as shown in Table 16, can be attributed to bad weather conditions resulting in serious crop failures. This is one of the main problems facing Soviet agriculture and therefore in maintaining food supplies. The reduction of this vulnerability is the most important task facing Soviet economists.

TABLE 15 Development of world agricultural and food production, 1952–70 (1952 = 100).

	Agricultural production		Food production	
	Total	Per capita	Total	Per capita
Africa	160	105	160	105
North America	130	100	140	105
South America	165	105	170	105
Asia	165	115	170	115
Europe	165	145	170	145
Oceania	185	125	190	130
USSR	225	170	225	175
World average	165	115	170	120

SOURCE: UN Statistical Yearbook 1969 (New York: United Nations, 1970).

TABLE 16 Fluctuations in grain yields in the USSR, 1956–75.

	Five-year averages	Yields in each year		Difference between max. and min. annual yields	
		Max.	Min.	($100\ kg\ ha^{-1}$)	% of five-year average
1956–60	10.1	11.1	8.4	2.7	27
1961–65	10.2	11.4	8.3	3.1	30
1966–70	13.7	15.6	12.1	3.5	25
1971–75	14.7	17.6	10.9	6.7	46

SOURCE: *Zernovoe Khozyaystvo*, No. 9, 1976.

The major indicators of CMEA grain and meat production are summarized in Table 17. The high intensity of Hungarian and GDR production can be seen in every respect. In all CMEA countries agricultural production is carried out on several different types of farms; with the exception of Poland, where most of the land has remained in the hands of peasant farmers, the most common types of farms are cooperatives and state farms (see Table 18). Some privately owned farms do still continue to operate, however. The private and state-owned (household) sectors produce mainly meat, vegetables, and fruits. In 1977 a considerable proportion of the cattle and pigs were reared on these farms in Bulgaria (22.2 and 25.3%, respectively), Poland (75 and 76%), and Romania (42 and 43%), while the situation was rather different in the GDR (only 0.8% of cattle and 2.4% of pigs), and Czechoslovakia (4.4 and 8.5%, respectively).

2.3 The Position of Agriculture in the National Economy

In spite of the absolute increases in production, the contribution of agriculture to the gross domestic product (GDP) or national income decreased in the smaller CMEA countries until the mid-1970s, but since then a slight increase in the share of agriculture in the total national income has been observed. As shown in Table 19, agriculture contributed the largest share to the generation of national income in 1977 in Bulgaria and Hungary, for example. The two countries in which agriculture contributed the smallest share were the GDR (10.9%) and Czechoslovakia (9.1%). This reduction in the importance

TABLE 17 Major indicators of grain and meat production in the CMEA (averages of 1976–78).

	Grain production (kg ha^{-1} arable land)	Meat production (kg ha^{-1} total agric. land)	Grain production (kg per capita)	Meat production (kg per capita)
Bulgaria	3425	102	895	69.7
Hungary	4077	194	1162	124.6
GDR	3506	276	525	104.2
Poland	2615	142	594	79.5
Romania	3015	99	889	68.4
Czechoslovakia	3802	190	674	89.1
USSR	1704	24	815	55.9

SOURCE: FAO Production Yearbook, 1979.

TABLE 18 Proportion of total agricultural land occupied by cooperative and state farms in the smaller CMEA countries, 1960–77 (%).

	Cooperative farms			State farms		
	1960	1970	1977	1960	1970	1977
Bulgaria	79.9	68.0	90.7	6.6	15.6	–
Hungary	48.6	67.6	69.8	12.2	12.8	12.6
GDR	72.8	78.2	82.1	6.2	6.5	7.8
Poland	1.1	1.2	1.4	11.2	14.0	16.7
Romania	50.2	54.1	54.1	11.8	14.0	13.6
Czechoslovakia	62.1	55.7	61.7	15.5	20.2	20.0

SOURCE: Statistical Yearbooks of the CMEA, 1972, 1978.

TABLE 19 Share of agriculture and forestry in national incomes of the CMEA countries, 1950–77 (%).

	1950	1960	1970	1975	1977
Bulgaria	42.5	32.2	22.6	21.9	18.3
Hungary	47.7	29.2	16.8	16.3	18.3
GDR	28.4	16.4	11.6	10.0	10.1
Poland	47.9	30.3	17.5	15.1	15.8
Romania	27.3	34.9	19.1	16.6	16.9
Czechoslovakia	16.2	14.7	10.1	8.3	9.1
USSR	22.2	20.7	22.0	16.8	17.1

SOURCE: *Thirty Years of the CMEA*. Hungarian Central Statistical Bureau, 1979.

of agriculture has come about despite significant increases in output as described above, mainly because of the vigorous growth achieved in other sectors of the economy.

In the USSR between 1965 and 1975, while the total GDP more than doubled, the amount contributed by agriculture increased by only 70%. The share of agriculture in national income was 20.7% in 1960, decreasing to 17.1% in 1977. Investments in agriculture from the productive fixed funds of the USSR have increased slowly, but were greater than those of industry. Although a relatively large proportion of the labor force is employed in agriculture, productivity is significantly lower than in other sectors of the economy.

Agricultural investments increased in all the other CMEA countries in real terms, but fell behind those in other sectors. This relative decrease is obvious in Bulgaria, for example, where the growth of agricultural investments was 193.5% between 1965 and 1973, while the total increased by 393%. In Romania, the respective figures were 341.4 and 498%. If we compare the share of agriculture in the generation of national income and fixed funds with the data in Table 20, it becomes even more obvious, especially in Bulgaria and Romania, that a considerable part of the income provided by agriculture was

TABLE 20 Rate of agricultural investments in the smaller CMEA countries, 1960–75 (total national investments = 100).

	1960	1975	1975/1960
Bulgaria	29.7	14.6	0.49
Hungary	14.1	13.8	0.98
GDR	12.0	12.0	1.06
Poland	12.6	13.5	1.07
Romania	19.6	13.5	0.69
Czechoslovakia	16.8	12.3	0.75

SOURCE: Statistical Yearbook of the CMEA, 1977.

reallocated to other sectors of the economy. The GDR was an exception, however, because the rate of agricultural investments increased more rapidly than the total, so that the relative share increased, and the contribution to the fixed funds of the economy grew even more rapidly than before. Apart from the GDR, however, an overall decrease in agricultural investments has generally been observed in the other smaller CMEA countries.

The trend in the USSR has been similar to that in the GDR, but with the difference that over the past 15 years, agricultural investments have increased, and in 1971–75 amounted to over a third of all investments. It is worth noting that in recent years the so-called complex development program in the USSR has increased the investments. One of the most important of these was related to the "black earth" (non-chernozem) zones, for which 35 billion (10^9) roubles were allocated in 1970–80. Irrigation and soil improvement schemes accounted for a significant proportion of this, as well as inter-farm cooperation and various agro-industrial integration projects. For these purposes 37.9 billion roubles were spent between 1971 and 1975. Apart from direct investments, there has been encouragement of some industry to provide a sound technological basis for agriculture, and up to 1975 a total of 320 billion roubles were invested, 213 billion of which (i.e. 66.5%) were allocated between 1966 and 1975.

3 THE CONSUMPTION OF AGRICULTURAL PRODUCTS

The consumption of agricultural products has a determinant importance in all the CMEA countries. The per capita food consumption has now reached a level of 3000–3200 calories per day, largely due to income increases, although the income and price elasticity of demand for most commodities is very small according to available data. In addition to incomes, demand is influenced by target consumption figures and the availability of supplies, which have played an important role in the improvement of diets.

The per capita consumption of basic foodstuffs in the smaller CMEA countries is outlined in Table 21, although the data from different countries are not always directly comparable (e.g. on meat consumption) because consumers' habits may simply reflect the production potential determined by natural conditions. However, if we disregard this and try to establish a precedent, then we may state that Czechoslovakia consumed the most meat and eggs, Poland most milk and potatoes, and Bulgaria most vegetables.

TABLE 21 The per capita consumption of major agricultural products in the smaller CMEA countries, 1960–79 (kg yr^{-1}).

	Bulgaria	Hungary[a]	GDR[a]	Poland	Romania	Czechoslovakia[b]
Meat and meat products (converted into meat)						
1960	32.7	47.6*	55.0*	49.9	–	56.8**
1975	60.6	70.5*	77.8*	78.4	45.7	82.0**
1979	65.4	73.0*	88.6*	81.3	–	84.0**
Milk and dairy products (converted into fresh)						
1960	126	114	–	363	–	173
1975	198	125	–	432	132.6	212
1979	229	157	–	457	–	226
Eggs***						
1960	84	160	197	143	–	179
1975	146	270	268	209	–	295
1979	187	324	284	221	–	310
Vegetables (converted into fresh)						
1960	122	84.1	60.7	–	–	63.1
1975	127	185	96.6	94	112.6	78
1979	141	83.1	96.8	118.6	–	70
Potatoes						
1960	34.8	97.6	174	223	–	100
1975	23.1	65.0	142	173	–	98
1979	27.4	60.0	140	160	–	86
Bakery products (converted into flour)						
1960	190	133	102	145	–	126
1975	157	118	94.2	120	–	107
1979	159	118	94.5	120	–	108

*Excluding bacon.
**Including fish.
***Number of eggs.
SOURCE: Statistical Yearbooks of the CMEA; *Ekonomicseszkoja Informacija*, November 1979.

In recent years real incomes have risen in all CMEA countries, so that people have therefore been able to spend more money on food. However, the income elasticity of consumption is relatively small in all the CMEA countries, and there is also a high demand elasticity for meat products and tropical fruits, so that, in addition to the general quantitative increase, there has also been a change in the consumption patterns in recent years. The further augmentation of average daily food intake levels is undesirable, even though the dietary structure may not be ideal. Most of it consists of carbohydrates and starch, and the level of animal proteins is inadequate (see Table 22). The situation is improving, but only slowly, and the recent significant increase in fruit, vegetable, and dairy produce consumption is a favorable trend. The present per capita level of meat consumption can be described as moderate in most of the CMEA countries, and the targets envisaged in the plans may not be reached.

TABLE 22 The consumption of major foodstuffs in the USSR, 1970–79 (kg per capita).

	1970	1974	1975	1979	Index 1979 (1975 = 100)
Cereals (converted into flour)	149	142	141	139	98.6
Potatoes	130	121	120	119	99.2
Vegetables (converted into fresh)	82	87	87	95	106.7
Fruits (converted into fresh)	35	–	50	41*	–
Meat (weight at slaughter)	48	55	57	58	101.7
Milk and dairy products (converted into milk)	307	316	315	319	100.9
Eggs**	159	205	215	233	107.8

*1977 data.
**Number of eggs per capita.
SOURCE: Statistical Yearbooks of the CMEA.

4 THE DEVELOPMENT OF AGRICULTURAL FOREIGN TRADE

Agriculture has traditionally been a major branch of foreign trade, but its importance varies throughout the smaller CMEA countries. Tables 23 and 24 show that the foreign trade balance of agriculture is usually negative, and in 1975 the deficit amounted to about 2 billion roubles. Bulgaria, Hungary, and Romania are net exporters of food and have considerable positive trade balances, while those of the GDR, Poland, and the USSR are usually negative. Under the impact of recent changes in the world economy, the endeavor for self-sufficiency in food and raw materials has strengthened in the CMEA countries, although the dependence of agriculture on natural and climatic conditions has so far precluded the accomplishment of this target.

The characteristics of the agricultural foreign trade of the smaller CMEA countries in the 1970s may be summarized as follows.

(a) The agricultural share of total foreign trade is on the whole decreasing, but there are differences between the various CMEA countries. The role of agriculture is greatest in Bulgaria and smallest in Czechoslovakia.

TABLE 23 Development of exports and imports in the smaller CMEA countries, 1960–75.

	Exports (10^6 roubles)		Imports at current prices		Index 1975 (1960 = 100)	
	1960	1975	1960	1975	Exports	Imports
Bulgaria						
total trade	515	3494	596	4027	678	707
agriculture	290.4	1181	95	511.4	407	538
Hungary						
total trade	787	3999	856	4646	508	543
agriculture	215.6	1007.7	249	882.7	467	354
GDR						
total trade	1987	7517	1975	413	378	425
agriculture	117.2	684	774	1901	584	245.6
Poland						
total trade	1193	7686	1346	9371	644	696
agriculture	274.4	807	456.3	1722	294	377
Romania						
total trade	645	3980	583	3980	617	683
agriculture	231.5	899.5	107	620.8	388.5	580
Czechoslovakia						
total trade	1737	5831	1635	6340	335.6	388
agriculture	180.6	419.8	606	1103	232.4	182

SOURCE: Statistical Yearbook of the CMEA, 1976; author's own calculations.

TABLE 24 Agricultural foreign trade as percentages of total trade in the smaller CMEA countries, 1960–75.

	Exports			Imports		
	1960	1975	1975/60	1960	1975	1975/60
Bulgaria	56.4	33.8	0.59	16.7	12.7	0.76
Hungary	27.4	25.2	0.91	29.2	19.0	0.65
GDR	5.9	9.1	1.54	39.2	22.6	0.57
Poland	23.0	15.5	0.45	33.9	17.7	0.52
Romania	35.9	22.6	0.62	19.4	15.6	0.84
Czechoslovakia	10.4	7.2	0.69	37.1	17.4	0.47

SOURCE: Statistical Yearbook of the CMEA, 1976.

(b) The most important agricultural commodity imported into the CMEA countries is grain, particularly in the GDR, Poland, and Czechoslovakia. The total quantity of fruit imported into these countries trebled between 1960 and 1975, mainly due to the increased demand for citrus fruits. The most important exports, on the other hand, were cereals (from Hungary and Romania), meat products, vegetables, and fruits. Hungary and Bulgaria exported fresh, preserved, or canned vegetables and fruits, and Hungary and Poland exported meat products. The development of this trade in major foodstuffs is outlined in Tables 25 and 26.

TABLE 25 Imports of major agricultural products into the smaller CMEA countries, 1960–75 (10^3 t).

	Bulgaria	Hungary	GDR	Poland	Romania	Czechoslovakia
Meat and meat products						
1960	15.2	25.2	97.0	18.1	3.5	99.4
1975	18.0	11.9	23.8	16.0	2.8	31.9
Cereals						
1960	154.0	340.0	2200.0	2122.0	–	2010.0
1975	653.0	172.0	3360.0	3963.0	–	885.0
Vegetables (fresh)						
1960	–	0.2	116.0	16.4	–	78.3
1975	–	5.4	129.0	31.6	–	71.0
Vegetables (canned)						
1960	–	2.2	28.6	0.9	–	18.5
1975	–	3.7	123.0	11.1	–	15.0
Fruit (fresh)						
1960	3.2	18.1	171.0	45.3	15.9	104.0
1975	32.4	79.5	487.0	196.0	75.8	335.0
Fruit (canned)						
1960	0.1	3.3	47.7	0.1	–	2.7
1975	0.9	12.8	117.0	18.3	–	30.1

SOURCE: Statistical Yearbook of the CMEA, 1976.

TABLE 26 Exports of major agricultural products from the smaller CMEA countries, 1960–75 (10^3 t).

	Bulgaria	Hungary	GDR	Poland	Romania	Czechoslovakia
Meat and meat products						
1960	32.4	51.7	–	110.0	54.9	11.0
1975	98.8	249.0	–	209.0	165.0	16.1
Cereals						
1960	174.0	38.4	–	89.3	707.0*	80.4
1975	195.0	1285.0	–	104.0	1163.0*	73.2
Vegetables (fresh)						
1960	247.0	92.2	17.8	37.0	25.7	15.1
1975	184.0	62.8	9.8	1.5	15.0	36.5
Vegetables (canned)						
1960	76.0	47.4	–	12.6	–	2.9
1975	253.0	289.0	1.6	29.9	–	13.3
Fruit (fresh)						
1960	129.0	55.8	0.1	32.2	56.4	10.1
1975	159.0	399.0	–	48.3	93.8	21.0
Fruit (canned)						
1960	72.0	18.4	–	0.8	–	4.3
1975	191.0	91.7	–	32.1	–	10.5

*Wheat and corn.
SOURCE: Statistical Yearbook of the CMEA, 1976.

(c) The general characteristics of agricultural trade of the CMEA as a whole are also prevalent in the smaller member states.

The trends outlined above, and also those of Soviet foreign trade, have not changed during recent years. Agriculture has become increasingly important in the foreign trade of the USSR, and imports to meet consumer demands have grown considerably. Bilateral and multilateral trade agreements, and contracts for the mutual supply of goods have been established between the USSR and other CMEA countries, amounting to 50.7 billion roubles in 1975. The increase in Soviet foreign trade was greatest in 1974 and 1975, when the increases on previous years reached 26 and 28%, respectively, although this represented only 3% of the national income. About 62–64% of Soviet foreign trade is with other CMEA countries, and although the share of agricultural products is relatively modest, it is gradually increasing: food and raw materials for the food industry accounted for 12% in 1970, and about 15% in the late 1970s. Agricultural exports are relatively small, however, representing 8.4% in 1970 and 4.8% in 1975, while imports increased from 15.9% in 1970 to about 25% in 1975–80.

Up to 1973, the USSR was a net exporter of wheat, and imports of meat products were relatively small, but as a result of the disastrous weather conditions of 1972 and 1975, this position was reversed, thereby increasing the burden on the balance of payments. In the late 1970s, about 14–15 $\times$ 10^6t of grain imports were necessary annually to improve living standards and to alleviate food shortages. However, imports of vegetables and fruits, both fresh and processed, were relatively modest because these crops were less badly affected by the weather (see Table 27).

Most of the exports of cereal grains from the USSR are destined for other socialist states (mainly the GDR, Czechoslovakia, Poland, and Cuba), while the main source of imports is the United States. In 1979–81 other countries such as Argentina, Canada, and Australia became further important sources of Soviet grain imports, and most of the meat and meat products come from Western Europe and Hungary. Most canned vegetables and about 40% of fresh fruits are imported from other CMEA countries, and a considerable amount of cane sugar is imported from Cuba. In recent years, cotton has been the only agricultural crop in the USSR that has provided a significant surplus, enabling about 0.6 $\times$ 10^6t to be exported.

5 AGRICULTURAL POLICY: GOVERNMENT CONTROL

5.1 Policy Objectives

The agricultural policies of the CMEA countries are based on the practice that agriculture forms an integral part of a centrally planned national economy. The basic targets for agricultural production are formulated in national economic plans, and these are implemented by an integrated system of smaller-scale plans drawn up for specific sectors of the economy, both for regions and for farms. Efforts to satisfy individual demands at a steadily increasing level are an important aspect of economic planning, and these are equally emphasized in all countries. With respect to agriculture, the quantity of produce needed to meet planned levels of consumption and for industry are the most important considerations in economic planning. These general targets depend, of course, on specific

TABLE 27 Development of foreign trade in the major agricultural products in the USSR, 1970–75 (10^3 t).

	1970	1973	1974	1975
Cereals				
exports	570	4853.3	7029.5	15,910
imports	2159	23,900	7131	15,909
Raw sugar				
exports (white)	1079	42.9	95.2	53.3
imports	3003	2485	1856	3236
Meat and meat products				
exports	–	75	55.9	–
imports	165	129	515	515
Vegetables (fresh)				
exports	–	–	–	–
imports	163	162	196	144
Vegetables (canned)				
exports	–	–	–	–
imports	249	351	339	322
Fruit (fresh)				
exports	–	–	–	–
imports	679	828	901	860
Fruit (canned)				
exports	–	–	–	–
imports	207	165	160	170
Cotton				
exports	517	728	739	800
imports	258	131	140	137

SOURCES: *The Foreign Trade of the Soviet Union*, 1973, 1974, 1975; Statistical Review, Moscow; *International Relations*, 1974, 1975; Statistical Yearbook of the CMEA, 1973, 1976.

conditions and on the economic situation of each particular country. The development of industry is usually central to economic policies, and although food production is also important, it remains a secondary economic and political objective.

Ideally, increases in food production should be achieved by improving efficiency and productivity, rather than by extending the area under cultivation (since in any case little or no possibility exists for this). In order to achieve this, the following methods are being used in the CMEA countries:

(i) the concentration and specialization of agriculture by means of large-scale, state-owned and cooperative farms, and agro-industrial complexes, and

(ii) the introduction of new technology and modern production methods throughout the entire food-producing sector.

The most important objectives of CMEA agricultural policy are to produce the quantity of food needed for the planned level of personal consumption and to cover industrial demand for agricultural products. This general target, of course, depends on the specific conditions and on the actual economic situation in each country, and in spite of the similarity between the basic objectives, no uniform agricultural policy prevails throughout the CMEA. The development of industry is central to economic policy in all countries, but, in addition, an increase in agricultural and food production is a politically important task.

Agricultural investment policy in the CMEA countries is developed according to central plans, or is determined by them. Thus the scale of investments or their share of the total at any time reflects the state of the economy in each country, and varies throughout the region in both space and time. Agriculture is often allotted considerable finance in excess of its eventual contribution to the national income, but the reverse case is not infrequent, such as when a part of the income does not remain in that sector, but is redistributed for the development of industry. If the situation in recent years is considered, it can be seen that the status of agriculture was different in various CMEA countries, and its role in the development plans and the corresponding investment also varied.

In the smaller CMEA countries in the 1970s the development of agriculture was not the main target, so that investments did not increase at the same rate as those in other sectors of the economy. In some countries, such as Bulgaria and Romania, a considerable part of the income produced in agriculture was redistributed to other sectors of the economy. The USSR represents a different case, where the development of agriculture has been stressed, and during the last two decades, the share of agricultural investments surpassed the levels in other CMEA countries. In the period up to 1975, a total of 320 billion roubles were invested in agriculture, 66.5% of which was allocated in 1966–75. The redistribution of investment goods, such as agricultural machinery to improve efficiency, was continued in the USSR in 1976–80. The share of agriculture within all investments was higher than its eventual contribution to the generation of national income (about 30% of all investments was allocated to agriculture and food production).

An important general characteristic of agricultural policy in the CMEA countries is the vigorous effort for self-sufficiency; i.e. in each country, domestic demands for all commodities that can be produced should be met as far as possible from domestic production. It can be observed that the treatment of agriculture and food production depends upon the state of the balance of payments. In those countries where natural conditions are favorable for agriculture this sector is utilized to augment foreign currency receipts. This is particularly true in Hungary, Bulgaria, and Romania, where the maximization of foreign currency receipts from agricultural exports is one of the most important economic-political targets.

Details of future agricultural policies are not easily available. Each CMEA country has certain preconceptions about the development of agriculture in the long term, up to 1990, and, in some cases, even up to 2000. The five-year plans represent the documents in which the decisions that are intended to be implemented are fixed. The present plan period in each country started on 1 January 1981. According to available plan documents, the development of agriculture will receive more attention than before in each country. Moderate increases (8–10%) in production are planned in Czechoslovakia and the GDR. In the USSR the total growth target is 12–14% for the five-year period 1981–85, with the production of 238–243 $\times$ 10^6 t of grain annually. The targets are most ambitious in Bulgaria and Romania, where a 20–25% increase in production is expected.

Based on conclusions reported at various forums as well as upon the characteristics of the economic situation and on analyses of the actual result of the current plan period, it is probable that the general rate of economic growth in the CMEA will be slower in the 1980s than in previous periods. The agricultural growth rate will probably be closer to the rate of general economic growth, but it will remain at the same relatively moderate level of the late 1970s. It is also probable that, because of balance of payments problems, efforts toward food self-sufficiency will increase and a greater stress will be laid on the development of agriculture.

In connection with this slower economic growth, agricultural investments will increase only slowly as a proportion of the total, with a slight decrease in the USSR. Grain and meat production will receive the greatest emphasis. Efforts to establish a production structure better adapted to world market demands will certainly be confirmed in the food-exporting countries, and this will presumably further consolidate the role of the grain economy.

5.2 Methods of Economic Management

In order to accomplish their economic-political goals, the CMEA countries use various strategies to improve the efficient management of agriculture. In centrally planned economies, so-called direct and indirect policy instruments are used to realize targets of the national plans, and those applied to agriculture are generally more complicated than in any other sector of the economy. The following list of policy instruments shows their complexity: the *direct* economic regulations of governments are, among others,

- (i) the determination of the type, size, location, and scheduling of the most important agricultural investments;
- (ii) the setting of targets for farm production;
- (iii) the central distribution of technical and financial resources;
- (iv) the determination of labor movements within agriculture, and between agriculture and other sectors of the economy;
- (v) the establishment of new production organizations in agriculture.

The *indirect* economic regulators of government include, for example,

- (i) price regulation and pricing policy;
- (ii) state budget and tax policy;
- (iii) the regulation of the depreciation system;
- (iv) the control of wages and the system of personal incentives in agriculture;
- (v) centralized credit and interest rate policy;
- (vi) state subsidies;
- (vii) export tariffs, import restrictions;
- (viii) exchange rates.

In the CMEA countries, the methods of agricultural management are not uniform, even though policy goals are similar. Both direct and indirect means may be used, but their roles are different. In countries with centralized economic management systems, governments usually use direct economic regulators, while in those with decentralized economic management systems, state control is effected by indirect means.

The application of direct means of economic management is determinant in the majority of the CMEA countries. In the course of the changes that have taken place in recent years, the role of economic stimulators (indirect means) has increased, but in spite of this agricultural management has remained centralized (except in Hungary, Poland and Bulgaria). In Hungary the use of indirect means of control increased after the economic reforms introduced in 1968, and the decentralized management system was extended even further in the 1970s. Conditions in Poland are dominated by the large proportion of privately owned farms, so that specific methods have to be used to influence the individual producers.

Considerable effort has been made in all countries to improve the governmental economic management of agriculture.

Bulgaria. A decision was made about the organization of agro-industrial complexes in April 1977, which made further decentralization of planning necessary, although the centralized nature of the system, did not change in practice. In recent years some buying-up prices were modified and the role of other economic stimulators was significantly increased. From practical experience, some reorganization of the complexes was also undertaken.

GDR. In addition to medium-term agricultural plans, the one-year plans are also important in economic management. Agricultural management continues to be characterized by the disaggregation of plans and by very close central control of targets. One of the main aims of management is the specialization of farms. The transition to production based on cooperation between individual farms is supported through pricing and credit policy, and by cheap machines and implements, and the concentration process will also accelerate by means of preferential credit.

Poland. Considerable steps were made in the development of centralized economic management by the Sixth Congress of the Polish Workers' Party. The previous system was modified and indirect economic and financial regulators were increased while targets were reduced. But on the whole these steps were not sufficient to increase agricultural production up to the desired level. The failures of agricultural production can definitely be considered to be one of the sources of the present overall economic problems of Poland.

Romania. Agricultural management in Romania is effected by direct means. The central organs have paid close attention to the consolidation of agricultural agencies and the associations of the farmers' cooperatives. Organizational measures have played a significant role in recent years, but agricultural prices have also been raised several times to give more incentive to farmers.

Czechoslovakia. Both direct and indirect means of economic management are used, although direct regulators are more common. Agricultural prices have also been raised several times to provide incentives.

Hungary. In the management of Hungarian agriculture, central plans are implemented by indirect means. Farms and other food-producing enterprises are not bound by any obligatory targets, and economic decisions are influenced by the central organs only through economic and financial regulators. These regulators are determined for each five-year plan period, but some modifications may be made in relation to the targets set in the one-year plans.

As stated above, the raising of agricultural prices and the increasing role of economic stimulators have been observed in all socialist countries. It must be emphasized, however, that domestic prices are not determined directly by world market prices – not even in Hungary, where a decentralized system of management is applied. The internal pricing system expresses the preferences made and the targets set by government, and price changes do not usually follow world market trends.

USSR. The management of Soviet agriculture is effected mostly by direct means; the major elements of the central plans are broken down for the republics, territories, and for farms. Economic stimulators also play an important role and prices have risen in recent years, but the nature of the system has not changed essentially. The increased support and stimulation of household and private farming is a new characteristic, but its effect on the increased development of this sector has not yet manifested itself.

In general it can be remarked that the application of direct means of economic management is determinant in the majority of the CMEA countries. The basic nature of the government management system is not changed, but serious efforts to improve the efficiency will be made, using indirect economic incentives. The further development of the domestic producer and consumer price system agricultural products seems to be unavoidable. The modification of low food price policies might also affect consumer demands and a wider range of price incentives will probably increase the overall efficiency of production.

The production potential of household farming by cooperative farm members and industrial workers is under-utilized in most CMEA countries, and production could be increased through this channel without heavy government investment. Encouragement of the utilization of these reserves is an economic necessity in the present situation, and the extension of these activities will make a great contribution to the fulfilment of national targets in the next 5–10 years.

6 METHODS OF FORECASTING – THE CMEA AGRICULTURAL MODEL

To project the development of agriculture in the CMEA countries up to the year 2000 is a rather complex task. As stated above, no official long-term targets for either consumption or production have yet been published. The majority of available estimates were elaborated before the recent changes in the world economy, and may therefore need to be adjusted accordingly. In several research institutes dealing with the economic problems of the socialist countries, forecasts and calculations have been made, such as the forecast elaborated in *Agriculture: Toward 2000* by the FAO, and other material. Making use of all these sources of information and considering their main conclusions, our forecasts have been made by means of mathematical methods. In using the complex mathematical model of the CMEA countries, including the Soviet Union, we applied the model structure elaborated within the framework of the Food and Agriculture Program (FAP) of IIASA. Below we outline the major characteristics of the CMEA Agricultural Model and then describe the most important attributes of the models that served as the basis of our forecasts. The details of the FAP agricultural models are not discussed here; for further information see Keyzer (1977, 1980), Fischer and Frohberg (1980), and Parikh and Rabar (1981).

6.1 General Characteristics of the CMEA Agricultural Model

The CMEA Agricultural Model was developed as part of IIASA's Food and Agriculture Model system. The main goal is not straightforward optimization, but the creation of a tool to enable the dynamic behavior of an agricultural system and the interactions of its elements to be understood, so that the model can be used for medium- and long-range projections. Unlike the normative agricultural models developed in the past, this model is descriptive in character, reflecting the present operation of centrally planned agricultural systems, decision-making, and economic management practices. At the same time, various normative elements such as government policy and published plan targets, which influence the operation of the system, are also considered. The FAP models describe an objective structure, but they enable the feasibility of normative targets and plans to be assessed.

In the CMEA Agricultural Model a large part of the economic environment and the most important factors of food production are taken into consideration. Food and agriculture are modeled as disaggregated parts of an economic system that is closed at a national as well as international level. Our model therefore has the following features:

(i) The food consumption sphere is incorporated.
(ii) The non-food production sectors of the economy are represented by assuming that they produce only one aggregated commodity.
(iii) The economic, technical, biological, and human aspects of food production are included.
(iv) Both the production of agricultural raw materials and food processing are modeled.
(v) Under "other", agricultural production, and food processing, all other products not individually represented are aggregated.
(vi) Basic financial equilibrium is maintained.

The major elements of the model are outlined in Figure 1. The basic methodology used is a simulation technique, and the model (which is actually a system of interconnected smaller models) is structured according to the main elements of a centrally planned agricultural system.

As Figure 1 shows, two spheres are differentiated within the model. The economic management and planning submodel describes the decision-making and control activities of the government. The submodel of the real sphere covers the realization of central plan targets including the whole national economy, with a disaggregated food production sector. The major blocks of the latter submodel are related to production, consumption, and trade, and they also update available resources and other model parameters. Other suitable techniques (e.g. linear and nonlinear programming, econometric methods, heuristic routines) can also be employed to describe the subsystems according to the specific conditions and objectives of the investigation.

The model is dynamic, with a one-year time increment. Subperiods within one year are not considered. The random effects of weather and animal diseases can also be taken into account.

The CMEA Agricultural Model has certain specific features that are not typical of other FAP models. The most important of these are:

(i) The modeling of central planning and economic management activities plays a crucial role in the system.
(ii) Certain overall economic targets are considered exogenously.

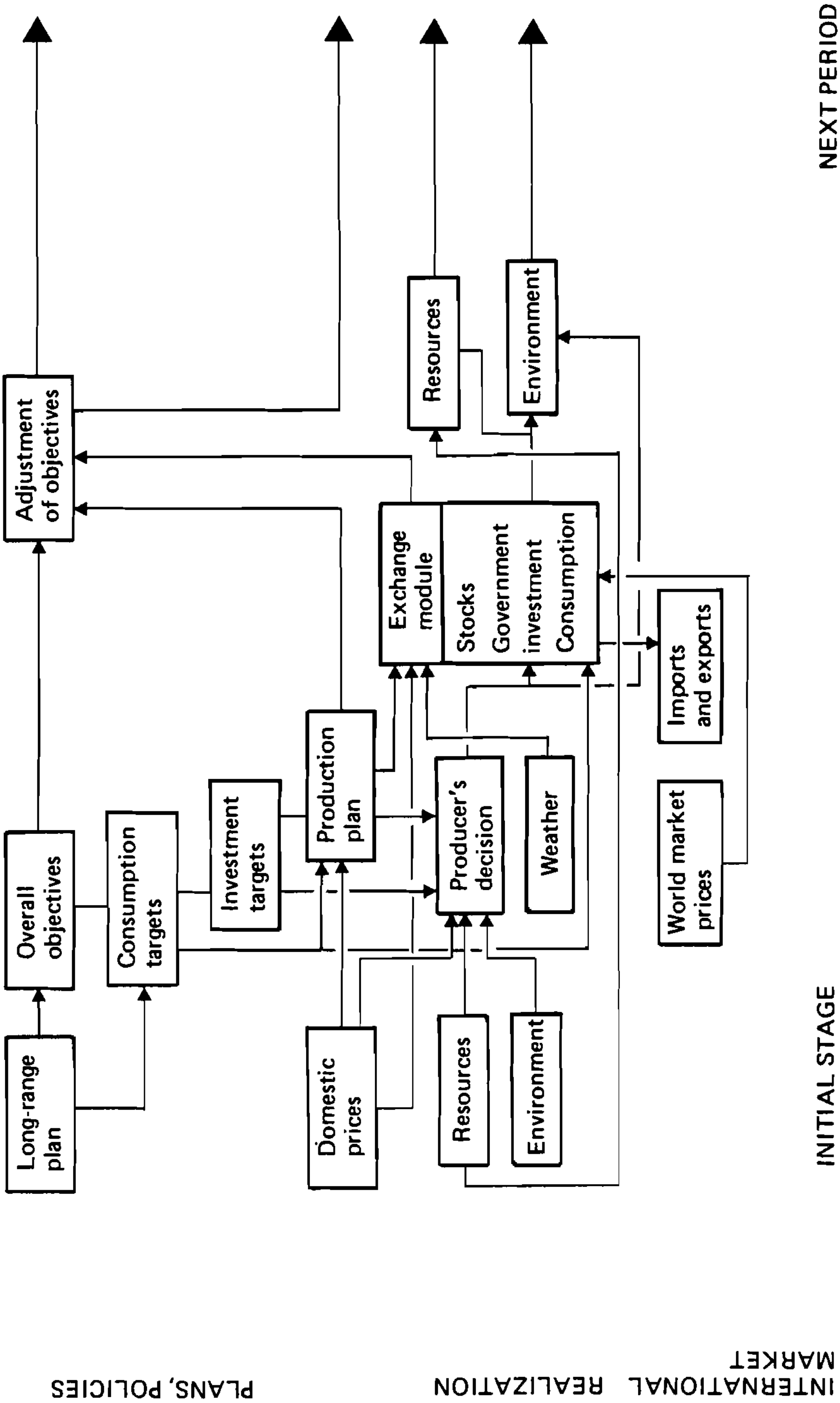


FIGURE 1 The structure of the CMEA Agricultural Model.

(iii) Only the implementation of a certain policy structure is considered endogenously.
(iv) The domestic market included in the model is not directly related to the international market.
(v) Domestic prices express government policy objectives instead of being related to a certain market equilibrium.

According to these specific features, long-range government objectives, such as the growth of the whole economy, the growth rate of food production and consumption, a given relation between consumption and accumulation, and a positive balance of payments in food and agriculture, are considered exogenously, as they are determined by the long-range development plan of the national economy. The model focuses on the development of food and agriculture (production structure, investments, etc) and its interaction with the rest of the economy. The major steps towards the solution can be described as follows.

(1) The overall growth targets are chosen for a given year, based on long-range objectives and previous results. After setting targets for gross and net production, planned consumption and accumulation levels are calculated, determining the targets for consumption of individual commodities and investment funds in food and agriculture, as well as in the rest of the economy.

(2) A detailed production plan for food and agriculture is determined, considering the available resources and minimum required production of certain commodities.

(3) The behavior of producers (state and cooperative farms, private producers) is determined, and the random effects on the final output of food and agriculture, as well as the rest of the economy, are calculated. In the model both direct and indirect instruments of government can be manipulated to realize the production targets of the central planners. According to the economic management system of the government (more or less decentralization) in a given country, the producers' decision model and relations between government and producers can be modeled in various ways.

(4) The exchange module compares supply and demand. Here export and import figures, consumption, and investment levels are calculated, satisfying the balance of trade and equilibrium constraints. The model can be linked with other IIASA national models through this part of the model. To express the reaction of a centrally planned economy to changing world market conditions, a special equilibrium type of model has been developed.

(5) As the final results for a given year are obtained, overall government objectives and policy instruments (prices, tax rates, etc) are adjusted, based on the analysis of the performance of the whole system. The available resources and some of the model parameters are also updated.

As a first step in the realization of IIASA's objectives in the modeling of centrally planned agricultural systems, the Hungarian Agricultural Model (HAM) was developed as a prototype for the CMEA countries (see Csáki 1981). The experience gained with HAM, and with the basic linked system elaborated at IIASA were used in constructing the CMEA Agricultural Model. The most important task set for the model is to obtain a realistic picture of the development trends that can be expected, and the probable import demands and the potential exports of agricultural products from the region. We should like to point out that this model does not aim to provide a detailed description and study of the agricultural development problems of each individual country, but in spite of this it can be a useful means of assistance for the elaboration of projections and of the various possibilities for development.

The CMEA Agricultural Model covers the European CMEA countries (Bulgaria, Czechoslovakia, GDR, Hungary, Poland, and Romania) and the Soviet Union (including its Asian territories). The model is divided into two major parts: the first submodel describes the agricultural system of the Soviet Union, and the second includes the smaller CMEA countries. The two submodels have a completely consistent structure and can be operated independently of each other (see Figure 2). Correspondingly, when describing the methodology, we do not deal with the two model parts separately, but mention the differences only as far as is necessary.

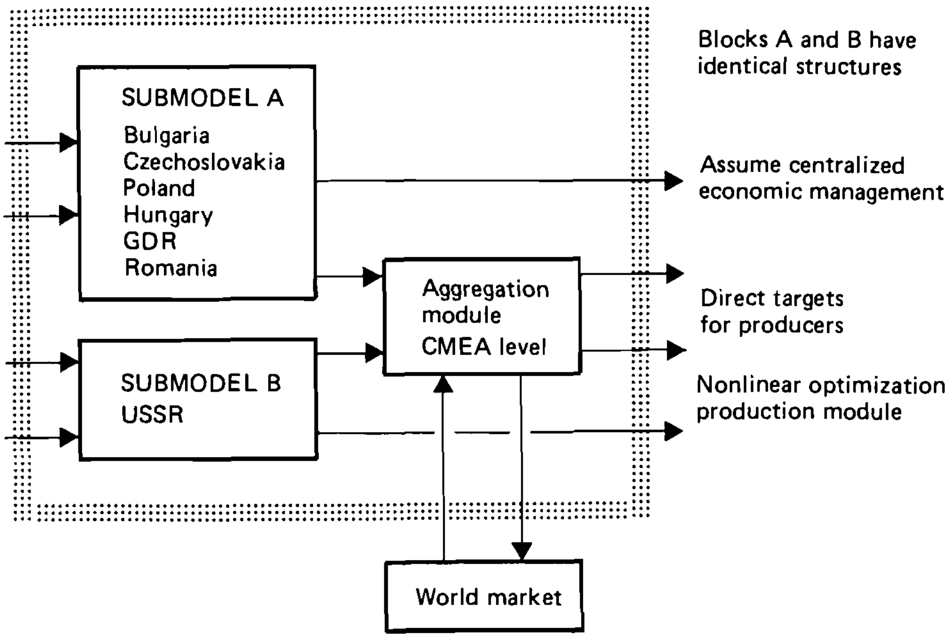


FIGURE 2 The structure of the CMEA Agricultural Model.

With respect to its fundamental principles, our model is similar to or includes the most important general characteristics of the Hungarian or other IIASA agricultural models. We assume that the most important long-range policy objectives, such as the required growth rate of the whole economy, the required growth in the rate of consumption, and the extent of the agricultural share of total investments are determined from CMEA data from previous years and by using published plan targets. We assume also that decisions concerning agricultural development are made centrally and that they are usually forwarded to the producing enterprises in a direct way. Therefore we do not model the producers' decisions separately.

The commodity classification follows that used in *AT 2000*, and only cereals, vegetables, and certain industrial crops are aggregated. Correspondingly, in both submodels 22 products are taken into consideration, as follows:

1	Wheat	12	Tea
2	Rice	13	Cotton
3	Feedgrains	14	Other non-food products
4	Sugar	15	Rubber
5	Vegetables	16	Other feeds
6	Bananas	17	Beef
7	Citrus fruits	18	Mutton
8	Other fruits	19	Pork
9	Vegetable oil	20	Poultry
10	Cacao	21	Dairy products
11	Coffee	22	Eggs

Aggregation of these products as compared to the FAO list is carried out using IIASA aggregating coefficients, but FAO measurements and units are otherwise retained. Two types of prices are taken into consideration in the model: domestic and international prices. Domestic prices are expressed in roubles, and for the other CMEA countries the rouble price is calculated on the basis of a weighted average of prices valid in the respective countries, using the CMEA exchange rates published in Hungary. The prices used in *AT 2000* were taken to be world market prices; in the course of the calculations neither domestic nor international prices are modified.

The model is based on data available from the FAO, but we also made use of CMEA Yearbooks, statistical yearbooks of the countries in question, and other analyses and statistical abstracts prepared on the agriculture of the CMEA countries. The model itself, i.e. its parts relating to the Soviet Union and to the smaller CMEA countries, is equally divided into four blocks.

6.2 Modeling of Government Economic Management and Major Policy Objectives

As mentioned above, the major government objectives are taken into consideration in an exogenous manner within the model. The first block of the model serves to determine these economic-political tasks. Within this scope, the following are assessed:

(i) targets for the general development of the economy,
(ii) estimated provisions for consumption,
(iii) required stockpiling, and
(iv) planned investments.

When assessing the overall objectives of economic policy, we determine the extent of the planned national income and consumption, as well as of the total investment required for a given period according to economic development, i.e. by the required rate of growth of consumption indicated in advance, as follows:

$PNIC_t = NIC_{t-1}(1 + a_1)$ (planned national income)
$PCONS_t = CONS_{t-1}(1 + a_2)$ (planned personal consumption)
$PINV_t = PNIC_t - PCONS_t$ (planned investments)

where

$PNIC_t$ = planned national income for period t,
NIC_{t-1} = actual national income in period $t - 1$,
$PCONS_t$ = planned consumption in period t,
$CONS_{t-1}$ = actual consumption in period $t - 1$,
$PINV_t$ = planned investments in period t.

With respect to foodstuffs, FAO forecasts are used as target figures for consumption in the model. In another version of the model, however, the probable development of consumption is projected by means of trend functions. Using these targets we calculate the expected consumption of non-agricultural products as a residual value subtracted from the total consumption. The required extent of stockpiling is fixed at a certain percentage of total consumption, which varies according to the type of product, and can also be varied in the course of the computations.

The expected total investment is calculated by applying the exogenous (a_3) parameter, which expresses the share of agriculture within all investments as follows:

$PINVA_t = a_3 PINV_t$ (planned agricultural investments)
$PINVN_t = PINV_t - PINVA_t$ (planned investment in other sectors of the economy)

where

$PINVA_t$ = planned investment in agriculture in period t, and
$PINVN_t$ = planned investment in the rest of the economy in period t.

6.3 The Production Model

The production model block follows the methodology of the simplified IIASA model system, using a nonlinear programming model, where linear constraints are applied with a nonlinear objective function. Most of the model parameters are estimated statistically and appear as Greek characters, while certain other parameters assessed on the basis of expert estimates or of calculation appear in Roman type. For further details on the methodology used in constructing the nonlinear production model, see Fischer and Frohberg (1980).

The allocation model can be written for any year t as follows:

$$\max \sum_{i=1}^{13} p_{it} Y_{it} - \sum_{i=11,13} \sum_{j=1,13} a_{ij} p_{jt}^x Y_{it}$$

so that

$$Y_i = \alpha_i(t) K_{it}^{\beta_i} L_{it}^{\gamma_i} F_{it}^{\delta_i} \qquad (i = 1, \ldots, 10)$$

$$Y_i = \alpha_i(t) K_{it}^{\beta_i} L_{it}^{\gamma_i} \qquad (i = 11, \ldots, 13)$$

$$\alpha_i(t) = \beta_{1i}/[1 + e^{-\beta_{2i}(t-1964)}]$$

$$Y_{it} \geqslant YLB_{it} \qquad (i = 1, \ldots, 13)$$

$$Y_{it} \geqslant YUB_{it} \qquad (i = 1, \ldots, 13)$$

$$\sum_{i=1}^{13} K_{it} \leqslant TK_t$$

$$\sum_{i=1}^{13} L_{it} \leqslant TL_t$$

$$\sum_{i=1}^{10} F_{it} \leqslant TL_t$$

where i refers to:

(1) Wheat
(2) Rice
(3) Other grains
(4) Oilseeds
(5) Sugar, raw
(6) Vegetables, roots
(7) Fruits
(8) Tea
(9) Seed cotton
(10) Other non-food products
(11) Bovine production [(in protein) = 0.147 × meat + 0.035 × milk]
(12) Pork
(13) Poultry and eggs (in protein)

Description of variables:

Y_{it} = net production of commodity i in year t (gross production minus seed use and wastage; beef and lamb products and milk are aggregated by using their respective protein contents).
TK_t = capital stock in agriculture in year t.
TL_t = agricultural labor force in year t.
TF_t = fertilizer (nitrogen) input in year t net of the quantity used for roughage production.
K_{it} = capital employed in the production of commodity i in year t.
L_{it} = labor employed in the production of commodity i in year t.
F_{it} = fertilizer applied to crop i in year t.
p_{it} = expected price of commodity i in year t.

The feed requirement coefficients are derived using an algorithm that tries to allocate the given total feed consumption figures based on known physiological requirements. The algorithm works by first trying to meet the requirements of pigs and poultry, and then treating bovine animals as a residual.

Based on the FAO time series, three sets of parameters of the production block are estimated. Appendix A compares actual and estimated data, using the third set of parameters in the model. Various other statistical methods are also used to test the validity of the parameters. The lower bounds of certain products in the module, as minimum production requirements expressing a required rate of self-sufficiency, can be given in advance. As can be seen from the list of commodities, only those that can be produced in the CMEA countries in question appear in the production module: milk and eggs do not count as independent products, since they are assessed after the solution of the model as by-products of beef and poultry production, respectively.

Three major production factors are taken into consideration: the available capital, labor, and fertilizers. In the course of model formulation and specification, the greatest problems occur in the assessment of capital stock, since accounting practices in the CMEA differ from those in the West and are not uniform; in several countries such data are not published at all. Finally, for these countries it was decided to express the value of invested capital by the value of fixed assets, since we were able to obtain concrete information about the latter. The assessment of the pool of fixed assets for a given year, taking investments and depreciation into consideration, is carried out as follows:

$$CSA_t = CSA_{t-1} + \frac{INVA_{t-1} + DEPA_{t-1}}{p_{nt}} = DEPA_{t-1} \text{(agriculture)}$$

$$CSN_t = CSN_{t-1} + \frac{INVN_{t-1} + DEPN_{t-1}}{p_{nt}} = DEPN_{t-1} \text{(other sectors of the economy)}$$

where

CSA_t = capital stock in agriculture in period t.
CSN_t = capital stock in the rest of the economy in period t.
$DEPA_{t-1}$ = depreciation in agriculture in period $t - 1$.
$DEPN_{t-1}$ = depreciation in the rest of the economy in period $t - 1$.
p_{nt} = price of investment goods.

Different values can also be indicated as depreciation rates.

With respect to the available labor force and the growth of the total population, we accept the projections of the FAO in *AT 2000* as a starting point. As alternative possibilities, however, other demographic forecasts or even a submodel describing this area can be considered.

The available quantity of fertilizers can be handled in two ways. It is possible to take levels given exogenously into consideration, or the model can be run using the following function:

$$FERT_t = FERT_{70} 1.001 \left(\frac{CSA_t}{CSA_{70}}\right)^{1.369}$$

where

$FERT_t$ = fertilizer availability in period t.

Non-agricultural production is taken into consideration as an aggregated activity, and the aggregation is performed according to the rules of the IIASA Agricultural Model. In this respect, there are again two possible solutions that could be applied to the model: one is the representation of the non-agricultural sector by a Cobb–Douglas production function, determined as explained in Fischer and Frohberg (1980):

$$Y_t^{NA} = \theta_t (K_t^{NA})^{\theta_t} (L_t^{NA})^{1-\theta_t} + u_{Nt}$$

where

Y_t^{NA} = non-agricultural production in year t.

K_t^{NA} = capital stock in the non-agricultural sector in year t.

L_t^{NA} = labor force in the non-agricultural sector in year t.

u_{Nt} = error term, identically and independently distributed.

θ_t = time variable; t = year minus 1965.

We can, however, also apply trends fixed in advance concerning the development of non-agricultural production, or the coefficients of these trends can even be discretionally modified.

6.4 The Consumption and Trade Block

A very important part of the model is designed to compare supply and demand, as well as to create equilibrium within the system and with external conditions. On the basis of results supplied by the production block, we assess first of all the quantity of feed and other intermediate inputs and of industrial utilization. The determination of feed inputs is performed by a matrix including preliminarily fixed coefficients of feed usage, and these are assessed statistically. In the basic version of the model, computations are performed with fixed coefficients of feeds used for the entire time horizon modeled. It is also possible to take certain increases or reductions of these coefficients into account. With respect to other uses such as seed wastage or industrial use, we apply coefficients used in *AT 2000*. After the subtraction of the above, we obtain the net production, i.e. the quantity of produce that in a given year will cover stockpiling, personal consumption, investments, and foreign trade. This solution renders the establishment of domestic equilibrium possible, without the modification of domestic prices. We assume that all those demands that do not belong to the category of inputs separable from production can be modified according to the actual conditions of a given economic year.

These so-called non-committed demands can be adjusted further. The non-committed demand for a specific commodity consists of various elements; therefore, let q_{ih} express the hth type of demand for commodity i. To reach a solution, first we define a target level of the hth demand of commodity i ($q_{ih}^{(t)}$) and introduce a vector λ that indicates the extent to which the target ($q_{ih}^{(t)}$) is realized. Obviously the realization levels are constrained between two bounds:

$$\lambda^* \leqslant \lambda \leqslant \lambda^{**}$$

Let us assume that

y = vector of supply after the deduction of committed expenditures;
p_i^W = world market price of commodity i;
k = preliminary fixed balance of foreign trade.

The solution of this module is equal to the determination of such values of λ that satisfy

$$p^W Q\lambda = p^W y = k$$

and

$$\lambda^* \leqslant \lambda \leqslant \lambda^{**}$$

where Q is a matrix of non-committed demands.

During the solution procedure a strict preference ordering of various types of demands is followed. In case of changes in world market prices, a new λ vector has to be calculated. If no solution can be obtained, λ^* and λ^{**} have to be adjusted so that a solution can be reached; the calculation of λ is easily programmed. It is worthwhile to consider 1 as an initial value of λ_i. It is obvious that, when the target is realized, $\lambda_i = 1$ and that $\lambda_i^* < 1$ and $\lambda_i^{**} > 1$ throughout.

As the above description shows, a basic assumption in the model is that a balance of trade equilibrium has to be maintained. Deficit or surplus can only be given exogenously (k). One should also remember this assumption when analyzing model results.

After the elaboration of final consumption figures for a given year, calculations concerning the financial results of the year may be made. First of all, the development of the national income is assessed as follows:

$$NICA_t = \Sigma_i \, YN_{t,i} p_{it} \quad \text{(national income from agriculture)}$$

$$NICN_t = YN_{t,n} p_{nt} \quad \text{(national income from other sectors of economy)}$$

$$NIC_t = NICA_t + NICN_t \quad \text{(total national income)}$$

$$a_1 = \frac{NIC_t - NIC_{t-1}}{NIC_{t-1}} \quad \text{(growth of national income)}$$

Summarizing with respect to the value of personal incomes,

$$CON_t = \Sigma_i \, TC_{5,i} p_{it} + TC_{t,n} p_{nt} \quad \text{(value of private consumption)}$$

The development of the gross national income:

$$GNPA_t = NICA_t + DEPA_t \quad \text{(gross national income from agriculture)}$$

$$GNPN_t = NICN_t + DEPN_t \quad \text{(gross national income from the rest of the economy)}$$

$$GNP_t = GNPA_t + GNPN_t \quad \text{(total gross national income)}$$

The calculation of total depreciation:

$$DEPA_t = BETA1 . CSA_t \quad \text{(depreciation in agriculture)}$$

$$DEPN_t = BETA2 . CSN_t \quad \text{(depreciation in the rest of the economy)}$$

where $BETA1$ and $BETA2$ are depreciation coefficients.

The balance of foreign trade activities for various products:

$$ZNEX_{t,i} = YSN_{t,i} - CINT_{t,i} - TC_{t,i} - S_{t,i} \quad \text{(agricultural products)}$$

$$ZNEX_{t,n} = YSN_t - TC_t - S_{t,n} - INVN_t - INVA_t \quad \text{(industrial products)}$$

6.4.1 Revision of Basic Policy Parameters

After completing the calculations for the year, corresponding to the descriptive character of the model, a revision of the basic economic objectives can be made. The objective of the system should be the maintenance of the exogenously fixed parameters of national income growth; therefore, based on an analysis of the actual performance of the system for the year, the parameters used to determine the fundamental objectives can be modified.

The first part of checking starts from the calculation of the actual growth rate of national income, and if this falls outside the limits of required growth, then the accumulation, the scale, or the required growth rate of consumption may be modified. If the increase is more rapid than required, then we envisage increased consumption and, if national income growth is slower than required, we reduce the growth of consumption. The course of the adjustment is as follows.

$$SA2 = \frac{NIC_t}{NIC_{t-1}} - 1$$

(1) If $SA2_{min} \leqslant SA2 \leqslant SA2_{max}$, no change in $A2$

$$A2_{t+1} = A2_t$$

(2) If $SA2 > SA2_{max}$, increase $A2$

$$A2_{t+1} = A2_t + 0.5(SA2 - SA2_{max})$$

$$A2_{t+1} = \min(A2_{t+1}, A2_{max})$$

(3) If $SA2 < SA2_{min}$, decrease $A2$

$$A2_{t+1} = A2_t - 0.5(SA2_{min} - SA2)$$
$$A2_{t+1} = \max(A2_{t+1}, A3_{min})$$

where $A2$ is the desired growth rate of consumption (a_2 in Section 6.2).

The other sphere of modifications is dependent on the growth of agriculture: if this is more rapid than required, we reduce the agricultural share of total investments, while if the rate is slower than required, we increase the rate of agricultural investments, i.e.

(1) If $SA3_{min} \leqslant SA3 \leqslant SA3_{max}$, no change in $A3$

$$A3_{t+1} = A3_t$$

(2) If $SA3 > SA3_{max}$, decrease $A3$

$$A3_{t+1} = A3_t - 0.5(SA3 - SA3_{max})$$
$$A3_{t+1} = \max(A3_{t+1}, A3_{min})$$

(3) If $SA3 < SA3_{min}$, increase $A3$

$$A3_{t+1} = A3_t + 0.5(SA3_{min} - SA3)$$
$$A3_{t+1} = \min(A3_{t+1}, A3_{max})$$

where $SA3$ is the actual growth rate of agriculture and $A3$ is the desired agricultural share of total investments (a_3 in Section 6.2).

6.5 Scenarios Computed by the CMEA Agricultural Model

To forecast the future development of agriculture in the CMEA countries, two basic scenarios have been calculated by the model, which are consistent with the assumptions used in *AT 2000*. As with other developed countries, we assume moderate rates of economic growth (growth rates of the FAO Normative Medium Scenario). Using this basic assumption, the two scenarios are as follows.

(1) *Constant-SSR Scenario*, where SSRs (self-sufficiency ratios) of 1975 are used as minimum requirements in the production modules.
(2) *Free Trade Scenario*, where most of the restrictions on the SSRs are removed, and we assume that production develops according to our production model, whose coefficients are estimated on the basis of a time series.

These scenarios are directly comparable with other *AT 2000* projections and serve as a basic source of information for our projections. These basic versions are based on FAO projections for population growth and consumer demands. As far as the agricultural labor force is concerned, the original FAO forecasts have been modified; in the case of the USSR we assume that a smaller labor force will migrate from agriculture than that indicated in the FAO forecast. In contrast, in the case of the smaller CMEA countries, we postulate that migration from agriculture will exceed the FAO level. Agricultural investments are estimated at 20% of the total in the USSR and 13.5% in the smaller CMEA countries (Appendix B contains the initial data used to compute the two basic scenarios).

Several other model versions have been computed to delimit the spectrum of likely production possibilities, and to point out some of the policy problems and options that governments might face. Starting from the two basic scenarios, several other model versions have been computed, mainly running the Soviet Union and the smaller CMEA country submodels separately (a list of model variants computed by the USSR and smaller CMEA submodels is presented in Appendix C). The main questions investigated were:

(i) What influence is exerted by the migration from agriculture on the development potential of agriculture? What would be the effects of a labor migration level greater or smaller than the FAO forecast on the expected development of production?

(ii) How is agricultural production influenced by higher or lower levels of investment than that considered in the basic version?

(iii) What is the potential impact of alternative feeding efficiencies on total agricultural output and projected exports and imports?

(iv) Several computations were performed to determine the influence exerted by overall economic development on agriculture by modifying those coefficients that express the required overall rate of development.

(v) Several computations were performed to demonstrate the effects of foreign trade by modifying the requirements regarding the level of self-sufficiency – in certain versions all constraints were completely removed.

(vi) A special series of computations was performed to demonstrate the effect of the balance of payments on agricultural development. Other computations were also carried out assuming (*a*) further drawing on credits, and (*b*) credit repayment obligations.

7 PROJECTED AGRICULTURAL DEVELOPMENT – RESULTS OF THE COMPUTATIONS

The basic scenarios and the 39 additional model runs have enabled a relatively detailed assessment to be made of the future course of agricultural production in the CMEA countries. Obviously, an analysis of future trends can be performed in several ways, under many aspects, and at various depths. We present in this section only the most important conclusions and findings, but add that the results may, of course, form the basis of still further investigations. Appendix D presents the two basic scenarios in detail, and shows that our model produces realistic forecasts in an aggregated manner. The real interrelations of the CMEA countries are reflected by the model parameters and structure (the results of scenarios computed by the submodels of the smaller CMEA countries and the USSR are listed in Appendixes E and F).

7.1 Future Agricultural Development in the CMEA Countries

The two basic scenarios and related calculations give reliable information on the possible lower and upper ranges of production. First of all, it is necessary to point out that the future course of agricultural development in CMEA countries will depend largely on national situations. Efforts to satisfy growing consumer demands for food and to maintain or increase levels of self-sufficiency will be the main driving forces of future development, but of course, changes in world market conditions might also have some influence. High world market prices might represent an additional reason for conserving foreign exchange by restricting imports and utilizing export potential in a surplus situation. Low international prices first have an influence on exporting countries, which might then restrain agricultural development and invest more in other areas. However, the CMEA countries' reactions to world market changes are much more moderate and lag behind those of other developed countries.

Our two basic scenarios are similar as far as the projected growth of agricultural production is concerned (2–3% per annum), in contrast to the relatively moderate overall growth of the economy. Agricultural production is expected to exceed domestic demand, parallel to the increase in the SSRs of the major agricultural commodities. This development reflects the fact that substantial production reserves exist in the area, especially in the USSR. In our opinion, the significant investment allotted to agriculture in recent years will bear fruit in the future, and a moderate food surplus can be forecast by the end of the century.

Domestic food demands are forecast according to FAO projections in our scenarios. On the whole, the CMEA region can expect a relatively moderate growth of both domestic food demand and consumption. Regarding the total calorie consumption, each CMEA country has already reached a daily intake level of 3000 calories per capita, and further increases are not desirable, although the details of consumption will change. Government planners use accepted norms of optimal diet to plan the growth of consumption, but in addition to rising personal incomes, the dynamics of food consumption are significantly influenced by supply. In the future, structural changes in food consumption will be determined by the fast-growing demand for meat and meat products, as well as for fruit and vegetables.

The projected growth of agriculture assumes that the present level of investment will be maintained, and that some of this will be used to provide more modern equipment and other resources to improve production. In the smaller CMEA countries, this will be about 13.5% of total investment, or maybe even higher. Model runs also indicate that, due to consumer pressures and the need for foreign exchange, lower levels of investment are not very likely. The results also demonstrate that, by increasing agricultural investment, governments can significantly increase output.

In the USSR, on the other hand, agricultural investments will probably fall below the present level, but this is already relatively high at about 20% of the total, and is greater than the contribution of agriculture to the total national income. However, an agricultural share of less than 15% would seriously threaten the realization of the main government objectives. Substantial investment must also continue to reduce fluctuations of yields and the unfavorable impact of weather conditions. On the whole, agriculture has to remain at the top of the government list of priorities.

The availability of labor will still remain a very important factor in agricultural development in the region. Migration from agriculture to industry and other sectors of the economy will undoubtedly continue, and this may limit production growth, especially that of labor-intensive products. The FAO predicts an agricultural labor force in the USSR of 7.5% of the total working population in the year 2000, and of 15% in the smaller CMEA countries. However, considering several possible levels of out-migration, and comparisons with other developed countries, our calculations indicate that the labor force will be larger in the USSR, and smaller in the other CMEA countries than these FAO projections. We therefore anticipate an overall agricultural labor force of 10% of the total working population in 2000, and this figure is used in the basic scenarios.

7.2 Constant-SSR Scenario

This scenario was designed to correspond to the *AT 2000* Constant-SSR Scenario. The actual SSRs of the Soviet Union and the smaller CMEA countries in 1975 were considered in both submodels as minimum requirements. It should be mentioned that, in *AT 2000* projections, "constant" is taken to mean "unchanged" and not a minimum requirement. However, for policy analysis reasons our interpretation is probably more realistic, but in any case it is acceptable. In analyzing the results presented in Table 28

TABLE 28 Agricultural output and SSRs of the CMEA countries, Constant-SSR Scenario.

	1975		1990		2000	
	Total output	SSR	Total output	SSR	Total output	SSR
Total cereals*	254,369	0.93	390,056	0.98	437,650	0.99
Wheat*	108,868	0.93	151,725	0.98	166,508	1.00
Rice*	2135	0.75	3837	0.79	5182	0.80
Coarse grain*	143,366	0.92	234,494	0.97	265,959	0.99
Total meat*	22,945	1.11	33,830	1.38	37,595	1.32
Beef and veal*	8551	0.99	13,604	1.35	14,744	1.32
Mutton and lamb*	1159	1.02	1845	1.49	1991	1.43
Pork*	10,564	1.25	14,357	1.49	15,816	1.42
Poultry*	2671	1.07	4024	1.12	5042	1.04
Milk and milk products***	129,507	1.00	203,398	1.13	221,520	1.14
Sugar*	11,798	0.75	16,109	0.88	19,268	0.95
Vegetable oil*	4937	1.11	6258	1.05	7361	1.06
Citrus fruit**	135	0.11	135	0.08	135	0.06
Other fruit**	26,753	1.09	41,032	1.25	45,598	1.16
Vegetables**	17,847	0.99	24,069	1.01	26,740	1.02
Cotton*	7662	1.00	11,021	1.20	12,105	1.20
Other non-food products**	1135	0.90	2139	1.40	3104	1.74
All commodities**	138,890	1.00	205,560	1.10	230,409	1.11
Total trade**	7491	5.4	22,249	10.8	23,196	10.1

*10^3 t.
**In US$ million (1972).
***In milk equivalent.

one should remember that upper bounds are not given in the model, so that production growth above minimum requirements is allowed. Thus agricultural growth almost follows the trends of the Free Trade Scenario and is substantially higher than the original *AT 2000* projection (see Figure 3).

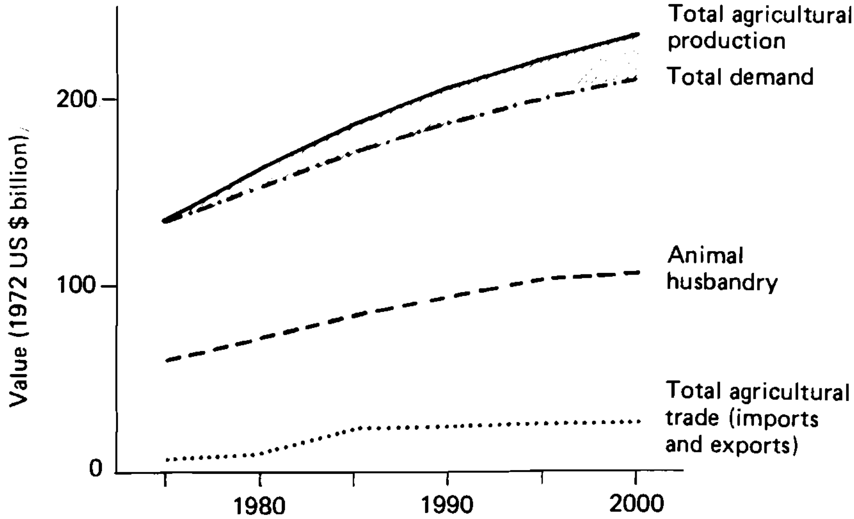


FIGURE 3 General indicators of the Constant-SSR Scenario.

The scenario also demonstrates the considerable agricultural potential of the region. As one can see from Table 29, the production of various commodities at least parallels or even exceeds demand; SSRs therefore remain stable or show a continuous increase up to 2000. On the whole, the overall food SSR increases. This scenario reflects the realization of existing long-range policy objectives in the CMEA countries aiming at self-sufficiency in food. The projected food SSR for 2000 is 1.01; practically all cereals are produced domestically, and the substantial wheat surplus allows an increase in meat production above the projected, relatively moderate level.

In line with past trends, growth of animal husbandry is faster than that of arable farming. The substantial meat surplus will probably be consumed domestically, since the projected 66 kg per capita consumption leaves enough room for further increases, and there is no question that demand will rise. If we assume that the future demand for and consumption of meat will be higher than the FAO estimates, then obviously we must also assume that the projected SSR for meat will not be around 1.4, but much less, probably somewhere close to 1.0–1.1. The projected grain output of 437×10^6 t appears to be realistic, and is expected to grow continuously, until the present grain deficit disappears.

The volume of agricultural trade (see Figure 3) grows at a faster rate than production, but remains relatively low (10% of output). An SSR of around 1.0 for meat should reduce this level even further. Apart from tropical fruits, coffee, and citrus fruits, the

TABLE 29 Agricultural output and SSRs of the CMEA countries, Free Trade Scenario.

	1975		1990		2000	
	Total output	SSR	Total output	SSR	Total output	SSR
Total cereals*	254,369	0.93	378,740	0.93	420,710	0.93
Wheat*	108,868	0.93	147,969	0.95	158,439	0.94
Rice*	2135	0.75	1722	0.36	955	0.15
Coarse grain*	143,366	0.92	229,049	0.93	261,316	0.94
Total meat*	22,945	1.11	35,043	1.42	39,998	1.40
Beef and veal*	8551	0.99	14,002	1.39	15,581	1.39
Mutton and lamb*	1159	1.02	1895	1.53	2097	1.17
Pork*	10,564	1.25	14,974	1.55	17,024	1.52
Poultry meat*	2671	1.07	4173	1.16	5295	1.09
Milk and milk products***	129,507	1.00	209,886	1.15	235,007	1.17
Sugar*	11,798	0.75	14,710	0.80	16,968	0.84
Vegetable oil*	4937	1.11	5834	0.99	6636	0.96
Citrus fruit**	135	0.11	135	0.08	135	0.06
Other fruit**	26,753	1.09	40,074	1.22	44,978	1.12
Vegetables**	17,847	0.99	22,413	0.94	23,455	0.89
Cotton*	7662	1.00	15,437	1.68	20,680	2.06
Other non-food products**	1135	0.90	2247	1.47	3374	1.89
All commodities**	138,890	1.00	206,124	1.10	232,410	1.10
Total trade**	7491	5.4	30,794	14.9	41,592	17.9

*10^3 t.
**In US$ million (1972).
***In milk equivalent.

SSRs for rice, sugar, and tea are considerably lower than 1. On the other hand, temperate fruits, cotton, and most meat products have SSRs considerably higher than 1.

7.3 Free Trade Scenario

This scenario reflects a less constrained production development than that of the Constant-SSR Scenario. Constraints on minimum levels of producing various commodities have been removed, and the structural changes and developments are limited only by available resources.

As Figure 4 shows, overall agricultural growth is somewhat higher in this case, but the basic patterns of development are the same as those of the Constant-SSR Scenario (see Table 29). Without restricting the SSRs of commodities, the rate of animal husbandry will be higher than in the Constant-SSR Scenario (the SSR of meat is 1.40). A higher meat consumption level than FAO estimates is a strong possibility, similar to the Constant-SSR Scenario, with the development of animal husbandry based partly on imported feeds. The Free Trade Scenario, which allows restricted agricultural development, obviously leads to the rapid growth of agricultural trade, and explores trade potential to a greater extent than the Constant-SSR Scenario. Trade potential has great importance for *AT 2000*, even if we know that it cannot be fully realized.

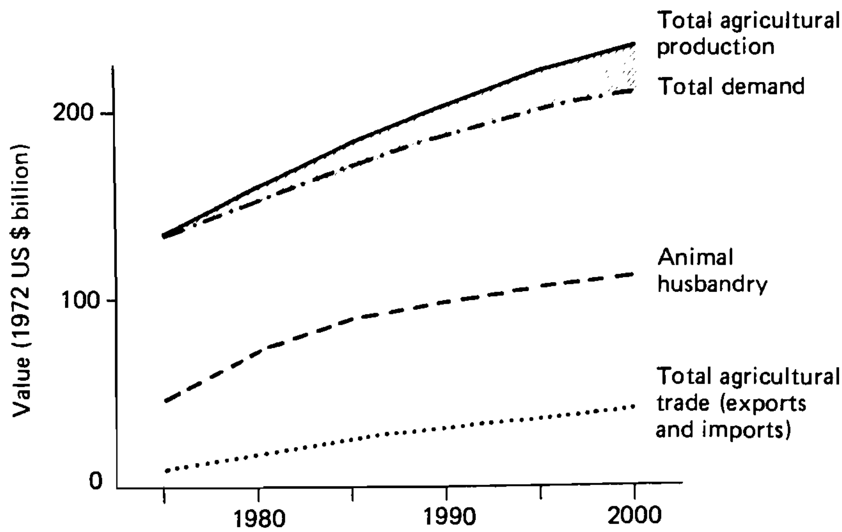


FIGURE 4 General indicators of the Free Trade Scenario.

The fastest growing area of agriculture in this scenario is animal husbandry. Production growth rates lead to substantial increases in the SSRs of animal products, generally to levels greatly in excess of domestic needs as identified by FAO demand projections. The meat surplus seems to be substantial, even if consumption above the projected level is expected. Meat production is partly based on imported feeds, so that by reducing the meat surplus, grain self-sufficiency could be achieved.

In addition to animal products, a surplus can be expected for cotton, other nonfood, and other fruit products. The SSR increases especially for cotton production. On the import side, rice is most important (SSR only 0.15), and there are also deficits in sugar, vegetables, vegetable oil, and tea; obviously, tropical and Mediterranean produce must be imported.

In the Free Trade Scenario the agricultural trade of the area shows a significant increase. In 2000, agricultural trade (exports and imports) amounts to 17.9% of output, which is a rather unrealistic figure. First of all, it reflects the influence of high meat SSRs due to low consumption levels, and, obviously, the realization of the trade potential depends largely on the extent of trade restrictions in other countries (such as meat import restrictions in the EC).

7.4 Future Trends in Cereal Production

The grain sector, especially feed grains, is the main obstacle to agricultural developin the CMEA countries at present. The failure to raise grain output for meat sufficiently to meet increasing consumer demand, together with a relatively low level of livestock feed conversion rates, have resulted in an overall negative grain balance.

The main reason for excessive feed consumption is the physiologically unbalanced composition of animal feed, particularly a lack of digestible protein. Significant losses of nutrients and vitamins, caused by the generally low level of harvesting and feeding techniques, and especially because of inadequate storage facilities, exert a negative influence on feeding efficiency. According to OECD estimates, an increase in the digestible protein content of 1 kg of feed from the present 85–86 g to 105–110 g could in itself be sufficient to improve the feed conversion ratio by 25–30%, which could save about $20–25 \times 10^6$ t of grain per year in the Soviet Union alone.

The CMEA region has the potential to be self-sufficient in grain, and the importance placed on an increase in meat production will ensure that the investments required to improve livestock feeding efficiency will also be forthcoming. Our scenarios forecast that $420–430 \times 10^6$ t of grain will be produced annually by the year 2000, and it is likely that actual development will follow the line of the Constant-SSR Scenario (see Figure 5). Grain needs will therefore be satisfied by domestic production, as will the feed requirements necessary to produce enough meat to reach the projected levels of consumption and/or exports,

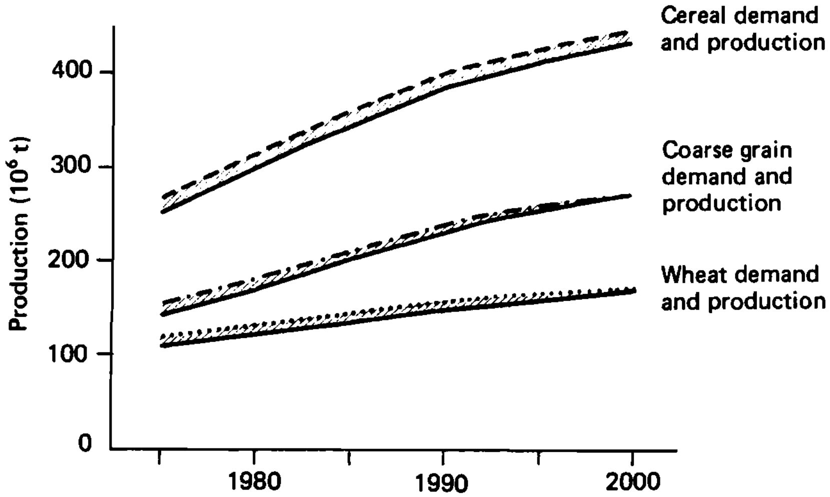


FIGURE 5 Cereal production in the Constant-SSR Scenario.

so that the area might once more become a net exporter of limited quantities of grain. But we should mention that, given the apparently low capital productivity in agriculture, it is highly unlikely that most of the CMEA countries, especially the USSR, will put more capital into agriculture than is necessary to gain full SSR in cereals. Substantial grain imports, as in the Free Trade Scenario (see Figure 6) to produce enough meat for export, are not likely to happen, except under very favorable market conditions, or if investment levels fall well below expectations.

In our classification, protein feeds do not appear as a separate commodity. The CMEA area has a deficit in this respect, and the relatively low feed conversion rates are partly the cause of this. Therefore, even though the computed results do not show it, increasing demand can be expected for protein feeds. Although the projected growth of vegetable oil production will meet consumer needs, and some surplus might occur,

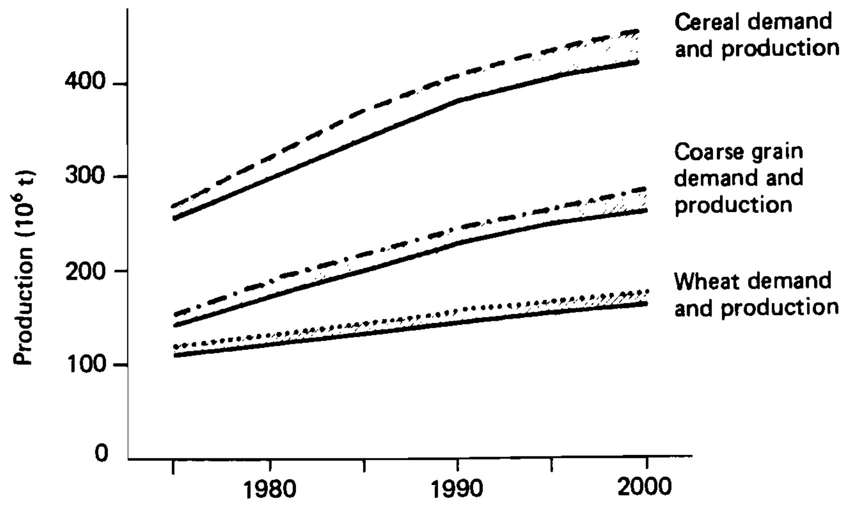


FIGURE 6 Cereal production in the Free Trade Scenario.

considering the production potential and given natural conditions, the deficit in protein feeds is not likely to disappear until 2000.

As far as cereals are concerned, rice has the lowest projected SSR; in the Free Trade Scenario, it drops continuously, so that most of the domestic requirement is imported. When irrigation projects and climatic conditions in Soviet Central Asia are taken into account, the actual trends will probably be closer to the Constant-SSR Scenario, where the rice SSR is about 0.80. The forecast of 10^6 t of imported rice is likely to be realistic.

7.5 Development of Animal Husbandry

Meat production and animal husbandry will be the fastest growing sector of CMEA agriculture in the future, and both scenarios, as well as the related calculations, project considerable growth. The existing meat surplus (SSR = 1.11 in 1975) is associated with a moderate level of consumption. The need for foreign exchange in these countries encourages meat exports and limits imports and domestic supply (projections for meat production and consumption can be seen in Figure 7).

The production of sufficient meat to satisfy the increasing domestic demand is the focus of current agricultural policy, which also assumes the domestic production of all animal feeds. One of the most important constraints on future meat supply will be the growth of domestic feed production.

(1) Meat production along the lines of the relatively moderate FAO demand projections seems to be the lower bound of technical feasibility. In the event of shortages of animal feed, large imports of grain can be expected, rather than significant meat imports.

(2) If grain production develops favorably, it will at first result in an increase in domestic meat consumption and only in the event of further improvements in the harvests can meat exports be considered probable.

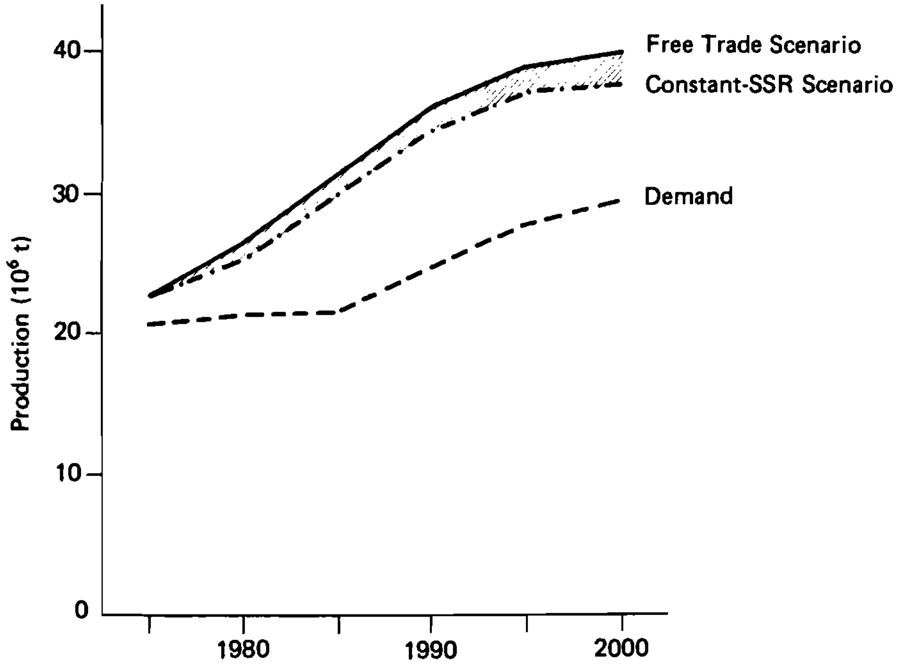


FIGURE 7 Projected meat demand in the CMEA countries.

(3) An improvement in feeding efficiencies can be expected, and if it is accomplished, it will advantageously influence the overall meat production potential.

Together with feed availability, the development of animal husbandry depends on further capital inputs and investments, as well as the availability of adequate labor in the agricultural sector.

Our computations clearly demonstrate that meat production is very sensitive to the level of agricultural investment; any reduction in the level will make itself felt first in meat production. This is not very surprising and leads to the conclusion that the realization of a meat surplus projected by our two scenarios is doubtful from the point of view of present investment trends.

The availability of labor is a very important factor in production growth, particularly in animal husbandry. Calculated results, even the comparison of the two basic scenarios, indicate that there is serious competition between the labor-extensive and labor-intensive branches of agriculture, and labor may become a major limiting factor during the second half of the projected period. Higher out-migration than is projected in the basic scenarios may result in a reduction in cattle and pig husbandry, as well as in fruit production, in turn leading to a grain surplus and a further increase in poultry production.

On the whole, the 40 × 10^6 t of meat in 2000 shown in the Free Trade Scenario is almost certainly the upper limit of technically feasible production development. Actual growth is at best more likely to follow the Constant-SSR Scenario and is expected to be around 33–36 × 10^6 t. Substantial surpluses of meat will probably not appear on international markets. Exports can be expected from the smaller CMEA countries, but not exceeding 4–5 $\times$ 10^6 t, which is double the present quantity exported.

The internal structure of meat production is not likely to change markedly. Growth will be fastest in poultry, but beef, mutton, and lamb production have similar rates of increase. Pork production will increase at a somewhat lower rate. SSRs will increase in each case, except for poultry, where demand growth will exceed the growth in production.

7.6 Other Commodities

A moderate increase in the sugar SSR is forecast in both basic scenarios, with a deficit of 1–2 $\times$ 10^6 t in 2000. The main source of cane sugar will probably be Cuba, which is a full member of the CMEA but is not covered in this modeling exercise.

Vegetables and vegetable oil production will probably follow domestic demands, although a slight increase in the SSR is forecast by the Constant-SSR Scenario, and the Free Trade Scenario projects a slight deficit in vegetable oils and a substantial increase in vegetable production. The area will probably be at or near the self-sufficiency level in both products, but considerable trade in these commodities cannot be expected. Substantial growth in temperate fruit production is shown in both basic scenarios, and will exceed consumption even though the increase in the latter is considerable. The exporting position of the area will remain with an increase in the surplus; this surplus will influence European markets and increase the competition, but will not be marketable without difficulties.

Almost all tropical and Mediterranean fruits are imported, although some citrus fruits and tea are produced in the USSR. The forecast consumption of these commodities is moderate, and reflects the supply situation in the past, rather than demand. The SSRs of citrus fruits (0.06) and tea (0.72) in 2000 demonstrate production potential.

According to our forecasts, a rapid increase in non-food agricultural production is expected in the CMEA area. The USSR already produces a cotton surplus, and this is expected to exceed the needs of the other CMEA countries, none of which is a producer. It is not likely that the surplus predicted by the Free Trade Scenario will actually occur, but a surplus of about 1–1.5 $\times$ 10^6 t seems to be realistic for 2000. Surpluses can also be expected in other non-food products such as tobacco.

7.7 Trade with Developing Countries

Concerning the products of developing countries, our projections forecast only a moderate trade potential. Obviously, there is more potential for products from developing countries in the Free Trade Scenario than in the Constant-SSR Scenario. The major imports will be sugar, rice, protein feeds, tropical and citrus fruits, coffee, and tea, in which the CMEA will not become self-sufficient in the foreseeable future. With the exception of protein feeds and sugar, imports of these commodities will be determined to a great extent by the state of the balance of payments.

As indicated, the projected consumption of tropical and citrus fruits, coffee, and tea reflects the supply situation in the past. Although the consumption of competing products is relatively high, there definitely are possibilities for further increases. Imports of 0.7 × 10^6 t of bananas, 2 × 10^6 t of citrus fruits, 0.4 × 10^6 t of coffee, and 0.5 × 10^6 t of cocoa in 2000 projected by the two basic scenarios are likely to be the lower rather than the upper limits of imports.

Comparing per capita consumption levels of these products with those in the other developed countries, a further increase of 30–40% seems to be realistic, but the balance of payments in the CMEA will determine to what extent these demands will be satisfied. From the point of view of the developing countries, to increase the exports of the above commodities to the CMEA, a corresponding increase in imports of industrial goods from the CMEA countries should be considered. The CMEA countries offer very substantial import potential for most of the tropical and Mediterranean products on the basis of an increase of bilateral trade; otherwise the projected lower bounds seem to be more probable.

REFERENCES

Csáki, C. (1981) A National Policy Model for the Hungarian Food and Agriculture Sector. RR-81-23. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Fischer, G. and Frohberg, K. (1980) Simplified National Models – the Condensed Version of the Food and Agriculture Model System of the International Institute for Applied Systems Analysis. WP-80-56. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Food and Agriculture Organization of the United Nations (1979) Agriculture: Toward 2000. Proc. of the 20th Session of the FAO, 10–20 November, 1979. C79-24. Rome.

Keyzer, M.A. (1977) Linking National Models of Food and Agriculture: An Introduction. RM-77-2. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Keyzer, M.A. (1980) An Outline of IIASA's Food and Agriculture Model. WP-80-9. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Nagy, J. (1978) The present situation and future perspective in the Soviet agriculture. Agrargazdasagi Kutato Intezet No. 6 (in Hungarian).

Nagy, J. and Gabor, J. (1979) The present situation and future perspectives in the agriculture of European CMEA countries. Agrargazdasagi Kutato Intezet No. 6 (in Hungarian).

Parikh, K. and Rabar, F. (1981) Food for all in a Sustainable World: The IIASA Food and Agriculture Program. SR-81-2. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Problems and Perspectives in the Soviet Grain Economy (1979) Paris: OECD.

Popov, T. (1978) The General Situation and Main Tendencies of Food and Agricultural Development in the European CMEA Member Countries (1960–1975 and up to 1980). RM-78-51. Laxenburg, Austria: International Institute for Applied Systems Analysis.

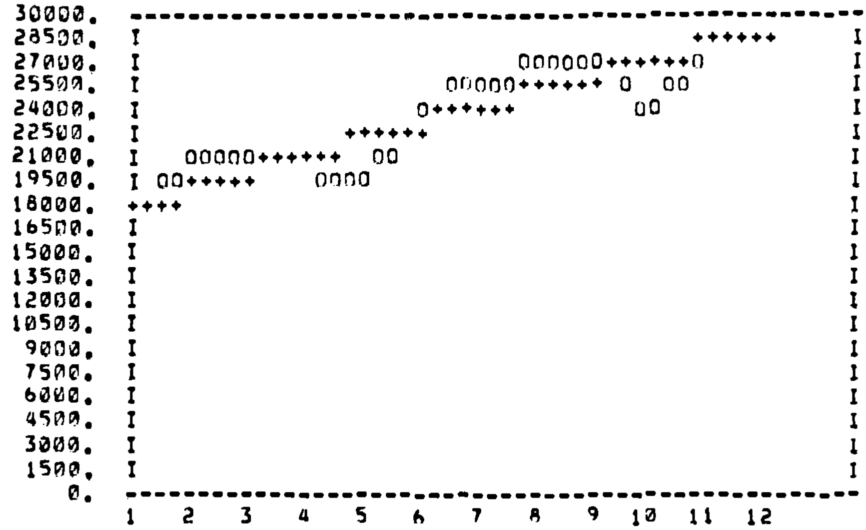
APPENDIX A Validity of the Production Modules

TABLE A.1 Validity of the production module in the East European submodel – comparison of observed and predicted production.

PLOTS FOR COMMODITY 1

OBSERVED VS PREDICTED PRODUCTION

O = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

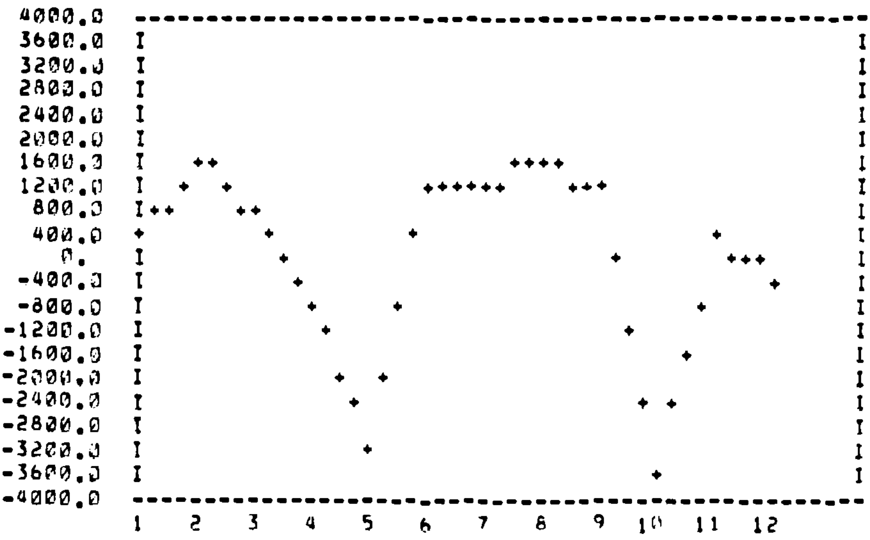
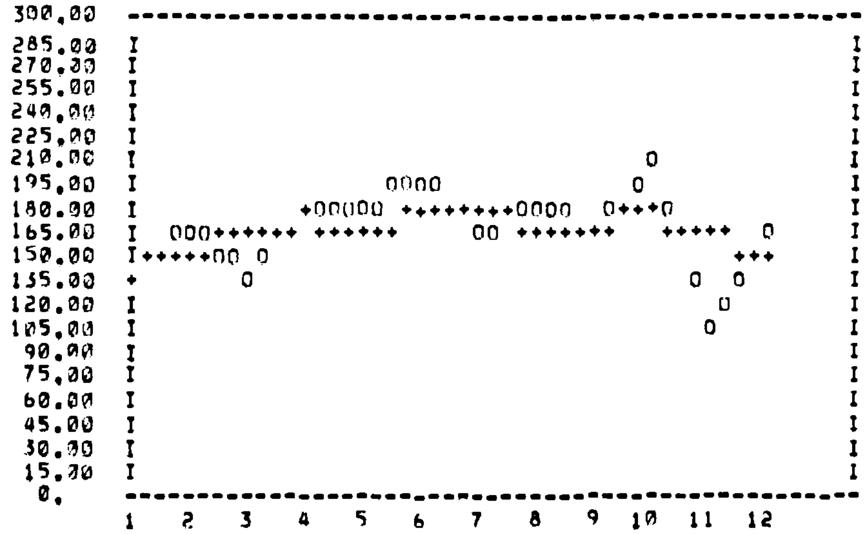


TABLE A.1 *Continued.*

PLOTS FOR COMMODITY 2

OBSERVED VS PREDICTED PRODUCTION

O = OBSERVED   + = PREDICTED



PLOT OF RESIDUALS

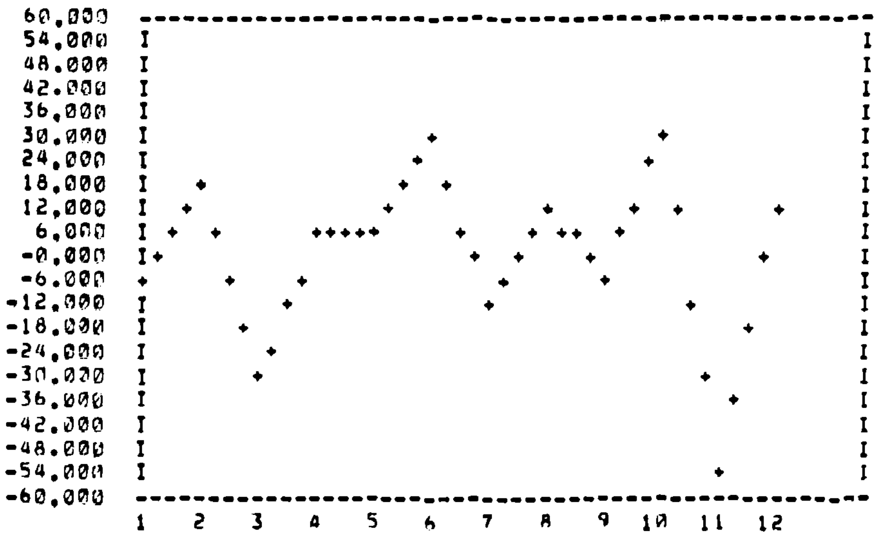


TABLE A.1 *Continued.*

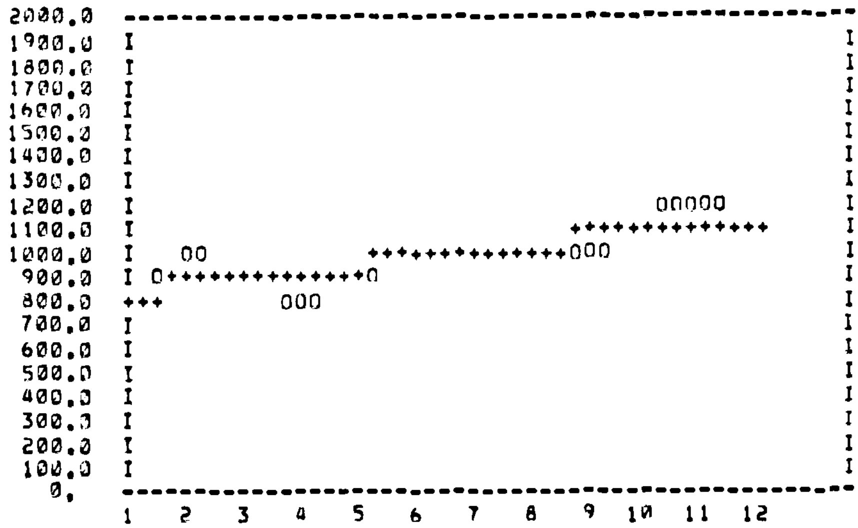
```
PLOTS FOR COMMODITY 3

OBSERVED VS PREDICTED PRODUCTION

O = OBSERVED      + = PREDICTED

  50000.  ---------------------------------+++++++++-------
  47500.  I                      OOO+++++++++OO          O+      I
  45000.  I                     +++++                            I
  42500.  I           O +++++++                                  I
  40000.  I       ++++++O    O                                   I
  37500.  OOOOO+++       O O                                     I
  35000.  I++++           O                                      I
  32500.  +                                                      I
  30000.  I                                                      I
  27500.  I                                                      I
  25000.  I                                                      I
  22500.  I                                                      I
  20000.  I                                                      I
  17500.  I                                                      I
  15000.  I                                                      I
  12500.  I                                                      I
  10000.  I                                                      I
   7500.  I                                                      I
   5000.  I                                                      I
   2500.  I                                                      I
      0.  --------------------------------------------------------
          1   2   3   4   5   6   7   8   9   10  11  12

PLOT OF RESIDUALS

  6000.0  --------------------------------------------------------
  5400.0  I                                                      I
  4800.0  +                                                      I
  4200.0  I+                                                     I
  3600.0  I +                                                    I
  3000.0  I                                                      I
  2400.0  I  +                                                   I
  1800.0  I   +                   +                              I
  1200.0  I    +                 + +                             I
   600.0  I     +    ++        ++    ++                          I
    -0.0  I      +  +         +        ++++           ++         I
  -600.0  I       ++                       +++++++++++           I
 -1200.0  I            +                                         I
 -1800.0  I                  +                                   I
 -2400.0  I             +                                        I
 -3000.0  I                 +                                    I
 -3600.0  I                                                      I
 -4200.0  I              + +                                     I
 -4800.0  I                                                      I
 -5400.0  I                                                      I
 -6000.0  ----------------+---------------------------------------
          1   2   3   4   5   6   7   8   9   10  11  12
```

TABLE A.1 *Continued.*

PLOTS FOR COMMODITY 4

OBSERVED VS PREDICTED PRODUCTION

O = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

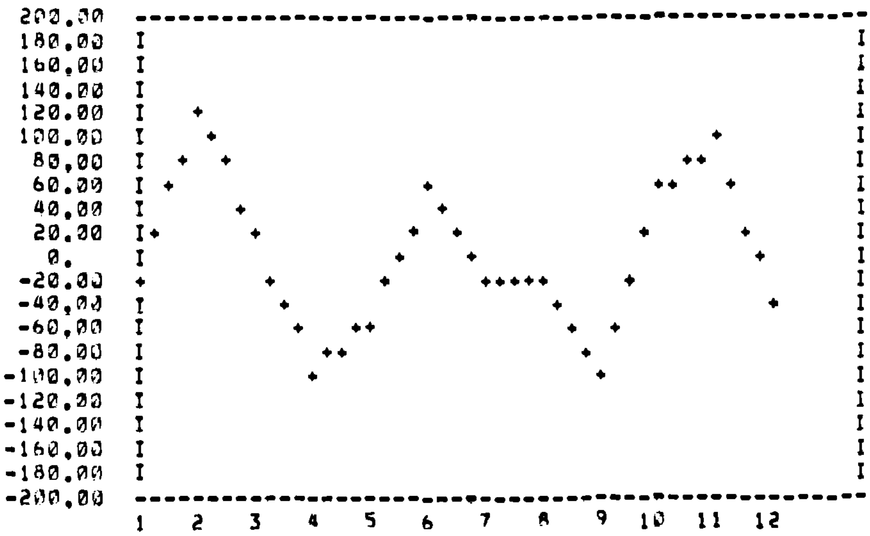
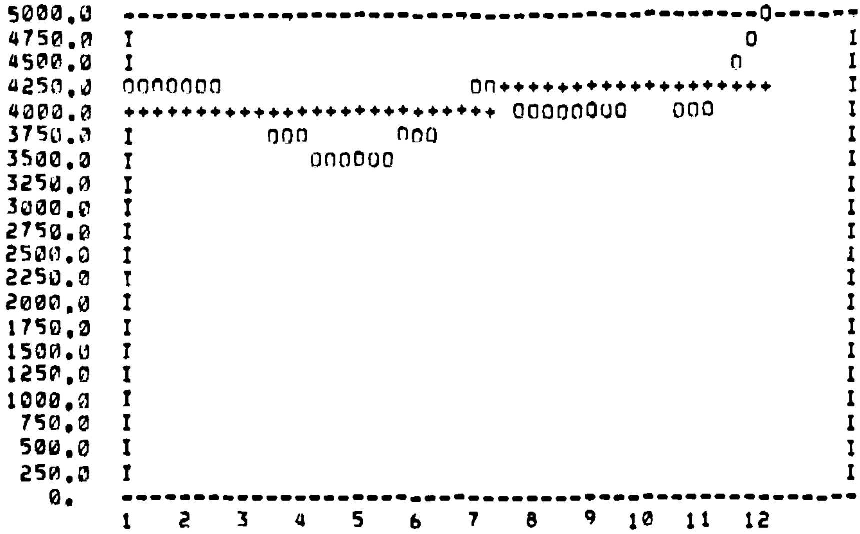


TABLE A.1 *Continued.*

PLOTS FOR COMMODITY 5

OBSERVED VS PREDICTED PRODUCTION

O = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

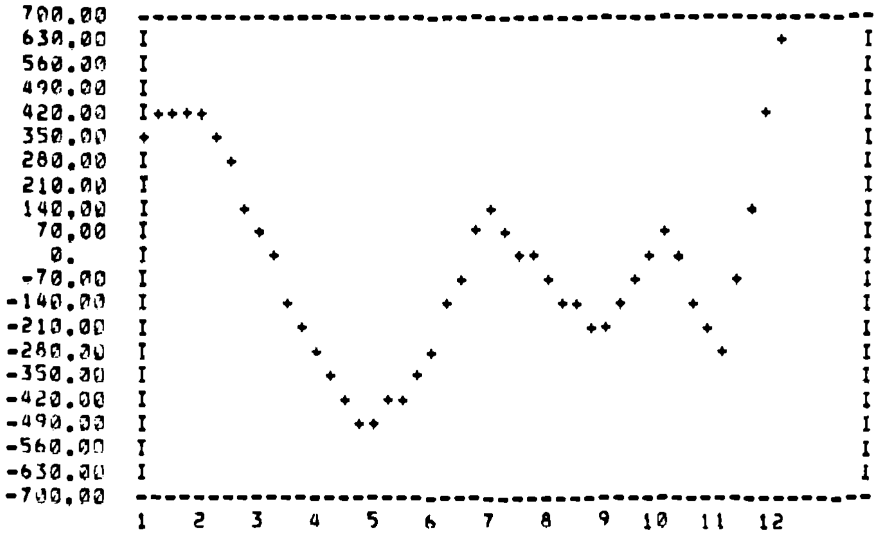
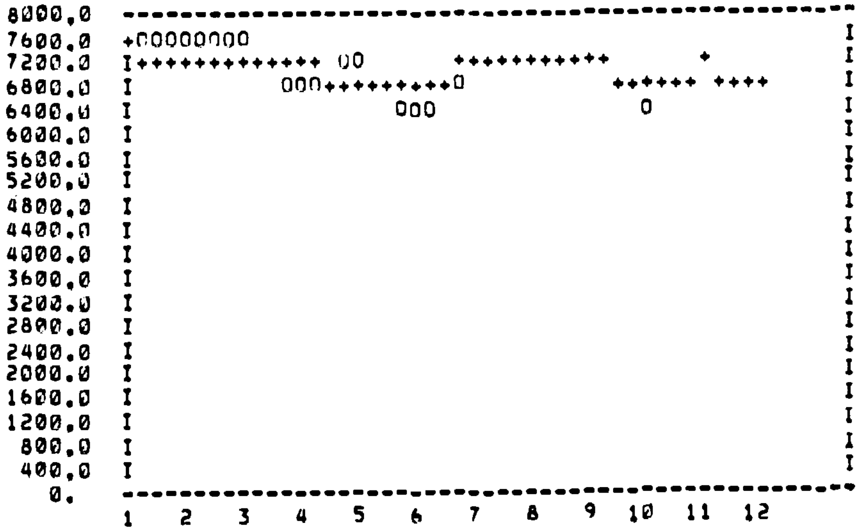


TABLE A.1 *Continued.*

PLOTS FOR COMMODITY 6

OBSERVED VS PREDICTED PRODUCTION

0 = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

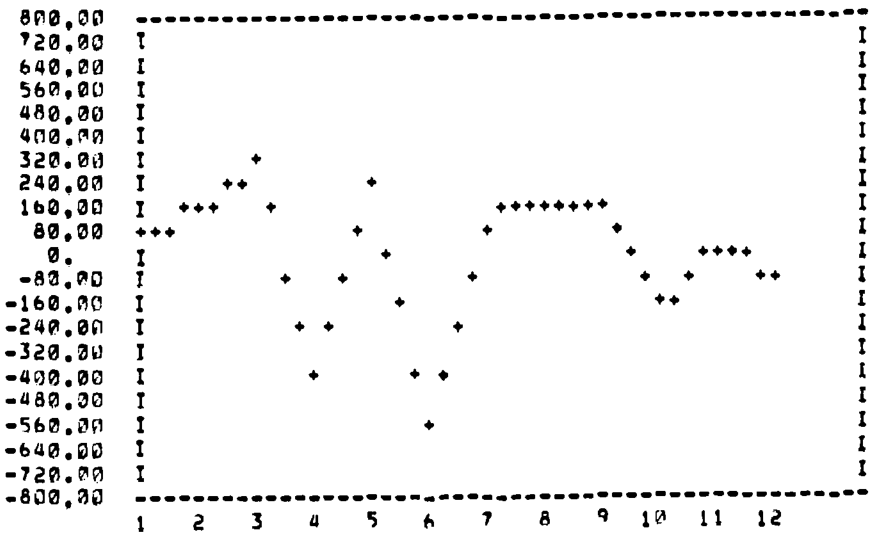
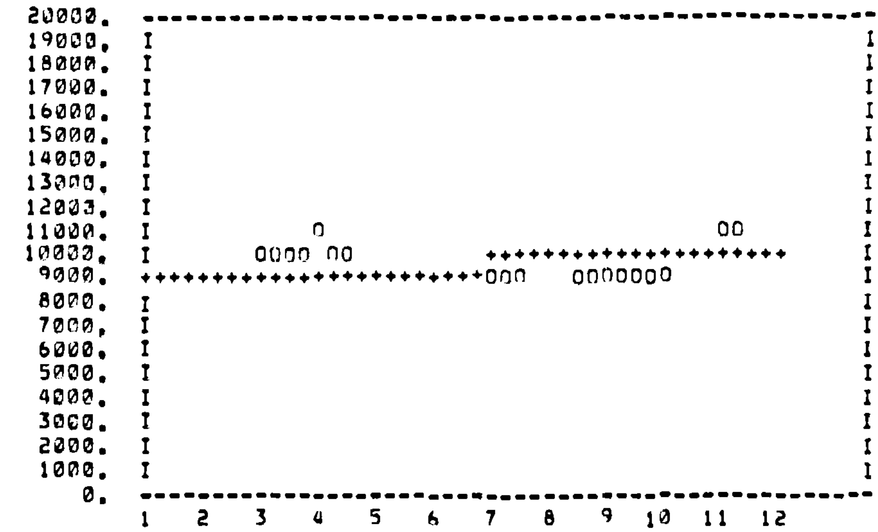


TABLE A.1 *Continued.*

PLOTS FOR COMMODITY 7

OBSERVED VS PREDICTED PRODUCTION

0 = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

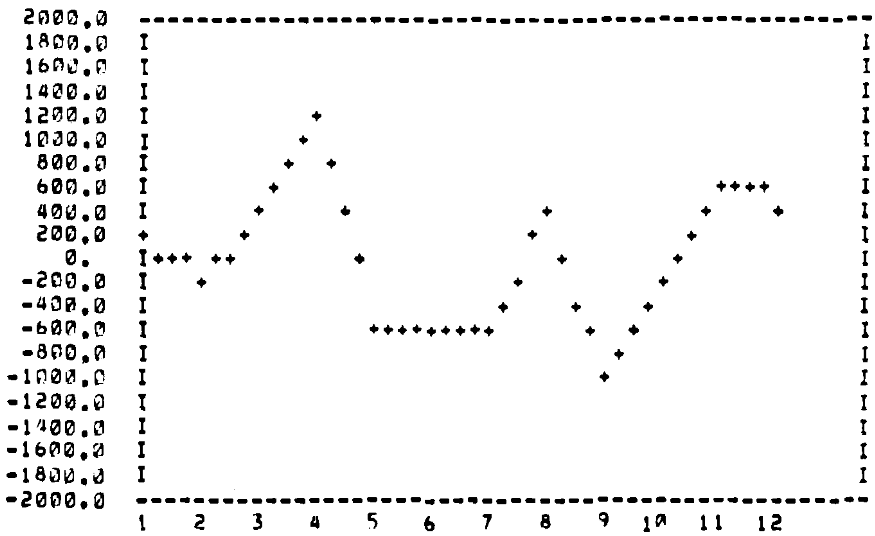
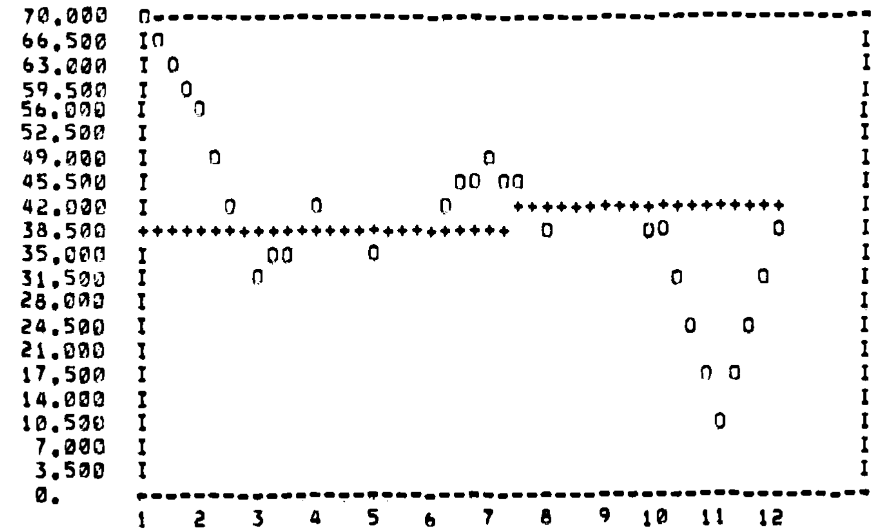


TABLE A.1 *Continued.*

PLOTS FOR COMMODITY 8

OBSERVED VS PREDICTED PRODUCTION

0 = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

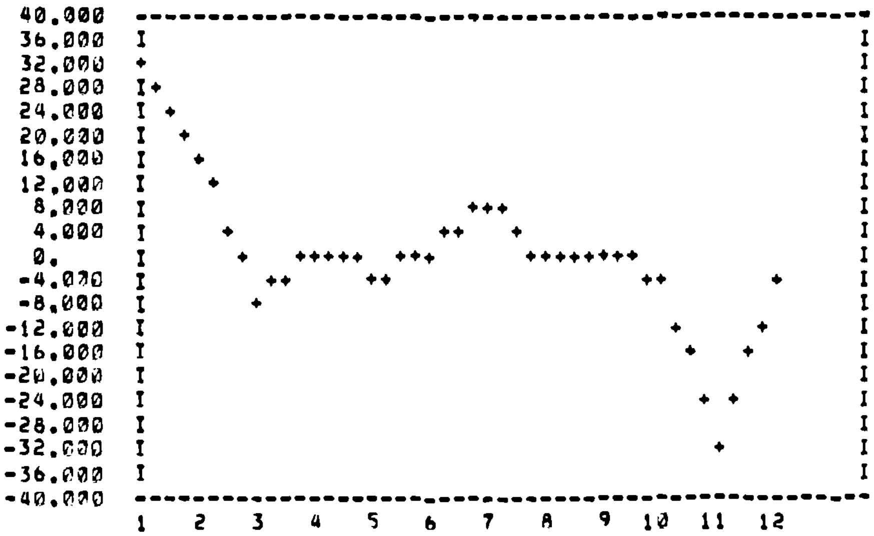
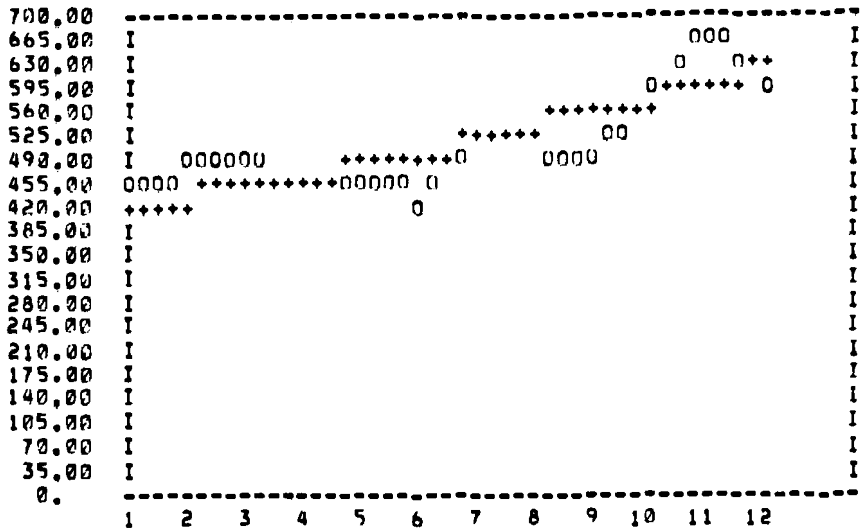


TABLE A.1 *Continued.*

PLOTS FOR COMMODITY 9

OBSERVED VS PREDICTED PRODUCTION

0 = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

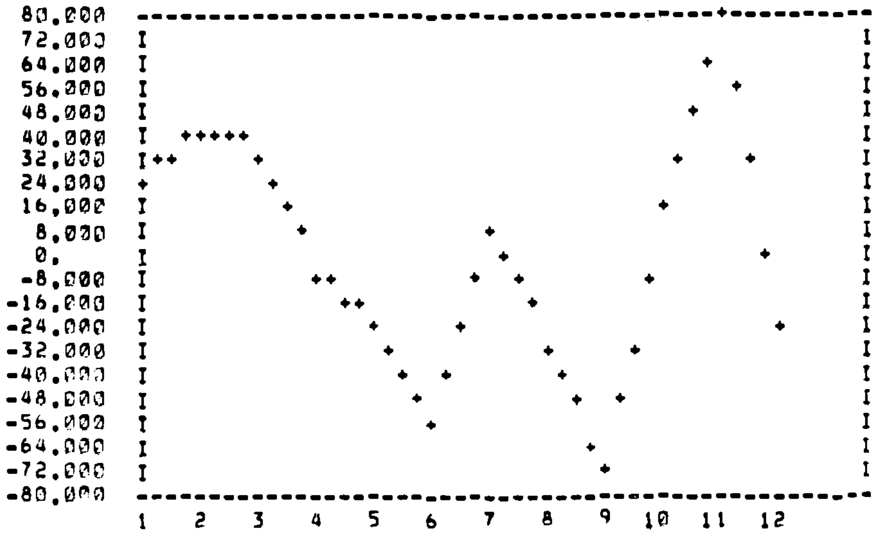
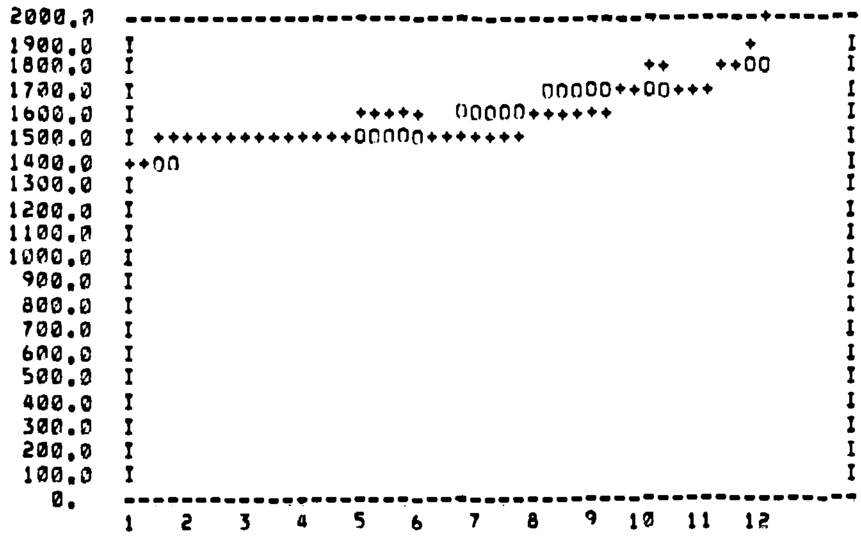


TABLE A.1 *Continued.*

PLOTS FOR COMMODITY10

OBSERVED VS PREDICTED PRODUCTION

O = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

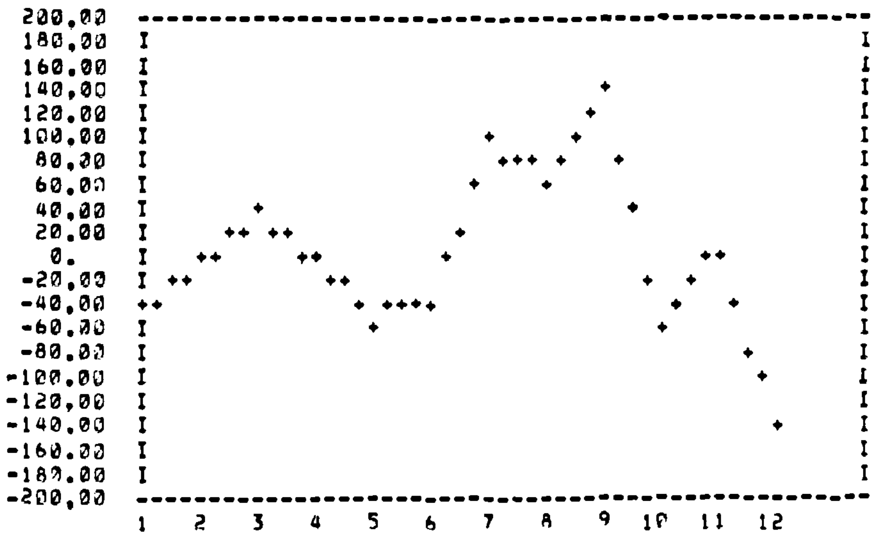
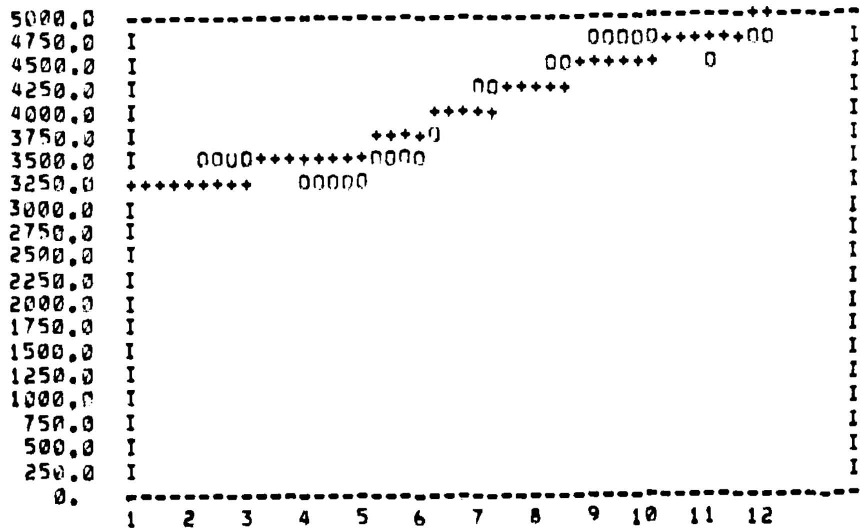


TABLE A.1 *Continued.*

PLOTS FOR COMMODITY11

OBSERVED VS PREDICTED PRODUCTION

O = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

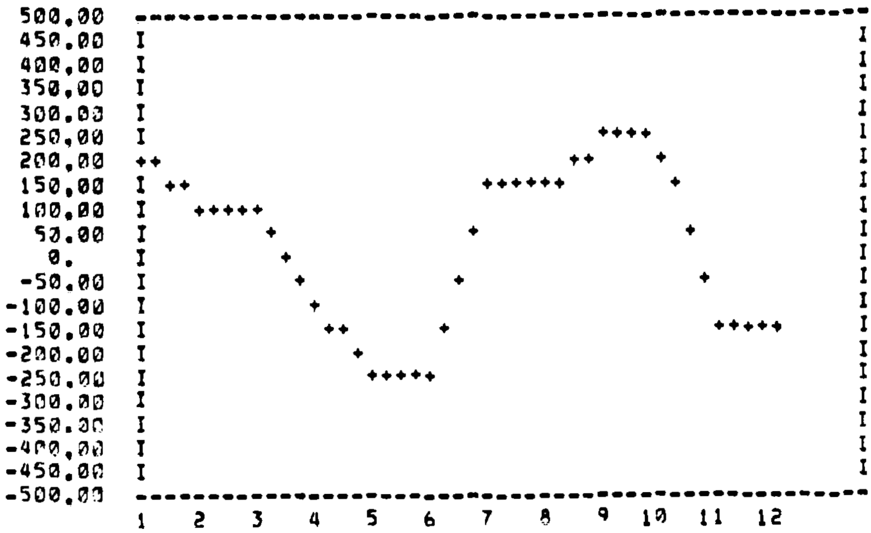
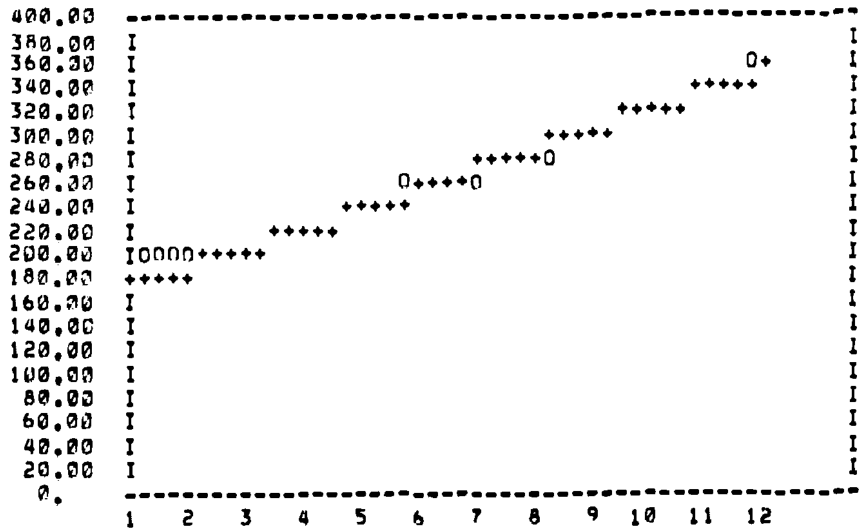


TABLE A.1 *Continued.*

PLOTS FOR COMMODITY12

OBSERVED VS PREDICTED PRODUCTION

O = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

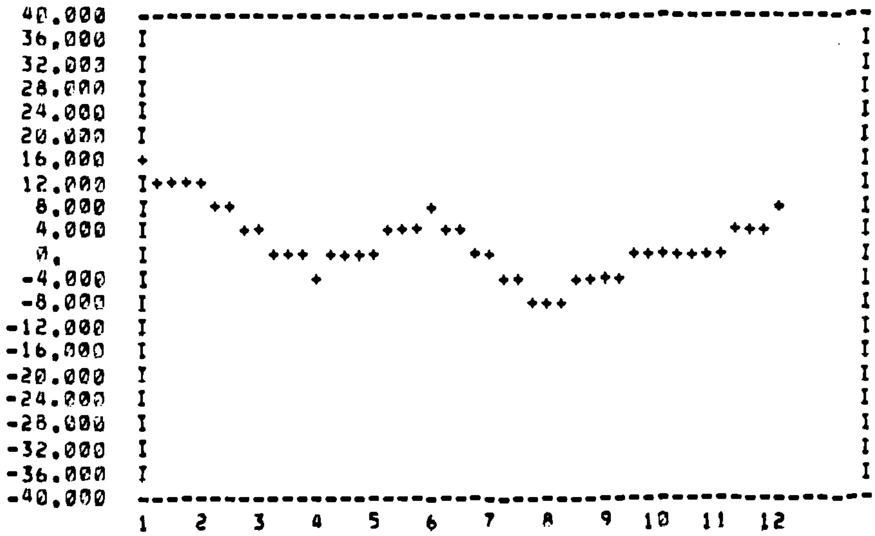
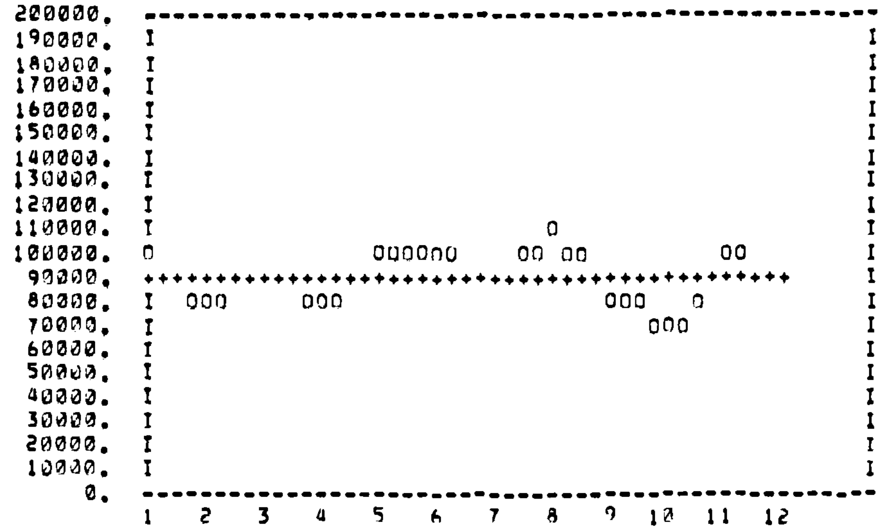


TABLE A.2 Validity of the production module in the Soviet submodel – comparison of observed and predicted production.

PLOTS FOR COMMODITY 1

OBSERVED VS PREDICTED PRODUCTION

O = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

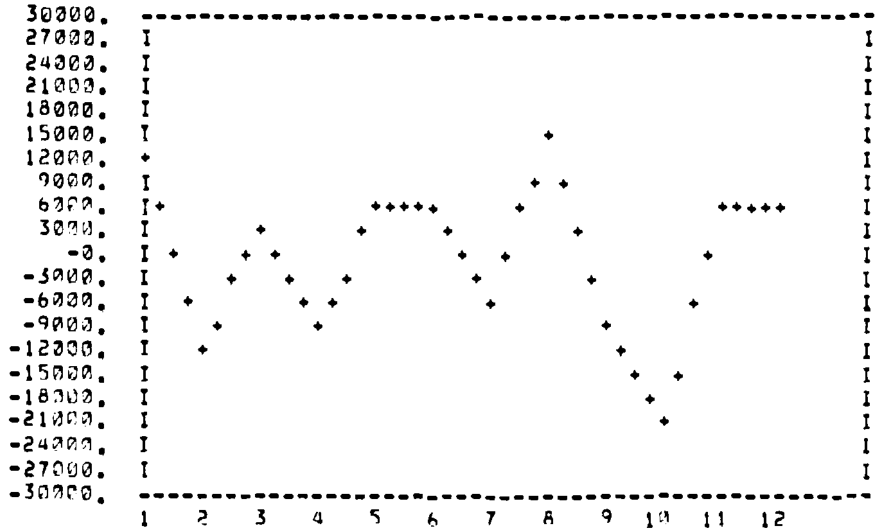
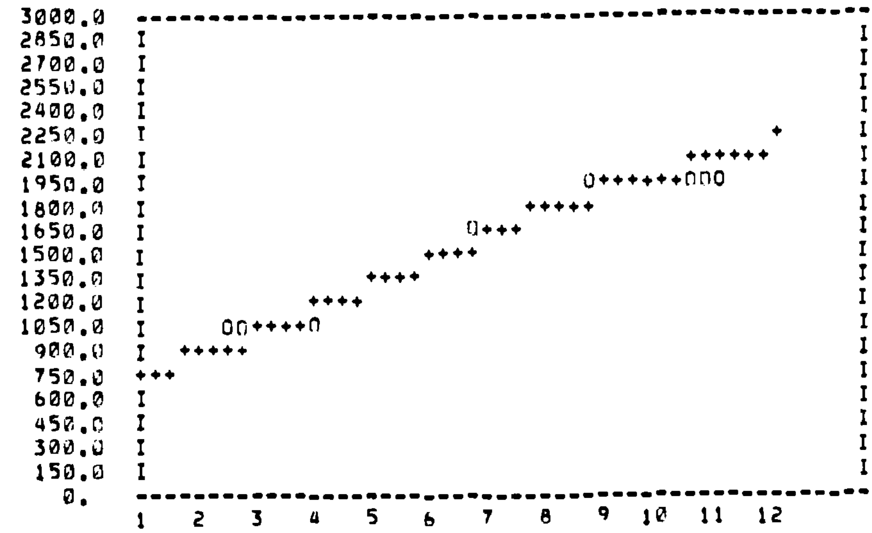


TABLE A.2 *Continued.*

PLOTS FOR COMMODITY 2

OBSERVED VS PREDICTED PRODUCTION

O = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

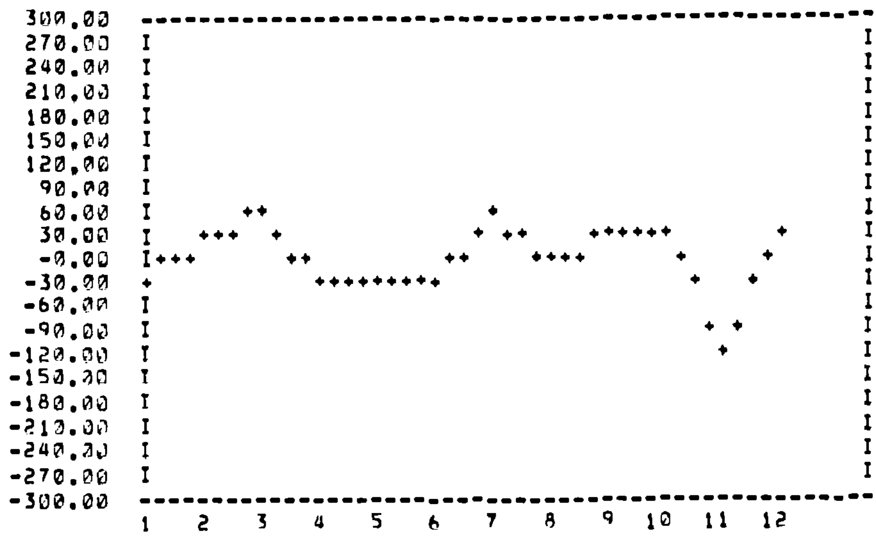
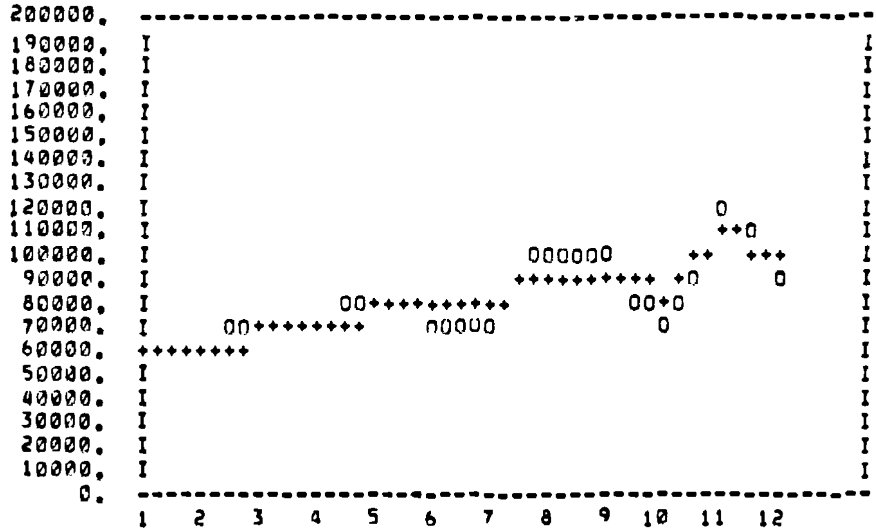


TABLE A.2 *Continued.*

PLOTS FOR COMMODITY 3

OBSERVED VS PREDICTED PRODUCTION

0 = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

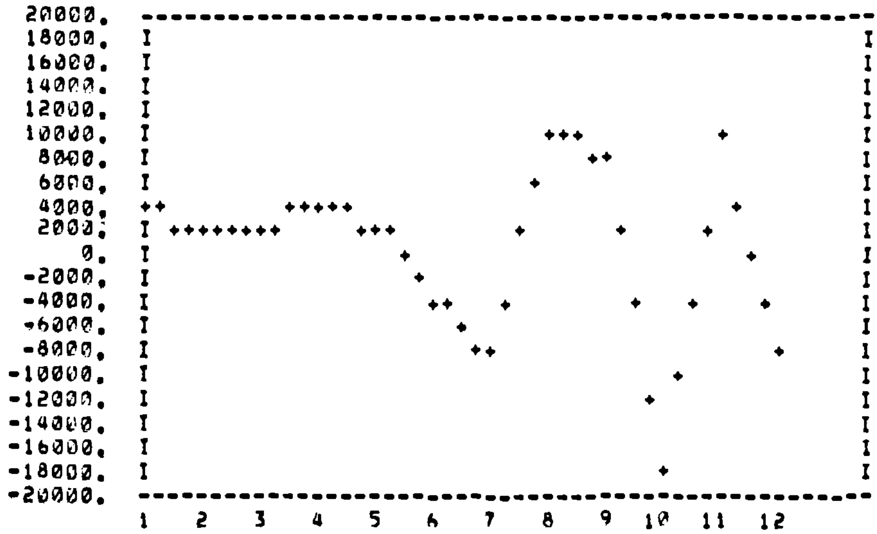
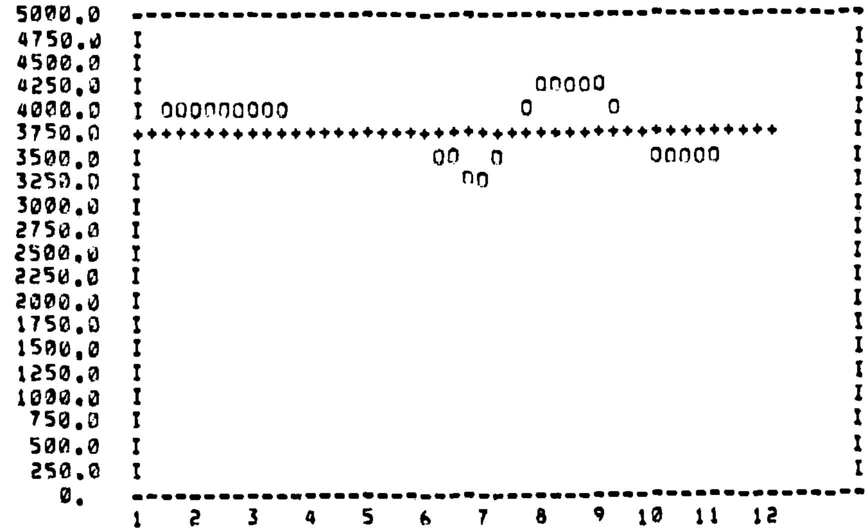


TABLE A.2 *Continued.*

PLOTS FOR COMMODITY 4

OBSERVED VS PREDICTED PRODUCTION

O = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

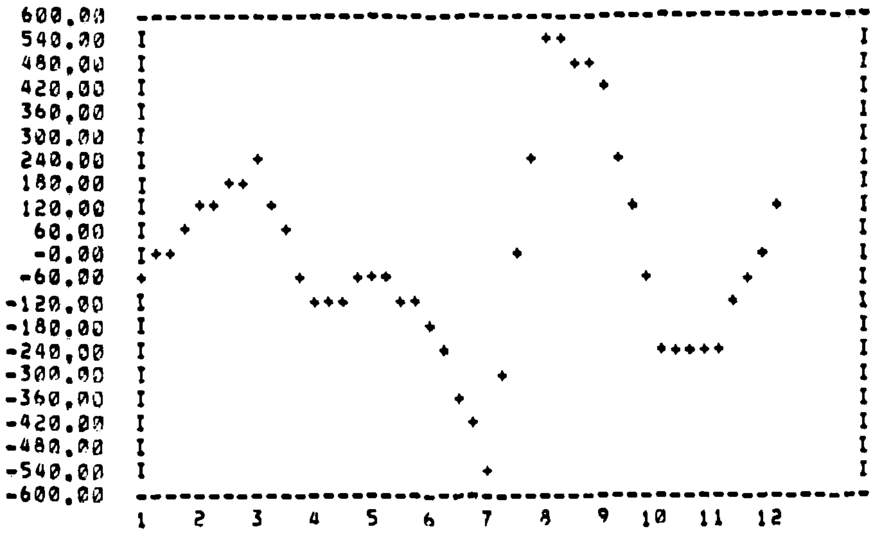
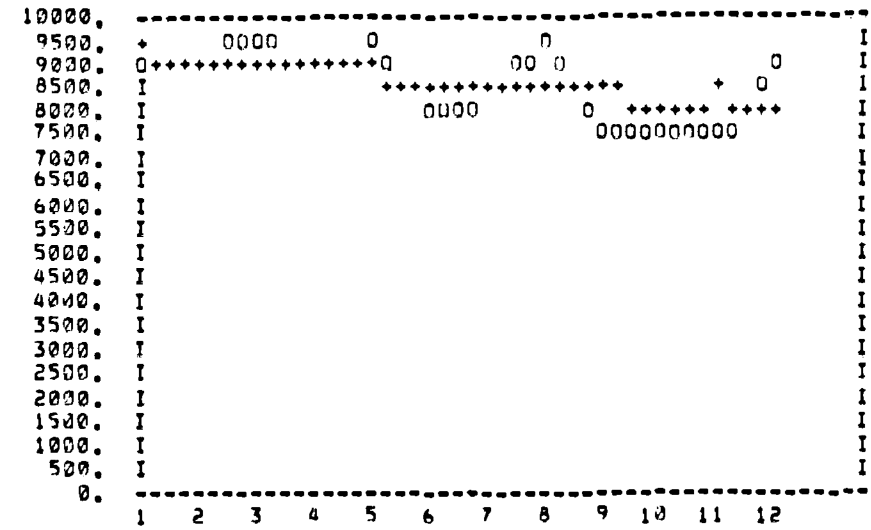


TABLE A.2 *Continued.*

PLOTS FOR COMMODITY 5

OBSERVED VS PREDICTED PRODUCTION

0 = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

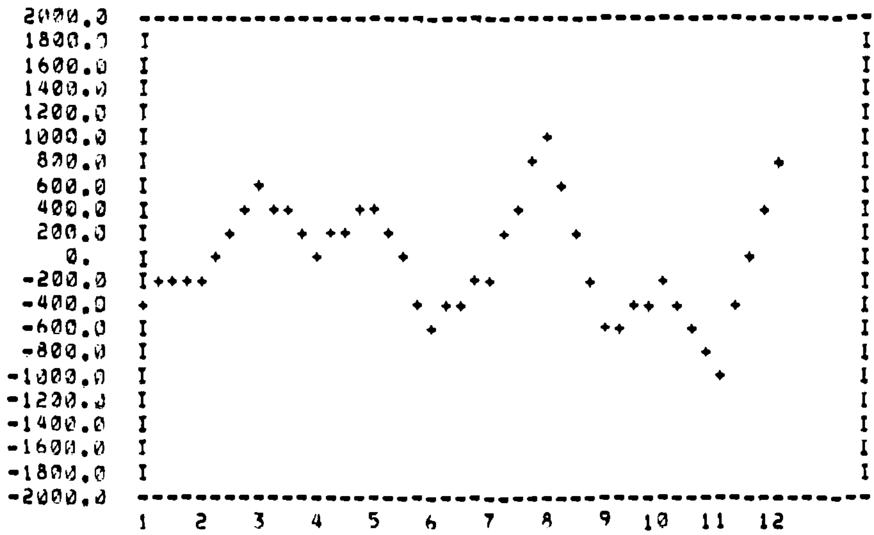
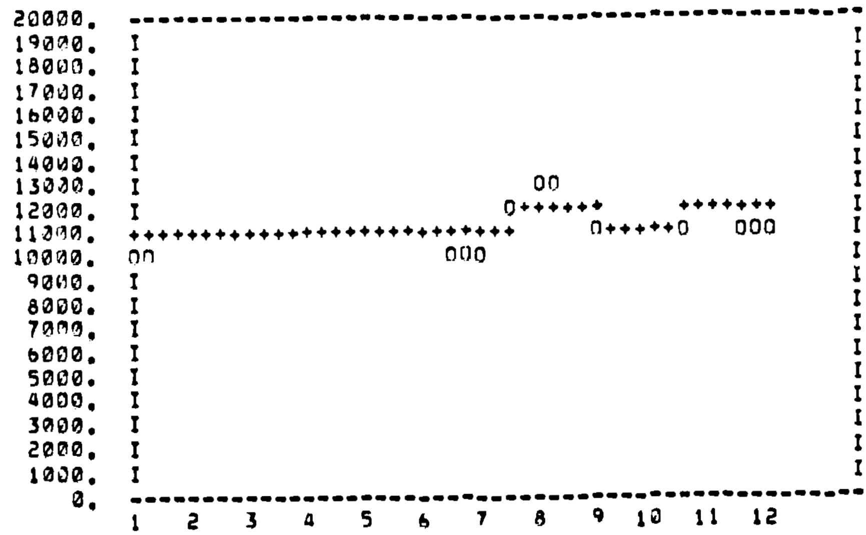


TABLE A.2 *Continued.*

PLOTS FOR COMMODITY 6

OBSERVED VS PREDICTED PRODUCTION

O = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

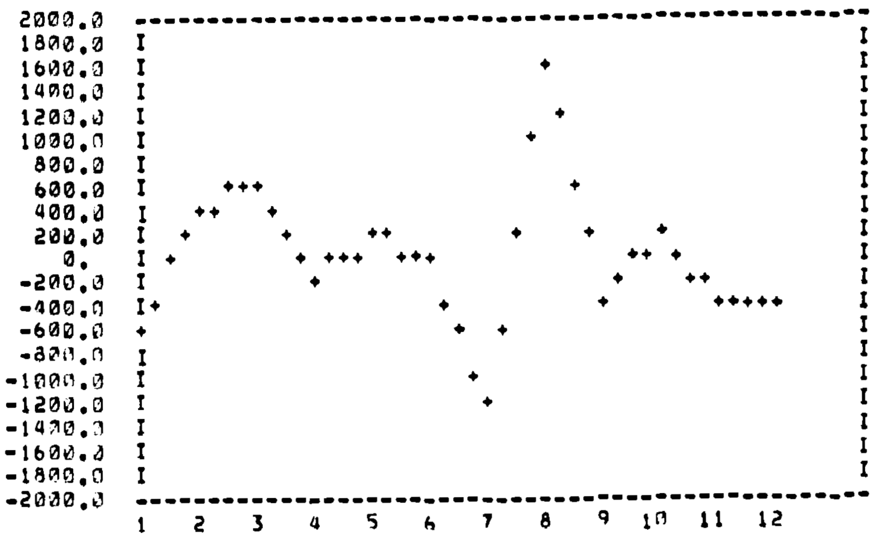
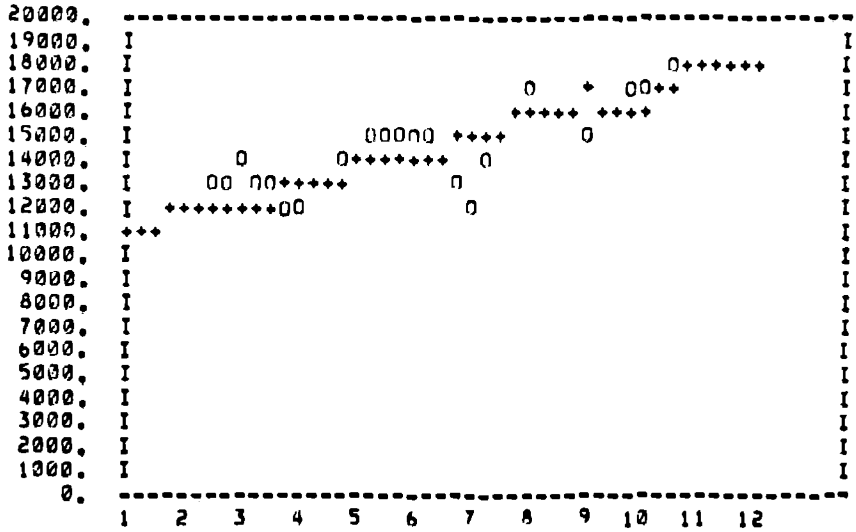


TABLE A.2 *Continued.*

PLOTS FOR COMMODITY 7

OBSERVED VS PREDICTED PRODUCTION

O = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

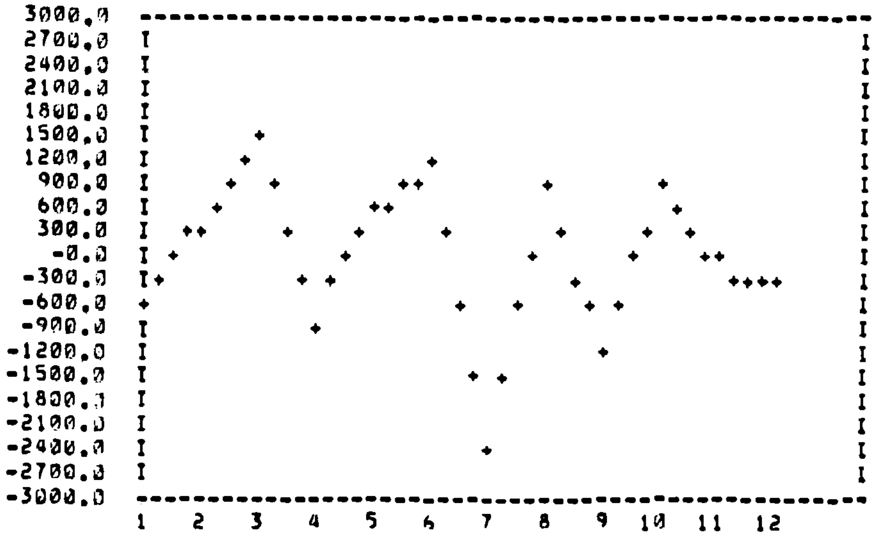
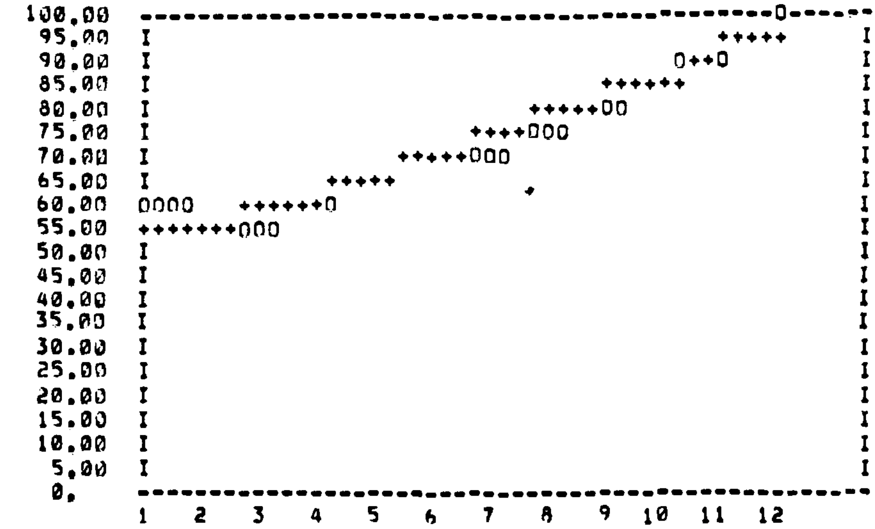


TABLE A.2 *Continued.*

PLOTS FOR COMMODITY 8

OBSERVED VS PREDICTED PRODUCTION

O = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

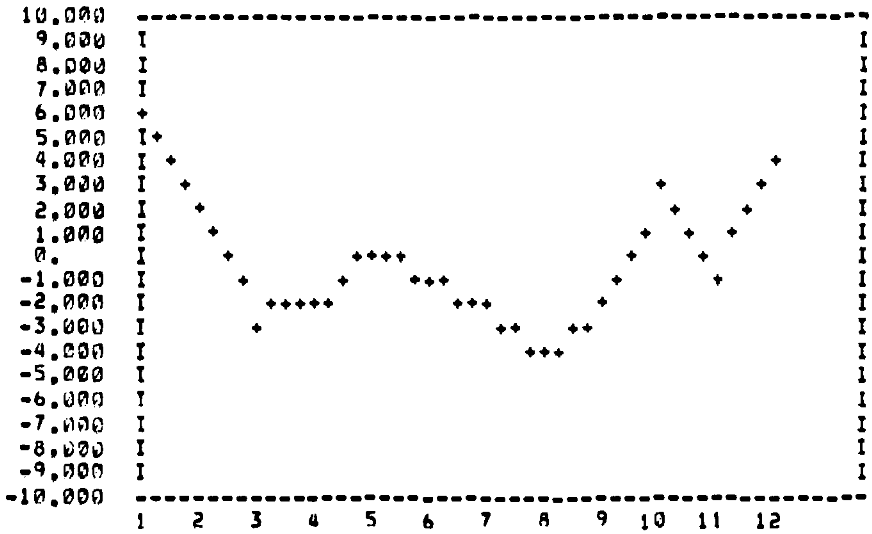
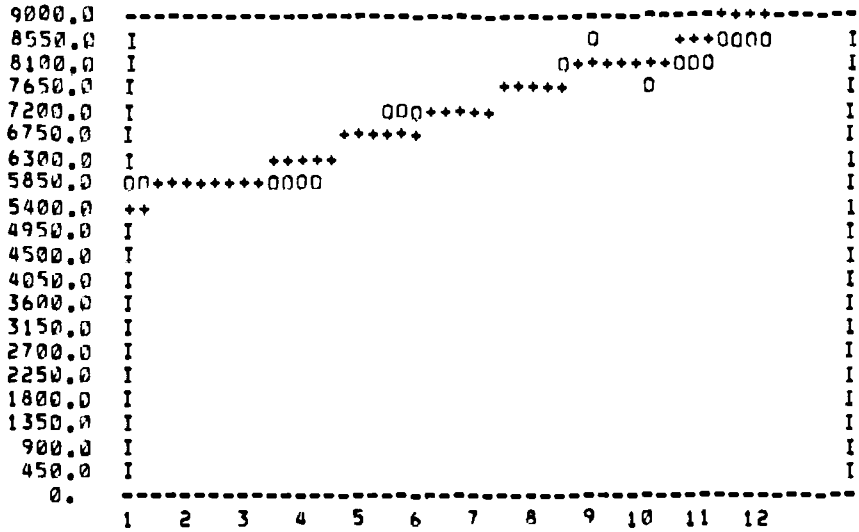


TABLE A.2 *Continued.*

PLOTS FOR COMMODITY 9

OBSERVED VS PREDICTED PRODUCTION

0 = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

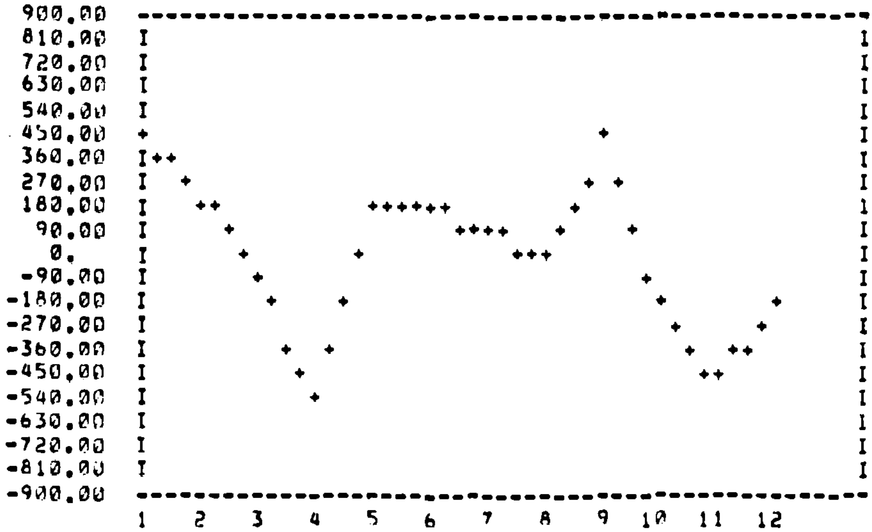
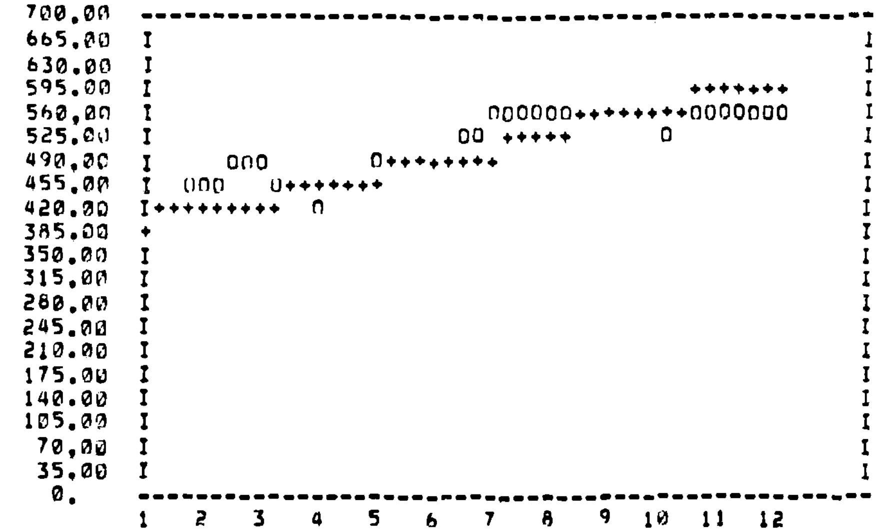


TABLE A.2 *Continued.*

PLOTS FOR COMMODITY10

OBSERVED VS PREDICTED PRODUCTION

0 = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

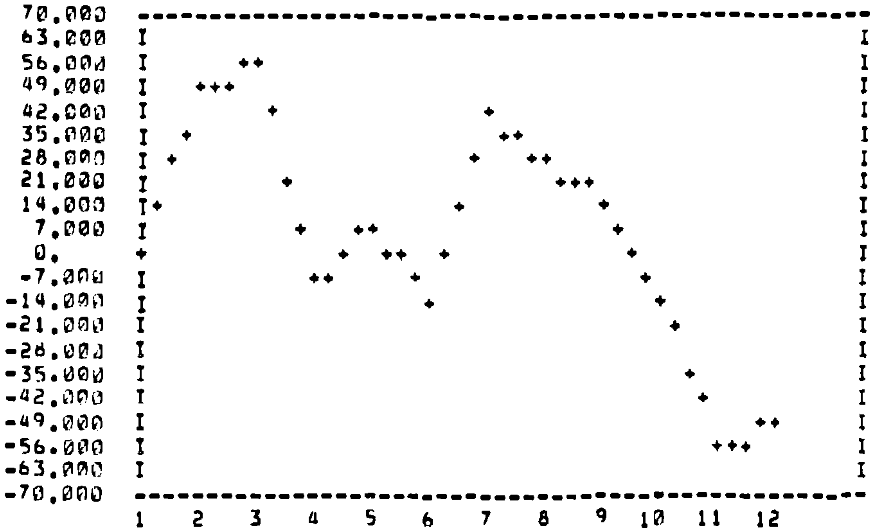
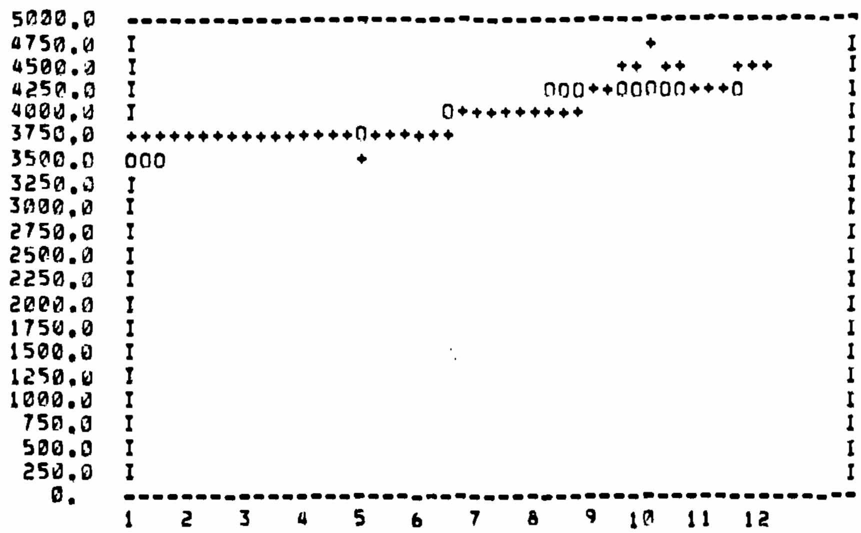


TABLE A.2 *Continued.*

PLOTS FOR COMMODITY11

OBSERVED VS PREDICTED PRODUCTION

O = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

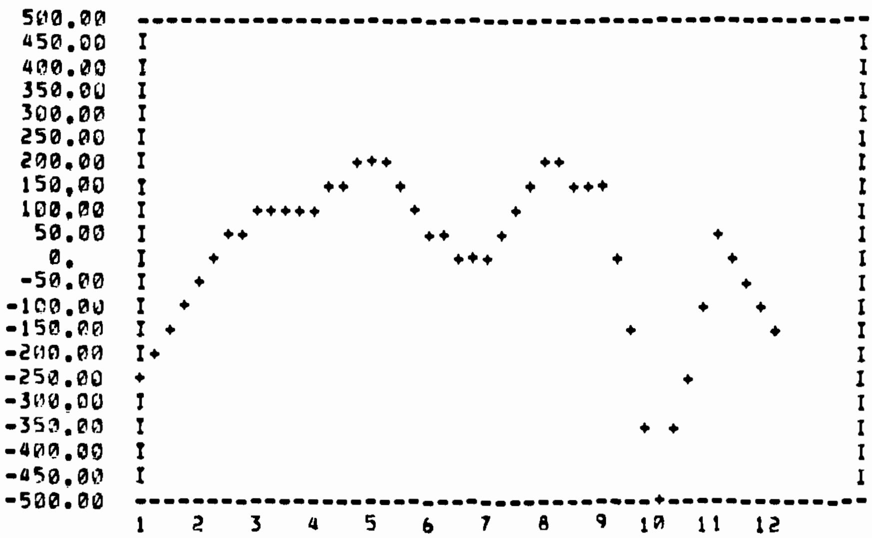
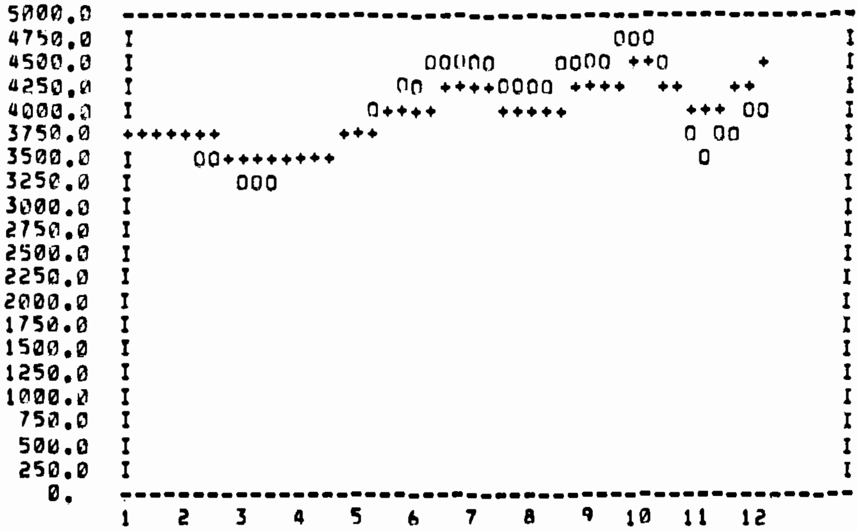


TABLE A.2 *Continued.*

PLOTS FOR COMMODITY12

OBSERVED VS PREDICTED PRODUCTION

0 = OBSERVED + = PREDICTED



PLOT OF RESIDUALS

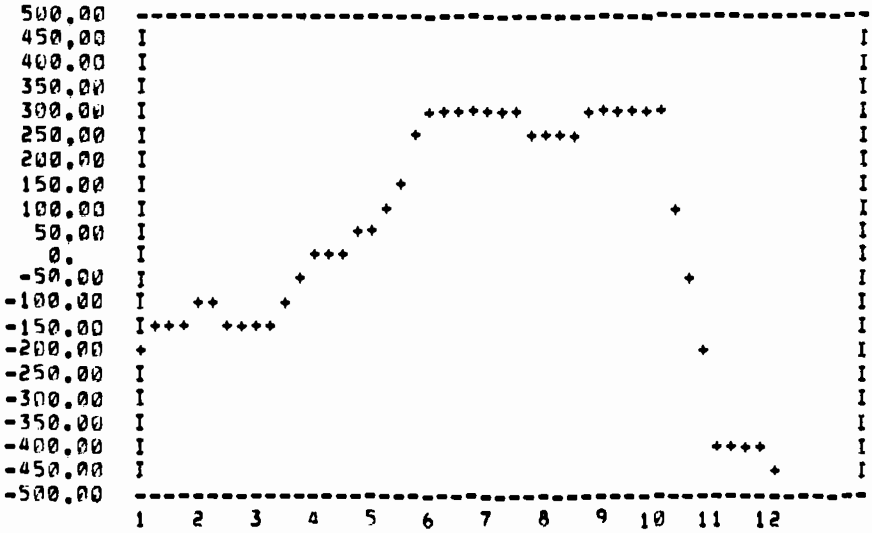
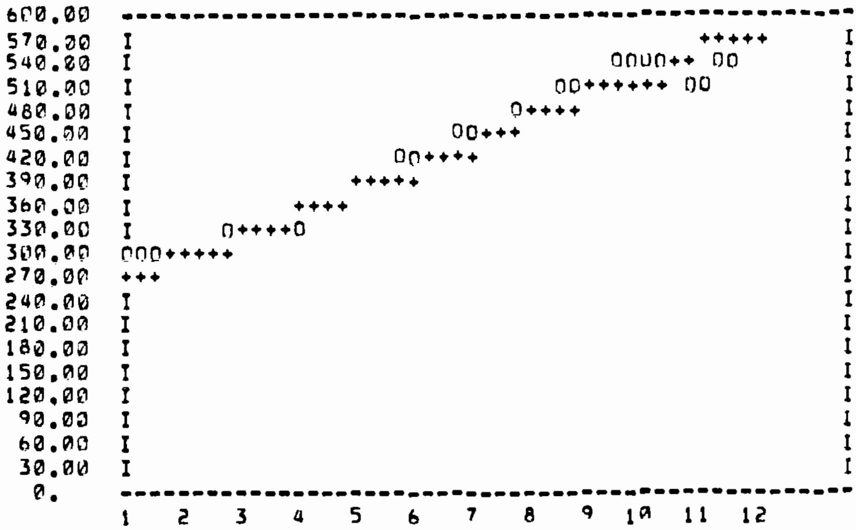


TABLE A.2 *Continued.*

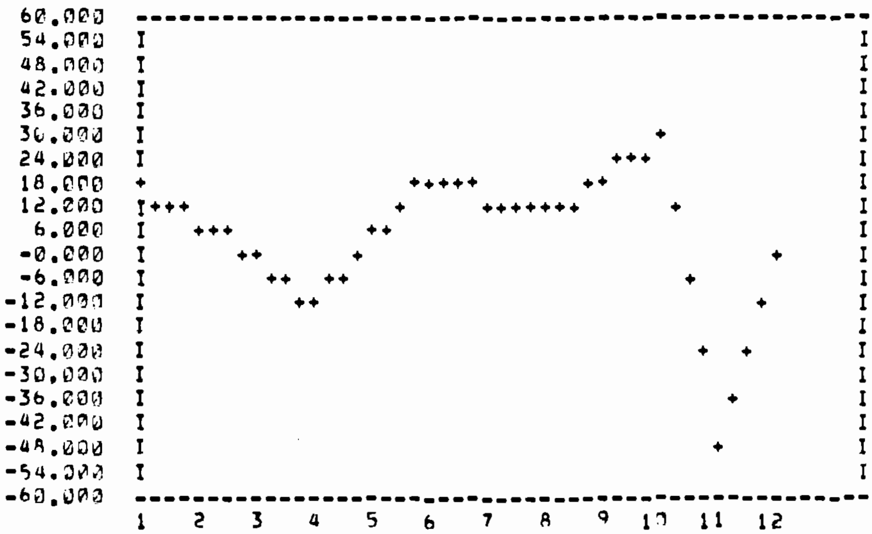
PLOTS FOR COMMODITY13

OBSERVED VS PREDICTED PRODUCTION

0 = OBSERVED + = PREDICTED



PLOT OF RESIDUALS



APPENDIX B Initial Data in the Basic Scenarios

TABLE B.1 Initial data of the Soviet submodel – Constant-SSR Scenario.

```
USSR
csa        171218.
csn        1116506.
a2         0.04
a2min      0.01
a2max      0.08
s2min      0.025
s2max      0.075
a3         0.2
a3min      0.1
a3max      0.3
s3min      0.015
s3max      0.045
a4min      0.6
a4max      0.85
exchr      0.9
shmlk      0.745
shbeef     0.875
shpltr     0.315
pyn1       .4659
pyn2       .2689
pyn3       1.106
pyn4       0.000
pinva      13329.
pinvn      70920.
depa       0.00
depn       0.00
rho        1.00
nprod      3
lmin       0.95,0.95,0.95,0.95,0.95,0.95,0.75,0.75,1.0,1.0,
lmax       1.05,1.05,1.05,1.05,1.05,1.05,1.25,1.25,1.1,1.1,
st1        4.,4.,4.,4.,4.,4.,4.,4.,4.,4.,
st2        4.,4.,4.,4.,4.,4.,4.,4.,4.,4.,
k11        999,0,999,0,40,40,999,60,999,80,
k12        0,999,0,999,40,40,60,999,80,999,
popt       254380., 266666., 279558., 291637., 301727., 311817.,
alt        0.035,0.035,0.035,0.035,0.035,0.035,
lftt       126605., 134560., 138912., 143194., 146745., 150296.,
lfat       25992.,23203.,20415.,17626.,14838.,12050.,
fertt      7339., 9367., 11954., 15257., 18562., 22584.,
balt       0., 0., 0., 0., 0., 0.,
  y,cint,seed,waste,feed,pw,
 1         82339.6,0.,9179.6,10725.2,32245.,159.,
 2         1974.5,0.,120.4,61.6,0.,230.,
 3         94652.,1518.1,9713.7,10896.6,67323.8,130.,
 4         7594.,0.,0.,0.,0.,208.,
 5         11350.,0.,1308.4,875.,2870.0,1420.,
 6         0.,0.,0.,2.4,0.,120.,
 7         134.7,0.,0.,53.1,0.,218.,
 8         16921.,0.,0.,1474.4,0.,210.,
 9         4074.4,911.7,292.7,96.,107.,760.,
10         0.,0.,0.,0.,0.,1421.,
11         0.,0.,0.,0.,0.,1586.,
12         86.4,0.,0.,0.,0.,1200.,
13         7629.,6120.,0.,0.,0.,420.,
14         552.15,741.,0.,0.,0.,1130.,
15         0.,244.,0.,0.,0.,656.,
16         0.,0.,0.,0.,0.,91.,
17         6421.2,0.,0.,0.,0.,1200.,
18         925.3,0.,0.,0.,0.,1108.,
19         5161.8,0.,0.,0.,0.,1626.,
20         1453.,0.,0.,0.,0.,1144.,
21         90519.3,0.,0.,3508.7,37578.2,209.,
22         3155.9,0.,95.9,159.8,0.,902.,
23         356800.,0.,0.,0.,0.,1000.,
```

TABLE B.1 *Continued.*

```
  hcons, pd, ssh, wsh, stfr
 1         37849.3,107.,0.115,0.1192,0.1,
 2         2112.4,193.,0.06,0.027,0.1,
 3         11414.8,96.,0.1115,0.1134,0.1,
 4         11365.1,238.,0.,0.,0.1,
 5         7011.5,1507.,0.115,0.0781,0.1,
 6         21.7,0.,0.,0.1,0.03,
 7         519.6,0.,0.,0.0928,0.03,
 8         14808.5,286.,0.,0.0828,0.03,
 9         2139.8,628.,0.07,0.,0.1,
10         172.2,0.,0.,0.,0.1,
11         50.4,0.,0.,0.,0.1,
12         130.0,1383.,0.,0.,0.1,
13         0.,610.,0.,0.,0.1,
14         0.,1035.,0.,0.,0.1,
15         0.,0.,0.,0.,0.03,
16         0.,0.,0.,0.,0.,
17         6862.0,2233.,0.,0.,0.1,
18         942.3,2233.,0.,0.,0.1,
19         4282.4,2148.,0.,0.,0.1,
20         1498.7,2000.,0.,0.,0.1,
21         49313.6,198.,0.,0.0387,0.03,
22         2941.7,2000.,0.03,0.05,0.03,
23         287800.,900.,0.,0.,0.025,
 pf1, pf2, pf3,
 1         5.,0.,0.9,0.,10.,0.,
 2         0.,0.,0.,0.,0.,0.,
 3         11.5,0.,1.7,0.,20.,0.,
 4         0.,0.,0.,0.,0.,0.,
 5         0.13,0.,0.5,0.,0.,0.,
 6         0.,0.,0.,0.,0.,0.,
 7         0.,0.,0.,0.,0.,0.,
 8         0.,0.,0.,0.,0.,0.,
 9         0.,0.,0.01,0.,0.13,0.,
10         0.,0.,0.,0.,0.,0.,
11         0.,0.,0.,0.,0.,0.,
12         0.,0.,0.,0.,0.,0.,
13         0.,0.,0.,0.,0.,0.,
14         0.,0.,0.,0.,0.,0.,
15         0.,0.,0.,0.,0.,0.,
16         0.,0.,0.,0.,0.,0.,
17         0.,0.,0.,0.,0.,0.,
18         0.,0.,0.,0.,0.,0.,
19         0.,0.,0.,0.,0.,0.,
20         0.,0.,0.,0.,0.,0.,
21         3.5,0.,5.85,0.,0.,0.,
22         0.,0.,0.,0.,0.,0.,
23         0.,0.,0.,0.,0.,0.,
   ifunc, neta, t1, t2,
 1         3,-0.3,0.,0.,
 2         2,0.3,0.,3.6,
 3         2,-0.4,0.,0.,
 4         3,0.2,-0.1,0.,
 5         2,0.,0.,0.,
 6         2,1.,55.7,0.,
 7         2,1.,-1.9,-2.1,
 8         2,0.7,0.,0.,
 9         3,0.4,0.6,0.2,
10         2,0.7,0.,0.,
11         2,1.,0.,0.,
12         2,0.4,0.,0.,
13         0,0.,0.,0.,
14         0,0.,0.,0.,
15         0,0.,0.,0.,
16         0,0.,0.,0.,
17         3,0.40,0.,-0.5,
```

TABLE B.1 *Continued.*

```
18          3,0.3,-0.8,-0.4,
19          2,1.20,0.,-1.2,
20          2,1.90,0.,0.,
21          2,0.,0.,0.,
22          2,0.5,0.,0.,
23          0,0.,0.,0.,
            ipr, ys, r3,
 1          1,66224.,2.52,
 2          2,2009.3,2.5,
 3          3,66567.,2.31,
 4          9,3434.8,1.,
 5          4,7702.,1.1,
 6          5,11107.,1.1,
 7          8,17158.,1.1,
 8          12,86.314,1.1,
 9          13,7864.,0.47,
10          14,542.19,0.47,
11          0,4255.1,0.7,
12          0,4761.5,0.,
13          0,540.62,0.,
parameters of allocation model
 1          145719.,0.333271e-01,0.,0.,0.125433,0.583692,0.124032,1.000000,
 2          79688.6,0.122214,0.,0.,0.117775,0.464124,0.118652,0.,
 3          72148.5,0.330040e-01,0.,0.,0.255557,0.565784,0.786596d-01,0.,
 4          151143.,0.262824e-01,0.,0.,0.101648,0.418975,0.470392d-01,0.,
 5          158450.,0.,0.,0.,0.228695,0.399239,0.487832d-01,0.,
 6          21362.1,0.,0.,0.,0.310398,0.385262,0.574238d-01,0.,
 7          95780.6,0.109227e-01,0.,0.,0.347888,0.317797,0.520073d-01,0.,
 8          9619.56,0.349097e-01,0.,0.,0.283939,0.318163,0.474769d-01,0.,
 9          212452.,0.,0.,0.,0.396484,0.785158d-01,0.250000d-01,0.,
10          46332.6,0.,0.,0.,0.374542,0.100458,0.250000d-01,0.,
11          11682.3,0.209552e-01,0.,0.,0.328571,0.328571,0.,0.,
12          157589.,0.128864e-01,0.,0.,0.250000,0.250000,0.,0.,
13          11273.0,0.950927e-01,0.,0.,0.250000,0.250000,0.,0.,
     cint
 1          0.,0.,0.,0.,0.,0.,
 2          0.,0.,0.,0.,0.,0.,
 3          1518.1,1706.6,1970.,2306.2,2520.7,2735.3.
 4          0.,0.,0.,0.,0.,0.,
 5          0.,0.,0.,0.,0.,0.,
 6          0.,0.,0.,0.,0.,0.,
 7          0.,0.,0.,0.,0.,0.,
 8          0.,0.,0.,0.,0.,0.,
 9          911.7,1022.1,1132.5,1254.4,1366.5,1478.7,
10          0.,0.,0.,0.,0.,0.,
11          0.,0.,0.,0.,0.,0.,
12          0.,0.,0.,0.,0.,0.,
13          6120.,6516.,6927.,7314.3,7673.7,8033.1,
14          741.,789.9,845.,904.9,993.,1081.2,
15          244.,283.,309.,330.,358.,386.,
16          0.,0.,0.,0.,0.,0.,
17          0.,0.,0.,0.,0.,0.,
18          0.,0.,0.,0.,0.,0.,
19          0.,0.,0.,0.,0.,0.,
20          0.,0.,0.,0.,0.,0.,
21          0.,0.,0.,0.,0.,0.,
22          0.,0.,0.,0.,0.,0.,
23          0.,0.,0.,0.,0.,0.,
            ssratt
 1          0.93,0.93,0.93,0.93,0.93,0.93,
 2
 3          0.96,0.96,0.96,0.96,0.96,0.96,
 4          0.67,0.67,0.67,0.67,0.67,0.67,
 5          0.96,0.96,.96,.96,.96,.96,
 6
 7
```

TABLE B.1 *Continued.*

```
 8
 9          1.00,1.00,1.00,1.00,1.00,1.00,
10
11
12
13
14
15
16
17          0.00,0.00,0.00,0.00,0.00,0.00
18          0.00,0.00,0.00,0.00,0.00,0.00
19
20          1.00,1.00,1.00,1.00,1.00,1.00,
21          0.00,0.00,0.00,0.00,0.00,0.00,
22
23
            pmratt
 1          0.0
 2
 3          0.0
 4          0.0
 5          0.0
 6
 7
 8
 9          0.0
10
11
12
13
14
15
16
17            0.00,0.00,0.00,0.00,0.00,0.00
18            0.00,0.00,0.00,0.00,0.00,0.00
19
20
21            0.00,0.00,0.00,0.00,0.00,0.00,
22
23
```

TABLE B.2 Initial data of the Soviet submodel – Free Trade Scenario.

```
USSR
csa          171218.
csn          1116506.
a2           0.04
a2min        0.01
a2max        0.08
s2min        0.025
s2max        0.075
a3           0.2
a3min        0.1
a3max        0.3
s3min        0.015
s3max        0.045
a4min        0.6
a4max        0.85
exchr        0.9
shmlk        0.745
shbeef       0.875
shpltr       0.315
pyn1         .4659
pyn2         .2689
pyn3         1.106
pyn4         0.000
pinva        13329.
pinvn        70920.
depa         0.00
depn         0.00
rho          1.00
nprod        3
lmin         0.95,0.95,0.95,0.95,0.95,0.95,0.75,0.75,1.0,1.0,
lmax         1.05,1.05,1.05,1.05,1.05,1.05,1.25,1.25,1.1,1.1,
st1          4.,4.,4.,4.,4.,4.,4.,4.,4.,4.,
st2          4.,4.,4.,4.,4.,4.,4.,4.,4.,4.,
k11          999,0,999,0,40,40,999,60,999,80,
k12          0,999,0,999,40,40,60,999,80,999,
popt         254380., 266666., 279558., 291637., 301727., 311817.,
alt          0.035,0.035,0.035,0.035,0.035,0.035,
lftt         126605., 134560., 138912., 143194., 146745., 150296.,
lfat         25992.,23203.,20415.,17626.,14838.,12050.,
fertt        7339., 9367., 11954., 15257., 18562., 22584.,
balt         0., 0., 0., 0., 0., 0.,
  y,cint,seed,waste,feed,pw,
 1           82339.6,0.,9179.6,10725.2,32245.,159.,
 2           1974.5,0.,120.4,61.6,0.,230.,
 3           94652.,1518.1,9713.7,10896.6,67323.8,130.,
 4           7594.,0.,0.,0.,0.,208.,
 5           11350.,0.,1308.4,875.,2870.0,1420.,
 6           0.,0.,0.,2.4,0.,120.,
 7           134.7,0.,0.,53.1,0.,218.,
 8           16921.,0.,0.,1474.4,0.,210.,
 9           4074.4,911.7,292.7,96.,107.,760.,
10           0.,0.,0.,0.,0.,1421.,
11           0.,0.,0.,0.,0.,1586.,
12           86.4,0.,0.,0.,0.,1200.,
13           7629.,6120.,0.,0.,0.,420.,
14           552.15,741.,0.,0.,0.,1130.,
15           0.,244.,0.,0.,0.,656.,
16           0.,0.,0.,0.,0.,91.,
17           6421.2,0.,0.,0.,0.,1200.,
18           925.3,0.,0.,0.,0.,1108.,
19           5161.8,0.,0.,0.,0.,1626.,
20           1453.,0.,0.,0.,0.,1144.,
21           90519.3,0.,0.,3506.7,37578.2,209.,
22           3155.9,0.,95.9,159.8,0.,902.,
23           356800.,0.,0.,0.,0.,1000.,
```

TABLE B.2 *Continued.*

```
   hcons, pd, ssh, wsh, stfr
 1          37849.3,107.,0.115,0.1192,0.1,
 2          2112.4,193.,0.06,0.027,0.1,
 3          11414.8,96.,0.1115,0.1134,0.1,
 4          11365.1,238.,0.,0.,0.1,
 5          7011.5,1507.,0.115,0.0781,0.1,
 6          21.7,0.,0.,0.1,0.03,
 7          519.6,0.,0.,0.0928,0.03,
 8          14808.5,286.,0.,0.0828,0.03,
 9          2139.8,628.,0.07,0.,0.1,
10          172.2,0.,0.,0.,0.1,
11          50.4,0.,0.,0.,0.1,
12          130.0,1383.,0.,0.,0.1,
13          0.,610.,0.,0.,0.1,
14          0.,1035.,0.,0.,0.1,
15          0.,0.,0.,0.,0.03,
16          0.,0.,0.,0.,0.,
17          6862.0,2233.,0.,0.,0.1,
18          942.3,2233.,0.,0.,0.1,
19          4282.4,2148.,0.,0.,0.1,
20          1498.7,2000.,0.,0.,0.1,
21          49313.6,198.,0.,0.0387,0.03,
22          2941.7,2000.,0.03,0.05,0.03,
23          287800.,900.,0.,0.,0.025,
 pf1, pf2, pf3,
 1          5.,0.,0.9,0.,10.,0.,
 2          0.,0.,0.,0.,0.,0.,
 3          11.5,0.,1.7,0.,20.,0.,
 4          0.,0.,0.,0.,0.,0.,
 5          0.13,0.,0.5,0.,0.,0.,
 6          0.,0.,0.,0.,0.,0.,
 7          0.,0.,0.,0.,0.,0.,
 8          0.,0.,0.,0.,0.,0.,
 9          0.,0.,0.01,0.,0.13,0.,
10          0.,0.,0.,0.,0.,0.,
11          0.,0.,0.,0.,0.,0.,
12          0.,0.,0.,0.,0.,0.,
13          0.,0.,0.,0.,0.,0.,
14          0.,0.,0.,0.,0.,0.,
15          0.,0.,0.,0.,0.,0.,
16          0.,0.,0.,0.,0.,0.,
17          0.,0.,0.,0.,0.,0.,
18          0.,0.,0.,0.,0.,0.,
19          0.,0.,0.,0.,0.,0.,
20          0.,0.,0.,0.,0.,0.,
21          3.5,0.,5.85,0.,0.,0.,
22          0.,0.,0.,0.,0.,0.,
23          0.,0.,0.,0.,0.,0.,
   ifunc, neta, t1, t2,
 1          3,-0.3,0.,0.,
 2          2,0.3,0.,3.6,
 3          2,-0.4,0.,0.,
 4          3,0.2,-0.1,0.,
 5          2,0.,0.,0.,
 6          2,1.,55.7,0.,
 7          2,1.,-1.9,-2.1,
 8          2,0.7,0.,0.,
 9          3,0.4,0.6,0.2,
10          2,0.7,0.,0.,
11          2,1.,0.,0.,
12          2,0.4,0.,0.,
13          0,0.,0.,0.,
14          0,0.,0.,0.,
15          0,0.,0.,0.,
16          0,0.,0.,0.,
17          3,0.40,0.,-0.5,
```

TABLE B.2 *Continued.*

```
18          3,0.3,-0.8,-0.4,
19          2,1.20,0.,-1.2,
20          2,1.90,0.,0.,
21          2,0.,0.,0.,
22          2,0.5,0.,0.,
23          0,0.,0.,0.,
            ipr, ys, r3,
 1          1,66224.,2.52,
 2          2,2009.3,2.5,
 3          3,66567.,2.31,
 4          9,3434.8,1.,
 5          4,7702.,1.1,
 6          5,11107.,1.1,
 7          8,17158.,1.1,
 8          12,86.314,1.1,
 9          13,7864.,0.47,
 10         14,542.19,0.47,
11          0,4255.1,0.7,
12          0,4761.5,0.,
13          0,540.62,0.,
parameters of allocation model
 1          145719.,0.333271e-01,0.,0.,0.125433,0.583692,0.124032,1.000000,
 2          79688.6,0.122214,0.,0.,0.117775,0.464124,0.118652,0.,
 3          72148.5,0.330040e-01,0.,0.,0.255557,0.565784,0.786596d-01,0.,
 4          151143.,0.262824e-01,0.,0.,0.101648,0.418975,0.470392d-01,0.,
 5          158450.,0.,0.,0.,0.228695,0.399239,0.487832d-01,0.,
 6          21362.1,0.,0.,0.,0.310398,0.385262,0.574238d-01,0.,
 7          95780.6,0.109227e-01,0.,0.,0.347888,0.317797,0.520073d-01,0.,
 8          9619.56,0.349097e-01,0.,0.,0.283939,0.318163,0.474769d-01,0.,
 9          212452.,0.,0.,0.,0.396484,0.785158d-01,0.250000d-01,0.,
10          46332.6,0.,0.,0.,0.374542,0.100458,0.250000d-01,0.,
11          11682.3,0.209552e-01,0.,0.,0.328571,0.328571,0.,0.,
12          157589.,0.128864e-01,0.,0.,0.250000,0.250000,0.,0.,
13          11273.0,0.950927e-01,0.,0.,0.250000,0.250000,0.,0.,
    oint
 1          0.,0.,0.,0.,0.,0.,
 2          0.,0.,0.,0.,0.,0.,
 3          1518.1,1706.6,1970.,2306.2,2520.7,2735.3,
 4          0.,0.,0.,0.,0.,0.,
 5          0.,0.,0.,0.,0.,0.,
 6          0.,0.,0.,0.,0.,0.,
 7          0.,0.,0.,0.,0.,0.,
 8          0.,0.,0.,0.,0.,0.,
 9          911.7,1022.1,1132.5,1254.4,1366.5,1478.7,
10          0.,0.,0.,0.,0.,0.,
11          0.,0.,0.,0.,0.,0.,
12          0.,0.,0.,0.,0.,0.,
13          6120.,6516.,6927.,7314.3,7673.7,8033.1,
14          741.,789.9,845.,904.9,993.,1081.2,
15          244.,283.,309.,330.,358.,386.,
16          0.,0.,0.,0.,0.,0.,
17          0.,0.,0.,0.,0.,0.,
18          0.,0.,0.,0.,0.,0.,
19          0.,0.,0.,0.,0.,0.,
20          0.,0.,0.,0.,0.,0.,
21          0.,0.,0.,0.,0.,0.,
22          0.,0.,0.,0.,0.,0.,
23          0.,0.,0.,0.,0.,0.,
            ssratt
 1          0.95,0.96,0.97.0.98,0.99,1.00,
 2          0.87,0.87,0.87,0.87,0.87,0.87,
 3          0.96,0.97,0.98,0.99,0.99,1.00,
 4          0.67,0.73,0.79,0.85,0.91,0.95,
 5          0.96,0.96,0.96,0.96,0.98,0.98,
 6
 7          0.24,0.24,0.24,0.24,0.24,0.24,
```

TABLE B.2 *Continued.*

8	1.00,1.00,1.00,1.00,1.00,1.00,
9	1.10,1.10,1.10,1.10,1.10,1.10,
10	
11	
12	0.67,0.67,0.67,0.67,0.67,0.67,
13	1.00,1.00,1.00,1.00,1.00,1.00,
14	0.75,0.75,0.75,0.75,0.75,0.75,
15	
16	
17	0.94,0.94,0.94,0.94,0.94,0.94
18	0.99,0.99,0.99,0.99,0.99,0.99
19	1.00,1.00,1.00,1.00,1.00,1.00
20	1.00,1.00,1.00,1.00,1.00,1.00
21	0.97,0.97,0.97,0.97,0.97,0.97
22	0.00,0.00,0.00,0.00,0.00,0.00
23	
	pmratt
1	0.0
2	
3	0.0
4	0.0
5	0.0
6	
7	
8	
9	0.0
10	
11	
12	
13	1.50,1.50,1.50,1.50,1.50,1.50,
14	1.50,1.50,1.50,1.50,1.50,1.50,
15	
16	
17	0.00,0.00,0.00,0.00,0.00,0.00
18	0.00,0.00,0.00,0.00,0.00,0.00
19	
20	
21	0.00,0.00,0.00,0.00,0.00,0.00,
22	
23	

TABLE B.3 Initial data of the East European submodel – Free Trade Scenario.

```
 CMEA in Europe (excl. USSR)
csa           133145.
csn           951487.
a2            0.045
a2min         0.
a2max         0.1
s2min         0.03
s2max         0.08
a3            0.135
a3min         0.075
a3max         0.25
s3min         0.01
s3max         0.04
a4min         0.6
a4max         0.85
exchr         0.9
shmlk         0.795
shbeef        0.9
shpltr        0.438
pyn1          0.5932
pyn2          0.1119
pyn3          1.322
pyn4          0.000
pinva         8860.
pinvn         65807.
depa          0.00
depn          0.00
rho           1.00
nprod         3
lmin          0.95,0.95,0.95,0.95,0.95,0.95,0.75,0.75,1.0,1.0,
lmax          1.05,1.05,1.05,1.05,1.05,1.05,1.25,1.25,1.1,1.1,
st1           4.,4.,4.,4.,4.,4.,4.,4.,4.,4.,
st2           4.,4.,4.,4.,4.,4.,4.,4.,4.,4.,
kl1           9999,0,9999,0,40,40,9999,60,9999,80,
kl2           0,9999,0,9999,40,40,60,9999,80,9999,
popt          106186.,110041.,113538.,116479.,119163.,121846.,
alt           0.045,0.045,0.045,0.045,0.045,0.045,
lftt          56162.,58442.,60931.,62379.,63878.,65376.,
lfat          17319.,15568.,13953.,12120.,10387.,8564.,
fertt         4141.7,5285.9,6746.4,8610.3,10475.7,12745.3,
balt          0.,0.,0.,0.,0.,0.,
   y, cint,   seed, waste, feed, pw,
 1            26528.3, 647.3, 1675.3, 1484.3, 11705.2, 159.,
 2            160.8, 31., 14.4, 13.1, 0.,230.,
 3            48713:6, 2139.2, 2242.1, 2322., 42819.4, 130.,
 4            4204.5, 0., 0., 14.1, 11.7, 208.,
 5            6497.5, 0., 571.1, 672.7, 2580.1, 1420.,
 6            0., 0., 0., 19.4, 0., 120.,
 7            0., 0., 0., 46.4, 0., 218.,
 8            9831.8, 0., 0., 634.7, 82.7, 210.,
 9            862.4, 93.9, 8.3, 6.4, 16.6, 760.,
10            0., 0., 0., 0.6, 0., 1421.,
11            0., 0., 0., 0., 0., 1586.,
12            0., 0., 0., 0., 0., 1200.,
13            33., 1683., 0., 0., 0., 420.,
14            583.2, 530.3, 0., 0., 0., 1130.,
15            0., 230., 0., 0., 0., 656.,
16            0., 0., 0., 0., 0., 91.,
17            2130.,103.6, 0., 16.6, 0., 1200.,
18            234.2, 0., 0., 0.9, 0., 1108.,
19            5402.4,114.9, 0., 66.7, 0., 1626.,
20            1217.6,3.2, 0., 13., 0., 1144.,
21            38988.1, 1555., 0., 901.7, 15698.6, 209.,
22            1564.9, 0., 73.4, 27.3, 0., 902.,
23            252600.,16.4, 0., 0., 0., 1000.,
```

TABLE B.3 *Continued.*

	hcons,pd, ssh, wsh, stfr
1	13308.,183.9, 0.0627, 0.0484, 0.1,
2	534.,390., 0.0898, 0.0222, 0.1,
3	7025.9,166.8, 0.065, 0.0431, 0.1,
4	4319.6,292., 0., 0.0034, 0.1,
5	2450.,879., 0.085, 0.1035, 0.1,
6	186.1,0., 0., 0.0916, 0.03,
7	635.1,0., 0., 0.0669, 0.03,
8	7702.4,225., 0., 0.0677, 0.03,
9	888.4,1069., 0.02, 0.0051, 0.1,
10	123.7,0., 0., 0.0044, 0.1,
11	145.4,0., 0., 0., 0.1,
12	20.9,0., 0., 0., 0.1,
13	0.,946., 0., 0., 0.1,
14	0.,2847., 0., 0., 0.1,
15	0.,0., 0., 0., 0.03,
16	0.,0., 0., 0., 0.,
17	1741.1,1987., 0., 0.0074, 0.1,
18	207.,1987., 0., 0.0041, 0.1,
19	4202.2,1945., 0., 0.0129, 0.1,
20	1014.2,1890., 0., 0.0127, 0.1,
21	21155.1,218., 0., 0.0232, 0.03,
22	1336.1,1890., 0.0489, 0.0181, 0.03,
23	203750.,900., 0., 0., 0.025,
	pf1, pf2, pf3,
1	4., 0., 0.6, 0., 6.8, 0.,
2	0., 0., 0., 0., 0., 0.,
3	15., 0., 2.,0., 23.2, 0.,
4	0.001, 0., 0.0025, 0., 0., 0.,
5	0.3, 0., 0.42, 0., 0., 0.,
6	0., 0., 0., 0., 0., 0.,
7	0., 0., 0., 0., 0., 0.,
8	0.01, 0., 0.014, 0., 0., 0.,
9	0., 0., 0.002, 0., 0.02, 0.,
10	0., 0., 0., 0., 0., 0.,
11	0., 0., 0., 0., 0., 0.,
12	0., 0., 0., 0., 0., 0.,
13	0., 0., 0., 0., 0., 0.,
14	0., 0., 0., 0., 0., 0.,
15	0., 0., 0., 0., 0., 0.,
16	0., 0., 0., 0., 0., 0.,
17	0., 0., 0., 0., 0., 0.,
18	0., 0., 0., 0., 0., 0.,
19	0., 0., 0., 0., 0., 0.,
20	0., 0., 0., 0., 0., 0.,
21	1.9, 0., 2.75, 0., 0., 0.,
22	0., 0., 0., 0., 0., 0.,
23	0., 0., 0., 0., 0., 0.,
	ifunc, neta, t1, t2,
1	3, -0.22, 0., 0.,
2	2, 0.2, 0., 0.,
3	3, -0.15, 0., 0.,
4	3, 0.25, -0.4, -0.1,
5	2, 0.2, 0., 0.,
6	2, 0.59, 8.3, -1.5,
7	2, 0.82, 0.8, 0.8,
8	2, 0.53, 0., 0.,
9	3, 0.14, 0.1, 0.6,
10	2, 0.46, 0., 0.,
11	2, 0.88, 0., 0.,
12	2, 0.84, 0., 0.,
13	0, 0., 0., 0., 0.,
14	0, 0., 0., 0., 0.,
15	0, 0., 0., 0., 0.,
16	0, 0., 0., 0., 0.,
17	3, 0.5, 0., 0.,

TABLE B.3 *Continued.*

```
18          2, 0.69, -1., -1.,
19          3, 0.14, 0.1, -0.2,
20          3, 0.58, 0., 0.,
21          3, 0.2, 0., 0.,
22          2, 0.43, 0., 0.,
23          0, 0., 0., 0., 0.,
            ipr, ys, r3
 1          1, 26528.3, 2.52,
 2          2, 204.7, 2.5,
 3          3, 48973., 2.31,
 4          9, 1137.4, 1.,
 5          4, 4239.5, 1.1,
 6          5, 6497.5, 1.1,
 7          8, 9436.4, 1.1,
 8          12, 0., 1.1,
 9          13, 37.782, 0.47,
10          14, 584.73, 0.47,
11          0, 1701.1, 0.7,
12          0, 4847.6, 0.,
13          0, 319.1, 0.,
parameters of allocation model
01          166131.,0.373652e-01,0.,0.,0.167748,0.403351,0.136846,1.000000,
02          10630.2,0.202671e-01,0.,0.,0.138387,0.570318,0.191295,0.,
03          33651.3,0.169477e-01,0.,0.,0.251367,0.508062,0.140571,0.,
04          59232.9,0.471159e-01,0.,0.,0.122023,0.359098,0.571289d-01,0.,
05          32432.4,0.,0.,0.,0.377723,0.339563,0.461721d-01,0.,
06          4656.20,0.,0.,0.,0.388272,0.448845,0.628829d-01,0.,
07          64228.1,0.,0.,0.,0.348510,0.331318,0.584686d-01,0.,
08          0.,
09          13096.8,0.,0.,0.,0.296051,0.178949,0.250000d-01,0.,
10          10208.2,0.,0.,0.,0.465204,0.749028d-01,0.284267d-01,0.,
11          34318.9,0.401869e-01,0.,0.,0.250000,0.250000,0.,0.,
12          112852.,0.412845e-01,0.,0.,0.250000,0.250000,0.,0.,
13          7856.96,0.937392e-01,0.,0.,0.250000,0.250000,0.,0.,
           cint
 1          647.3, 702.9, 780., 887.1, 961.5, 1036.,
 2          3.1, 3.5, 4., 4.7, 5.1, 5.5,
 3          2139.2, 2371.4, 2693., 2962.9, 3332.4, 3701.9,
 4          0., 0., 0., 0., 0., 0.,
 5          0., 0., 0., 0., 0., 0.,
 6          0., 0., 0., 0., 0., 0.,
 7          0., 0., 0., 0., 0., 0.,
 8          0., 0., 0., 0., 0., 0.,
 9          93.9, 105.9, 118., 130.5, 135.3, 140.1,
10          0., 0., 0., 0., 0., 0.,
11          0., 0., 0., 0., 0., 0.,
12          0., 0., 0., 0., 0., 0.,
13          1683., 1740., 1812., 1849.8, 1933.2, 2016.6,
14          530.3, 559.6, 592.9, 619.3, 658.7, 698.,
15          230., 266., 290., 309., 335.5, 362.,
16          0., 0., 0., 0., 0., 0.,
17          0., 0., 0., 0., 0., 0.,
18          0., 0., 0., 0., 0., 0.,
19          0., 0., 0., 0., 0., 0.,
20          0., 0., 0., 0., 0., 0.,
21          1555., 1834.4, 2217.2, 2592.9, 2850.3, 3107.6,
22          0., 0., 0., 0., 0., 0.,
23          0., 0., 0., 0., 0., 0.,
            ssratt
 1          0.00,0.00,0.00,0.00,0.00,0.00
 2           0.00,0.00,0.00,0.00,0.00,0.00,
 3          0.87,0.85,0.85,0.85,0.85,0.85,
 4           0.00,0.00,0.00,0.00,0.00,0.00,
 5           0.00,0.00,0.00,0.00,0.00,0.00,
 6
 7
```

TABLE B.3 *Continued.*

```
pmratt
0.00,0.00,0.00,0.00,0.00,0.00
 0.00,0.00,0.00,0.00,0.00,0.00,
 0.00,0.00,0.00,0.00,0.00,0.00,
 0.00,0.00,0.00,0.00,0.00,0.00,
 0.00,0.00,0.00,0.00,0.00,0.00,
```

TABLE B.4 Initial data of the East European submodel – Constant-SSR Scenario.

```
 CMEA in Europe (excl. USSR)
csa           133145.
csn           951487.
a2            0.045
a2min         0.
a2max         0.1
s2min         0.03
s2max         0.08
a3            0.135
a3min         0.075
a3max         0.25
s3min         0.01
s3max         0.04
a4min         0.6
a4max         0.85
exchr         0.9
shmlk         0.795
shbeef        0.9
shpltr        0.438
pyn1          0.5932
pyn2          0.1119
pyn3          1.322
pyn4          0.000
pinva         8860.
pinvn         65807.
depa          0.00
depn          0.00
rho           1.00
nprod         3
lmin          0.95,0.95,0.95,0.95,0.95,0.95,0.75,0.75,1.0,1.0,
lmax          1.05,1.05,1.05,1.05,1.05,1.05,1.25,1.25,1.1,1.1,
st1           4.,4.,4.,4.,4.,4.,4.,4.,4.,4.,
st2           4.,4.,4.,4.,4.,4.,4.,4.,4.,4.,
k11           9999,0,9999,0,40,40,9999,60,9999,80.
k12           0,9999,0,9999,40,40,60,9999,80,9999,
popt          106186.,110041.,113538.,116479.,119163.,121846.,
alt           0.045,0.045,0.045,0.045,0.045,0.045,
lftt          56162.,58442.,60931.,62379.,63878.,65376.,
lfat          17319.,15568.,13953.,12120.,10387.,8564.,
fertt         4141.7,5285.9,6746.4,8610.3,10475.7,12745.3,
balt          0.,0.,0.,0.,0.,0.,
   y, cint,   seed, waste, feed, pw,
 1            26528.3, 647.3, 1675.3, 1484.3, 11705.2, 159.,
 2            160.8, 31., 14.4, 13.1, 0.,230.,
 3            48713.6, 2139.2, 2242.1, 2322., 42819.4, 130.,
 4            4204.5, 0., 0., 14.1, 11.7, 208.,
 5            6497.5, 0., 571.1, 672.7, 2580.1, 1420.,
 6            0., 0., 0., 19.4, 0., 120.,
 7            0., 0., 0., 46.4, 0., 218.,
 8            9831.8, 0., 0., 634.7, 82.7, 210.,
 9            862.4, 93.9, 8.3, 6.4, 16.6, 760.,
10            0., 0., 0., 0.6, 0., 1421.,
11            0., 0., 0., 0., 0., 1586.,
12            0., 0., 0., 0., 0., 1200.,
13            33., 1683., 0., 0., 0., 420.,
14            583.2, 530.3, 0., 0., 0., 1130.,
15            0., 230., 0., 0., 0., 656.,
16            0., 0., 0., 0., 0., 91.,
17            2130.,103.6, 0., 16.6, 0., 1200.,
18            234.2, 0., 0., 0.9, 0., 1108.,
19            5402.4,114.9, 0., 66.7, 0., 1626.,
20            1217.6,3.2, 0., 13., 0., 1144.,
21            38988.1, 1555., 0., 901.7, 15698.6, 209.,
22            1564.9, 0., 73.4, 27.3, 0., 902.,
23            252600.,16.4, 0., 0., 0., 1000.,
```

TABLE B.4 *Continued.*

```
      hcons,pd, ssh, wsh, stfr
 1    13308.,183.9, 0.0627, 0.0484, 0.1,
 2    534.,390., 0.0898, 0.0222, 0.1,
 3    7025.9,166.8, 0.065, 0.0431, 0.1,
 4    4319.6,292., 0., 0.0034, 0.1,
 5    2450.,879., 0.085, 0.1035, 0.1,
 6    186.1,0., 0., 0.0916, 0.03,
 7    635.1,0., 0., 0.0669, 0.03,
 8    7702.4,225., 0., 0.0677, 0.03,
 9    888.4,1069., 0.02, 0.0051, 0.1,
10    123.7,0., 0., 0.0044, 0.1,
11    145.4,0., 0., 0., 0.1,
12    20.9,0., 0., 0., 0.1,
13    0.,946., 0., 0., 0.1,
14    0.,2847., 0., 0., 0.1,
15    0.,0., 0., 0., 0.03,
16    0.,0., 0., 0., 0.,
17    1741.1,1987., 0., 0.0074, 0.1,
18    207.,1987., 0., 0.0041, 0.1,
19    4202.2,1945., 0., 0.0129, 0.1,
20    1014.2,1890., 0., 0.0127, 0.1,
21    21155.1,218., 0., 0.0232, 0.03,
22    1336.1,1890., 0.0489, 0.0181, 0.03,
23    203750.,900., 0., 0., 0.025,
      pf1, pf2, pf3,
 1    4., 0., 0.6, 0., 6.8, 0.,
 2    0., 0., 0., 0., 0., 0.,
 3    15., 0., 2.,0., 23.2, 0.,
 4    0.001, 0., 0.0025, 0., 0., 0.,
 5    0.3, 0., 0.42, 0., 0., 0.,
 6    0., 0., 0., 0., 0., 0.,
 7    0., 0., 0., 0., 0., 0.,
 8    0.01, 0., 0.014, 0., 0., 0.,
 9    0., 0., 0.002, 0., 0.02, 0.,
10    0., 0., 0., 0., 0., 0.,
11    0., 0., 0., 0., 0., 0.,
12    0., 0., 0., 0., 0., 0.,
13    0., 0., 0., 0., 0., 0.,
14    0., 0., 0., 0., 0., 0.,
15    0., 0., 0., 0., 0., 0.,
16    0., 0., 0., 0., 0., 0.,
17    0., 0., 0., 0., 0., 0.,
18    0., 0., 0., 0., 0., 0.,
19    0., 0., 0., 0., 0., 0.,
20    0., 0., 0., 0., 0., 0.,
21    1.9, 0., 2.75, 0., 0., 0.,
22    0., 0., 0., 0., 0., 0.,
23    0., 0., 0., 0., 0., 0.,
      ifunc, neta, t1, t2,
 1    3, -0.22, 0., 0.,
 2    2, 0.2, 0., 0.,
 3    3, -0.15, 0., 0.,
 4    3, 0.25, -0.4, -0.1,
 5    2, 0.2, 0., 0.,
 6    2, 0.59, 8.3, -1.5,
 7    2, 0.82, 0.8, 0.8,
 8    2, 0.53, 0., 0.,
 9    3, 0.14, 0.1, 0.6,
10    2, 0.46, 0., 0.,
11    2, 0.88, 0., 0.,
12    2, 0.84, 0., 0.,
13    0, 0., 0., 0., 0.,
14    0, 0., 0., 0., 0.,
15    0, 0., 0., 0., 0.,
16    0, 0., 0., 0., 0.,
17    3, 0.5, 0., 0.,
```

TABLE B.4 *Continued.*

```
18          2, 0.69, -1., -1.,
19          3, 0.14, 0.1, -0.2,
20          3, 0.58, 0., 0.,
21          3, 0.2, 0., 0.,
22          2, 0.43, 0., 0.,
23          0, 0., 0., 0., 0.,
            ipr, ys, r3
 1          1, 26528.3, 2.52,
 2          2, 204.7, 2.5,
 3          3, 48973., 2.31,
 4          9, 1137.4, 1.,
 5          4, 4239.5, 1.1,
 6          5, 6497.5, 1.1,
 7          8, 9436.4, 1.1,
 8          12, 0., 1.1,
 9          13, 37.782, 0.47,
10          14, 584.73, 0.47,
11          0, 1701.1, 0.7,
12          0, 4847.6, 0.,
13          0, 319.1, 0.,
parameters of allocation model
01          166131.,0.373652e-01,0.,0.,0.167748,0.403351,0.136846,1.000000,
02          10630.2,0.202671e-01,0.,0.,0.138387,0.570318,0.191295,0.,
03          33651.3,0.169477e-01,0.,0.,0.251367,0.508062,0.140571,0.,
04          59232.9,0.471159e-01,0.,0.,0.122023,0.359098,0.571289d-01,0.,
05          32432.4,0.,0.,0.,0.377723,0.339563,0.461721d-01,0.,
06          4656.20,0.,0.,0.,0.388272,0.448845,0.628829d-01,0.,
07          64228.1,0.,0.,0.,0.348510,0.331318,0.584686d-01,0.,
08          0.,
09          13096.8,0.,0.,0.,0.296051,0.178949,0.250000d-01,0.,
10          10208.2,0.,0.,0.,0.465204,0.749028d-01,0.284267d-01,0.,
11          34318.9,0.401869e-01,0.,0.,0.250000,0.250000,0.,0.,
12          112852.,0.412845e-01,0.,0.,0.250000,0.250000,0.,0.,
13          7856.96,0.937392e-01,0.,0.,0.250000,0.250000,0.,0.,
            cint
 1          647.3, 702.9, 780., 887.1, 961.5, 1036.,
 2          3.1, 3.5, 4., 4.7, 5.1, 5.5,
 3          2139.2, 2371.4, 2693., 2962.9, 3332.4, 3701.9,
 4          0., 0., 0., 0., 0., 0.,
 5          0., 0., 0., 0., 0., 0.,
 6          0., 0., 0., 0., 0., 0.,
 7          0., 0., 0., 0., 0., 0.,
 8          0., 0., 0., 0., 0., 0.,
 9          93.9, 105.9, 118., 130.5, 135.3, 140.1,
10          0., 0., 0., 0., 0., 0.,
11          0., 0., 0., 0., 0., 0.,
12          0., 0., 0., 0., 0., 0.,
13          1683., 1740., 1812., 1849.8, 1933.2, 2016.6,
14          530.3, 559.6, 592.9, 619.3, 658.7, 698.,
15          230., 266., 290., 309., 335.5, 362.,
16          0., 0., 0., 0., 0., 0.,
17          0., 0., 0., 0., 0., 0.,
18          0., 0., 0., 0., 0., 0.,
19          0., 0., 0., 0., 0., 0.,
20          0., 0., 0., 0., 0., 0.,
21          1555., 1834.4, 2217.2, 2592.9, 2850.3, 3107.6,
22          0., 0., 0., 0., 0., 0.,
23          0., 0., 0., 0., 0., 0.,
            ssratt
 1          0.93,0.95,0.96,0.97,0.98,0.99,
 2          0.27,0.27,0.27,0.27,0.27,0.27,
 3          0.87,0.89,0.91,0.93,0.94,0.95,
 4          0.97,0.97,0.97,0.97,0.97,0.97,
 5          1.10,1.10,1.10,1.10,1.10,1.10,
 6
 7
```

TABLE B.4 *Continued.*

```
1.18,1.18,1.18,1.18,1.18,1.18,
0.90,0.91,0.92,0.93,0.94,0.95,




1.0,1.0,1.0,1.0,1.0,1.0,









pmratt
0.00,0.00,0.00,0.00,0.00,0.00
 0.00,0.00,0.00,0.00,0.00,0.00,
 0.00,0.00,0.00,0.00,0.00,0.00,
 0.00,0.00,0.00,0.00,0.00,0.00,
 0.00,0.00,0.00,0.00,0.00,0.00,
```

APPENDIX C Model Variants

I Model Variants for the CMEA Countries, Excluding the Soviet Union

(1) FAO/1 version
Standard model structure, using the forecasts of the FAO for agricultural population and labor capacity, and taking into account the pool of fixed assets calculated at gross value. Autarchy limitation is applied only for vegetables (SSR ⩾ 1).

(2) FAO/2 version
Similar to FAO/1, but fixed assets are considered at net value. Labor forecasts taken into account in the East European model are outlined in Table C.1.

TABLE C.1 Forecasts for the agricultural labor force in the East European model (in thousands).

Year	FAO forecast	Modified forecasts A	B	C
1975	17,319	17,319	17,319	17,319
1980	15,788	15,568	15,373	15,161
1985	14,347	13,953	13,428	13,003
1990	12,742	12,120	11,482	10,845
1995	11,324	10,387	9537	8687
2000	9905	8564	7592	6530

(3) A/1 version
Forecast for labor force according to version A, fixed assets at net value. No prescribed figure in the model about autarchy.

(4) A/2 version
The same as A/1, but SSR ⩾ 0.3 for rice and SSR ⩾ 1 for vegetables are prescribed.

(5) A/3 version
The same as A/2, but SSR ⩾ 0.95 also prescribed for corn.

(6) A/4 version
The same as A/1, but in addition the autarchy levels of 1974–76 are set as lower limits.

(7) A/I version
The same as A/2, but agriculture accounts for 20% instead of 13.5% of total investments.

(8) A/II version
The same as A/2, but agriculture accounts for 25% instead of 13.5% of total investments.

(9) A/III version
The same as A/2, but agriculture accounts for 10% instead of 13.5% of total investments.

(10) A/IV version
The same as A/2, but agriculture accounts for 7.5% instead of 13.5% of total investments.

(11) A/a version
The same as A/2, but instead of the remainder of the balance of payments an obligation of $500 million credit reimbursement is included.

(12) A/b version
The same as A/2, but instead of the remainder of the balance of payments an obligation of $1 billion credit reimbursement is included.

(13) A/c version
The same as A/2, but there is the allocation of $500 million new credits taken into account in the balance of payments.

(14) A/A version
The same as A/2, but the required annual rate of overall economic growth prescribed is 4.1% instead of 4.8%.

(15) A/T version
The same as A/2, but we assume that the specific coefficients of feed conversion will be improved by 10% by the year 2000.

(16) A/M version
The same as A/2, but the growth in the amount of fertilizer available is 20% smaller than in version A/2.

(17) B/1 version
This is a standard version of the model without autarchy limitations, using the agricultural labor force forecast C.

(18) B/2 version
The same as B/1, but there is a prescribed SSR $\geqslant 0.3$ for rice and SSR $\geqslant 1.0$ for vegetables.

(19) C/1 version
Includes forecast C for the agricultural labor force and the quantities of fixed assets taken into account in the FAO/1 version.

(20) C/2 version
The same as C/1, except that fixed assets are taken into account according to the FAO/2 version (net value).

(21) C/3 version
The same as C/1, but with a prescribed SSR $\geqslant$ 0.3 for rice and SSR $\geqslant$ 1.0 for vegetables.

(22) C/4 version
The same as C/1, but prescribed SSR $\geqslant$ 1.0 for pork and beef.

II Model Variants for the Soviet Union

(1) FAO/1 version
This is a standard model version making use of FAO forecasts for the labor force and not including autarchy limitations.

(2) FAO/2 version
The same as FAO/1, but with a prescribed SSR $\geqslant$ 1.0 for meat products.

(3) FAO/3 version
The same as FAO/2, but a 10% improvement in feed conversion is assumed for 2000.

(4) A/1 version
This is a standard version of the model assuming that a smaller number migrate from agriculture than forecast by the FAO. The agricultural labor force will amount to 10% of the total and will decrease linearly. Agriculture will account for 20% of total investments. SSR $\geqslant$ 1.0 is prescribed for meat products.

(5) A/2 version
The same as version A/1, but agriculture accounts for 15% instead of 20% of total investments.

(6) A/3 version
The same as version A/1, but agriculture accounts for 10% instead of 20% of total investments.

(7) A/4 version
The same as version A/1, but agriculture accounts for 7.5% instead of 20% of total investments.

(8) A/5 version
The same as version A/1, but agriculture accounts for 15% instead of 20% of total investments.

(9) A/6 version
The same as version A/1, but agriculture accounts for 30% instead of 20% of total investments.

(10) A/I version
The same as version A/1, but the required annual rate of economic growth is 3.5% instead of 4.2%.

(11) A/II version
The same as version A/2, but the required annual rate of economic growth is 3.5% instead of 4.2%.

(12) A/III version
The same as version A/2, but the required annual rate of economic growth is 2.5% instead of 4.2%.

(13) A/IV version
The same as version A/2, but the required annual rate of economic growth is 5% instead of 4.2%.

(14) A/a version
The same as version A/1, but with $1 billion new allocation of credits annually in the balance of payments.

(15) A/b version
The same as version A/1, but with $1 billion new allocation of credits annually.

(16) A/c version
The same as version A/1, but with $1.5 billion credit reimbursements annually.

(17) A/T version
The same as version A/1, but with a 10% improvement in feed conversion efficiency by the year 2000.

APPENDIX D The Scenarios

TABLE D.1 Constant-SSR Scenario.

IIASA - FAP agriculture programming system - basic data set

Normative Medium Constant SSR Scenario 2

sum for CMEA 1975

	food	industry	feed	seed	waste	stocks	demand	import	export	trade	output	ssr	price
whea	51157.3	647.3	43950.2	10854.9	12209.5	-1870.8	116948.4	8080.5	0.	-8080.5	108867.9	0.93	159.
rice	2646.4	31.0	0.	134.8	74.7	-26.9	2860.0	724.7	0.	-724.7	2135.3	0.75	230.
c.gr	18440.7	3657.3	110143.2	11955.8	13218.6	-2324.9	155090.7	11725.0	0.	-11725.0	143365.6	0.92	130.
suga	15684.7	0.	11.7	0.	14.1	-78.5	15632.0	3833.5	0.	-3833.5	11798.5	0.75	208.
vege	9461.5	0.	5450.1	1879.5	1547.7	-361.9	17976.9	129.4	0.	-129.4	17847.5	0.99	1420.
bana	207.8	0.	0.	0.	21.8	-0.3	229.3	229.3	0.	-229.3	0.	0.	120.
citr	1154.7	0.	0.	0.	99.5	-1.7	1252.5	1117.8	0.	-1117.8	134.7	0.11	218.
frui	22510.9	0.	82.7	0.	2109.1	-144.6	24558.1	0.	2194.7	2194.7	26752.8	1.09	210.
vego	3028.2	1005.6	123.6	301.0	102.4	-105.3	4455.5	0.	481.3	481.3	4936.8	1.11	760.
coco	295.9	0.	0.	0.	0.6	-1.5	295.0	295.0	0.	-295.0	0.	0.	1421.
coff	195.8	0.	0.	0.	0.	-1.0	194.8	194.8	0.	-194.8	0.	0.	1586.
teas	150.9	0.	0.	0.	0.	-0.8	150.1	63.7	0.	-63.7	86.4	0.58	1200.
cott	0.	7803.0	0.	0.	0.	-174.6	7628.4	0.	33.6	33.6	7662.0	1.00	420.
o.nf	0.	1271.3	0.	0.	0.	-11.0	1260.3	125.0	0.	-125.0	1135.4	0.90	1130.
rubb	0.	474.0	0.	0.	0.	-0.7	473.3	473.3	0.	-473.3	0.	0.	656.
fodd	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	91.
beef	8603.1	103.6	0.	0.	16.6	-69.8	8653.5	102.3	0.	-102.3	8551.2	0.99	1200.
mutt	1149.3	0.	0.	0.	0.9	-8.2	1142.0	0.	17.5	17.5	1159.5	1.02	1108.
pigm	8484.6	114.9	0.	0.	66.7	-223.4	8442.8	0.	2121.4	2121.4	10564.2	1.25	1626.
poul	2512.9	3.2	0.	0.	13.0	-31.3	2497.8	0.	172.8	172.8	2670.6	1.07	1144.
milk	70468.7	1555.0	53276.8	0.	4408.4	-249.0	129459.9	0.	47.5	47.5	129507.4	1.00	209.
eggs	4277.8	0.	0.	169.3	187.1	-19.2	4615.0	0.	105.8	105.8	4720.8	1.02	902.
cgrn	18440.7	3657.3	110143.2	11955.8	13218.6	-2324.9	155090.7	11725.0	0.	-11725.0	143365.6	0.92	
cere	72244.4	4335.6	154093.4	22945.5	25502.8	-4222.6	274899.1	20530.2	0.	-20530.2	254368.8	0.93	
meal	20749.9	221.7	0.	0.	97.2	-332.7	20736.1	102.3	2311.7	2209.4	22945.5	1.11	
cer$	11140.0	585.5	21306.7	3311.2	3676.9	-605.9	39414.4	2975.7	0.	-2975.7	36438.6	0.92	
fod$	21652.8	764.3	7850.4	2897.6	2743.6	-629.2	35279.6	1259.7	826.7	-433.0	34846.6	0.99	
nfd$	0.	5024.8	0.	0.	0.	-86.2	4938.6	451.7	14.1	-437.6	4501.0	0.91	
liv$	46854.4	639.8	11134.9	152.7	1234.4	-561.2	59454.9	122.8	3771.8	3649.0	63103.9	1.06	
tfo$	79647.2	1989.6	40292.0	6361.5	7654.9	-1796.3	134148.9	4358.2	4598.5	240.3	134389.1	1.00	
gvp$	79647.2	7014.3	40292.0	6361.5	7654.9	-1882.5	139087.4	4809.9	4612.6	-197.3	138890.1	1.00	
gdp	602717.0			tot pop	360566.0			lab for	0.	ag lab	0.		

notes

TABLE D.1 *Continued.*

IIASA - FAP agriculture programming system - basic data set

Normative Medium Constant SSR Scenario 2

sua for CMEA — 1980

	food	industry	feed	seed	waste	stocks	demand	import	export	trade	output	ssr	price
whea	53724.4	702.9	50062.5	12833.0	12804.8	153.4	130281.1	5067.7	0.	-5067.7	125213.4	0.96	159.
rice	2750.6	3.5	0.	140.6	75.4	3.2	2973.2	715.1	0.	-715.1	2258.2	0.76	230.
c.gr	19353.8	4078.0	128536.4	16698.6	15783.9	312.0	184762.6	10566.7	0.	-10566.7	174195.9	0.94	130.
suga	16225.6	0.	16.6	0.	15.2	16.4	16273.7	3327.6	0.	-3327.6	12946.1	0.80	208.
vege	9923.7	0.	6520.6	2128.8	1794.5	20.1	20387.6	0.	111.2	111.2	20498.9	1.01	1420.
bana	365.9	0.	0.	0.	34.2	1.1	401.2	401.2	0.	-401.2	0.	0.	120.
citr	1193.9	0.	0.	0.	92.1	0.8	1286.9	1152.2	0.	-1152.2	134.7	0.10	218.
frui	23389.2	0.	101.1	0.	2225.3	13.1	25728.7	0.	3079.6	3079.6	28808.3	1.12	210.
vego	3210.5	1128.0	157.9	306.1	5.5	8.4	4816.4	0.	331.9	331.9	5148.4	1.07	760.
coco	308.0	0.	0.	0.	0.6	0.5	309.1	309.1	0.	-309.1	0.	0.	1421.
coff	210.6	0.	0.	0.	0.	0.7	211.3	211.3	0.	-211.3	0.	0.	1586.
teas	157.1	0.	0.	0.	0.	0.2	157.4	59.3	0.	-59.3	98.1	0.62	1200.
cott	0.	8256.0	0.	0.	0.	9.5	8265.5	0.	1463.3	1463.3	9728.7	1.18	420.
o.nf	0.	1349.5	0.	0.	0.	1.6	1351.1	32.1	0.	-32.1	1319.0	0.98	1130.
rubb	0.	549.0	0.	0.	0.	0.4	549.5	549.5	0.	-549.5	0.	0.	656.
fodd	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	91.
beef	8949.8	0.	0.	0.	17.5	13.3	8980.5	0.	988.1	988.1	9968.6	1.11	1200.
mutt	1152.2	0.	0.	0.	1.1	0.8	1154.1	0.	195.0	195.0	1349.1	1.17	1108.
pigm	8705.7	0.	0.	0.	75.8	12.9	8794.4	0.	2755.6	2755.6	11550.1	1.31	1626.
poul	2551.8	0.	0.	0.	17.3	6.1	2575.3	0.	443.9	443.9	3019.2	1.17	1144.
milk	73909.1	1834.4	70457.1	0.	5144.7	214.9	151560.2	2145.3	0.	-2145.3	149414.9	0.99	209.
eggs	4451.5	0.	0.	193.6	211.6	2.2	4858.9	0.	490.6	490.6	5349.5	1.10	902.
cgrn	19353.8	4078.0	128536.4	16698.6	15783.9	312.0	184762.6	10566.7	0.	-10566.7	174195.9	0.94	
cere	75828.8	4784.4	178598.9	29672.2	28664.1	468.5	318017.0	16349.5	0.	-16349.5	301667.5	0.95	
meat	21359.5	0.	0.	0.	111.7	33.1	21504.4	0.	4382.7	4382.7	25887.1	1.20	
cer$	11690.8	642.7	24669.7	4243.6	4105.2	65.7	45417.7	2343.9	0.	-2343.9	43073.8	0.95	
fod$	22707.7	857.3	9400.5	3255.6	3044.7	40.2	39305.9	1144.9	1056.9	-87.9	39218.0	1.00	
nfd$	0.	5352.6	0.	0.	0.	6.1	5358.7	396.7	614.6	217.8	5576.5	1.04	
liv$	48553.4	383.4	14725.5	174.6	1431.4	91.7	65360.0	448.4	6832.9	6384.5	71744.6	1.10	
tfo$	82952.0	1883.4	48795.7	7673.8	8581.3	197.5	150083.6	3937.1	7889.8	3952.7	154036.3	1.03	
gvp$	82952.0	7236.0	48795.7	7673.8	8581.3	203.6	155442.3	4333.9	8504.4	4170.6	159612.9	1.03	
gdp	718250.9			tot pop	376707.0			lab for	193002.0	ag lab	38771.0		

notes

IIASA - FAP agriculture programming system - basic data set

Normative Medium Constant SSR Scenario 2

sua for CMEA 1985

	food	industry	feed	seed	waste	stocks	demand	import	export	trade	output	ssr	price
whea	55266.4	780.0	59808.4	14233.5	14216.3	271.6	144576.3	6086.7	0.	-6086.7	138489.6	0.96	159.
rice	3749.7	4.0	0.	196.4	103.6	87.0	4140.7	959.4	0.	-959.4	3181.3	0.77	230.
c.gr	19862.2	4663.0	153387.8	19427.6	18368.9	628.7	216338.2	13891.5	0.	-13891.5	202446.8	0.94	130.
suga	17009.9	0.	19.4	0.	16.0	12.0	17057.4	2741.3	0.	-2741.3	14316.1	0.84	208.
vege	10484.8	0.	7472.7	2245.3	1910.8	35.4	22149.0	425.0	0.	-425.0	21724.0	0.98	1420.
bana	526.3	0.	0.	0.	49.5	0.3	576.1	576.1	0.	-576.1	0.	0.	120.
citr	1289.1	0.	0.	0.	94.8	-0.9	1383.0	1248.3	0.	-1248.3	134.7	0.10	218.
frui	25623.1	0.	118.6	0.	2750.2	15.0	28506.9	0.	6942.3	6942.3	35449.3	1.24	210.
vego	3584.9	1250.5	184.3	339.3	6.2	20.2	5385.4	0.	288.7	288.7	5674.2	1.05	760.
coco	337.5	0.	0.	0.	0.7	0.6	338.8	338.8	0.	-338.8	0.	0.	1421.
coff	251.5	0.	0.	0.	0.	0.9	252.4	252.4	0.	-252.4	0.	0.	1586.
teas	169.8	0.	0.	0.	0.	0.3	170.1	46.6	0.	-46.6	123.5	0.73	1200.
cott	0.	8739.0	0.	0.	0.	10.1	8749.1	0.	1687.0	1687.0	10436.0	1.19	420.
o.nf	0.	1437.9	0.	0.	0.	1.8	1439.7	0.	264.7	264.7	1704.4	1.18	1130.
rubb	0.	599.0	0.	0.	0.	0.3	599.3	599.3	0.	-599.3	0.	0.	656.
fodd	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	91.
beef	9241.4	0.	0.	0.	20.5	-24.2	9237.7	0.	2809.4	2809.4	12047.1	1.30	1200.
mutt	1136.8	0.	0.	0.	1.3	-5.3	1132.8	0.	500.5	500.5	1633.2	1.44	1108.
pigm	8649.1	0.	0.	0.	89.0	-55.9	8682.1	0.	4455.3	4455.3	13137.4	1.51	1626.
poul	2850.4	0.	0.	0.	20.7	6.6	2877.7	0.	754.6	754.6	3632.3	1.26	1144.
milk	78034.4	2217.2	81061.8	0.	6198.5	110.0	167621.9	0.	12583.1	12583.1	180205.0	1.08	209.
eggs	4817.9	0.	0.	232.9	255.6	2.4	5308.8	0.	1137.4	1137.4	6446.2	1.21	902.
cgrn	19862.2	4663.0	153387.8	19427.6	18368.9	628.7	216338.2	13891.5	0.	-13891.5	202446.8	0.94	
cere	78878.4	5447.0	213196.3	33857.4	32688.8	987.3	365055.3	20937.6	0.	-20937.6	344117.7	0.94	
meat	21877.6	0.	0.	0.	131.4	-78.7	21930.3	0.	8519.7	8519.7	30450.0	1.39	
cer$	12231.9	731.1	29450.0	4833.9	4672.2	144.9	52064.0	2994.3	0.	-2994.3	49069.6	0.94	
fod$	24420.2	950.4	10776.3	3446.1	3323.2	71.2	42987.4	1882.3	1677.3	-205.0	42782.4	1.00	
nfd$	0.	5688.2	0.	0.	0.	6.5	5694.6	393.1	1007.6	614.5	6309.1	1.11	
liv$	50328.4	463.4	16941.9	210.1	1720.3	-93.0	69571.1	0.	15689.1	15689.1	85260.2	1.23	
tfo$	86980.5	2144.9	57168.1	8490.1	9715.8	123.1	164622.5	4876.7	17366.4	12489.7	177112.2	1.08	
gvp$	86980.5	7833.1	57168.1	8490.1	9715.8	129.5	170317.1	5269.8	18374.0	13104.2	183421.3	1.08	

gdp 935067.6 tot pop 393096.0 lab for 199843.0 ag lab 34368.0

notes

TABLE D.1 *Continued.*

IIASA - FAP agriculture programming system - basic data set

Normative Medium Constant SSR Scenario 2

sum for CMEA 1990

	food	industry	feed	seed	waste	stocks	demand	import	export	trade	output	ssr	price
whea	55204.2	887.1	66902.0	15620.0	15610.5	136.7	154360.4	2635.4	0.	-2635.4	151725.0	0.98	159.
rice	4470.0	4.7	0.	236.2	123.9	14.9	4849.6	1013.1	0.	-1013.1	3836.5	0.79	230.
c.gr	19677.1	5269.1	171743.1	22547.5	21228.6	353.5	240818.9	6324.5	0.	-6324.5	234494.4	0.97	130.
suga	18200.5	0.	21.8	0.	17.1	23.8	18263.1	2154.3	0.	-2154.3	16108.9	0.88	208.
vege	11038.7	0.	8199.7	2485.0	2119.3	25.3	23868.0	0.	200.5	200.5	24068.5	1.01	1420.
bana	564.1	0.	0.	0.	53.1	0.2	617.4	617.4	0.	-617.4	0.	0.	120.
citr	1534.2	0.	0.	0.	112.1	1.5	1647.8	1513.1	0.	-1513.1	134.7	0.08	218.
frui	29446.7	0.	133.1	0.	3183.6	25.2	32788.5	0.	8243.2	8243.2	41031.7	1.25	210.
vego	3953.1	1384.9	201.6	376.0	6.8	11.0	5933.3	0.	325.1	325.1	6258.4	1.05	760.
coco	385.9	0.	0.	0.	0.8	1.0	387.6	387.6	0.	-387.6	0.	0.	1421.
coff	305.8	0.	0.	0.	0.	1.1	306.9	306.9	0.	-306.9	0.	0.	1586.
teas	190.3	0.	0.	0.	0.	0.4	190.7	47.8	0.	-47.8	142.9	0.75	1200.
cott	0.	9164.1	0.	0.	0.	8.9	9173.0	0.	1847.5	1847.5	11020.5	1.20	420.
o.nf	0.	1524.2	0.	0.	0.	1.8	1526.0	0.	613.4	613.4	2139.4	1.40	1130.
rubb	0.	639.0	0.	0.	0.	0.2	639.2	639.2	0.	-639.2	0.	0.	656.
fodd	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	91.
beef	10014.9	0.	0.	0.	22.9	16.1	10053.9	0.	3549.6	3549.6	13603.5	1.35	1200.
mutt	1232.8	0.	0.	0.	1.4	2.0	1236.3	0.	608.7	608.7	1845.0	1.49	1108.
pigm	9533.2	0.	0.	0.	99.9	19.5	9652.6	0.	4704.6	4704.6	14357.2	1.49	1626.
poul	3543.6	0.	0.	0.	22.9	15.2	3581.7	0.	442.7	442.7	4024.4	1.12	1144.
milk	81882.6	2592.9	88902.5	0.	7002.0	73.6	180453.5	0.	22944.1	22944.1	203397.6	1.13	209.
eggs	5405.6	0.	0.	258.0	283.5	3.8	5951.0	0.	1194.1	1194.1	7145.0	1.20	902.
cgrn	19677.1	5269.1	171743.1	22547.5	21228.6	353.5	240818.9	6324.5	0.	-6324.5	234494.4	0.97	
cere	79351.2	6160.9	238645.1	38403.6	36963.0	505.1	400028.9	9973.0	0.	-9973.0	390055.9	0.98	
meat	24324.5	0.	0.	0.	147.1	52.9	24524.5	0.	9305.6	9305.6	33830.1	1.38	
cer$	12363.6	827.1	32964.0	5469.1	5270.3	71.1	56965.2	1474.2	0.	-1474.2	55490.9	0.97	
fod$	26526.9	1052.5	11824.8	3814.5	3714.9	53.6	46987.2	1498.9	2262.9	764.0	47751.2	1.02	
nfd$	0.	5990.5	0.	0.	0.	5.9	5996.4	419.3	1469.1	1049.8	7046.2	1.18	
liv$	54927.9	541.9	18580.6	232.8	1936.8	89.6	76309.6	0.	18962.4	18962.4	95272.0	1.25	
tfo$	93818.4	2421.6	63369.4	9516.3	10922.0	214.3	180262.0	2973.1	21225.3	18252.2	198514.2	1.10	
gvp$	93818.4	8412.0	63369.4	9516.3	10922.0	220.2	186258.4	3392.5	22694.4	19302.0	205560.3	1.10	
gdp	1197257.1			tot pop	408116.0			lab for	205573.0	ag lab	29746.0		

notes:

IIASA – FAP agriculture programming system – basic data set

Normative Medium Constant SSR Scenario 2

sua for CMEA 1995

	food	industry	feed	seed	waste	stocks	demand	import	export	trade	output	ssr	price
whea	55179.5	961.5	72470.6	16507.8	16494.0	94.3	161707.8	1256.8	0.	-1256.8	160451.0	0.99	159.
rice	5198.3	5.1	0.	276.4	144.5	14.7	5639.0	1138.1	0.	-1138.1	4500.9	0.80	230.
o.gr	19419.3	5853.1	186224.3	24301.1	22813.9	241.1	258852.8	5471.5	0.	-5471.5	253381.2	0.98	130.
suga	19214.3	0.	24.1	0.	18.0	19.3	19275.7	1434.4	0.	-1434.4	17841.3	0.93	208.
vege	11527.3	0.	8756.9	2652.6	2271.2	19.1	25227.1	0.	516.0	516.0	25743.0	1.02	1420.
bana	598.5	0.	0.	0.	56.3	0.2	655.0	655.0	0.	-655.0	0.	0.	120.
citr	1769.3	0.	0.	0.	128.6	1.3	1899.3	1764.6	0.	-1764.6	134.7	0.07	218.
frui	33141.6	0.	146.7	0.	3472.4	22.5	36783.3	0.	8069.5	8069.5	44852.8	1.22	210.
vego	4295.1	1501.8	225.7	410.2	7.2	9.9	6449.9	0.	369.3	369.3	6819.1	1.06	760.
coco	432.6	0.	0.	0.	0.8	0.9	434.3	434.3	0.	-434.3	0.	0.	1421.
coff	358.4	0.	0.	0.	0.	1.0	359.5	359.5	0.	-359.5	0.	0.	1586.
teas	209.7	0.	0.	0.	0.	0.4	210.1	55.1	0.	-55.1	154.9	0.74	1200.
cott	0.	9606.9	0.	0.	0.	9.2	9616.1	0.	1946.9	1946.9	11563.1	1.20	420.
o.nf	0.	1651.7	0.	0.	0.	2.7	1654.4	0.	956.8	956.8	2611.2	1.58	1130.
rubb	0.	693.5	0.	0.	0.	0.3	693.8	693.8	0.	-693.8	0.	0.	656.
fodd	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	91.
beef	10644.6	0.	0.	0.	25.3	12.0	10681.9	0.	3893.3	3893.3	14575.1	1.36	1200.
mutt	1315.2	0.	0.	0.	1.6	1.6	1318.3	0.	655.4	655.4	1973.7	1.50	1108.
pigm	10347.1	0.	0.	0.	110.1	15.7	10473.0	0.	4862.1	4862.1	15335.1	1.46	1626.
poul	4208.5	0.	0.	0.	24.4	13.2	4246.1	0.	301.2	301.2	4547.2	1.07	1144.
milk	85087.9	2850.3	94149.3	0.	7490.4	43.6	189621.5	0.	28691.8	28691.8	218313.4	1.15	209.
eggs	5967.9	0.	0.	291.9	330.2	3.4	6593.4	0.	1582.6	1582.6	8176.0	1.24	902.
cgrn	19419.3	5853.1	186224.3	24301.1	22813.9	241.1	258852.8	5471.5	0.	-5471.5	253381.2	0.98	
cere	79797.1	6819.7	258694.9	41085.4	39452.5	350.1	426199.6	7866.4	0.	-7866.4	418333.2	0.98	
meat	26515.3	0.	0.	0.	161.4	42.6	26719.3	0.	9711.9	9711.9	36431.2	1.36	
cer$	12493.7	915.0	35732.0	5847.5	5621.6	49.7	60659.4	1172.9	0.	-1172.9	59486.5	0.98	
fod$	28485.0	1141.4	12637.1	4078.5	3995.8	43.0	50380.8	1716.7	2707.9	991.2	51372.0	1.02	
nfd$	0.	6356.3	0.	0.	0.	7.1	6363.4	455.2	1899.0	1443.8	7807.2	1.23	
liv$	59036.1	595.7	19677.2	263.3	2102.3	69.1	81743.7	0.	21072.5	21072.5	102816.1	1.26	
tfo$	100014.8	2652.0	68046.3	10189.2	11719.7	161.8	192783.8	2889.6	23780.4	20890.8	213674.6	1.11	
gvp$	100014.8	9008.3	68046.3	10189.2	11719.7	168.9	199147.2	3344.7	25679.3	22334.6	221481.8	1.11	
gdp	1486149.9			tot pop	420890.0			lab for	210623.0	ag lab	25225.0		

notes

TABLE D.1 *Continued.*

IIASA - FAP agriculture programming system - basic data set

Normative Medium Constant SSR Scenario 2

sua for CMEA — 2000

	food	industry	feed	seed	waste	stocks	demand	import	export	trade	output	ssr	price
whea	55598.1	1036.0	75116.5	17110.9	17089.5	38.2	165989.2	0.	519.1	519.1	166508.3	1.00	159.
rice	5942.2	5.5	0.	317.7	165.5	15.0	6445.9	1264.1	0.	-1264.1	5181.9	0.80	230.
c.gr	19287.4	6437.2	193106.7	25435.0	23780.7	75.9	268123.0	2163.5	0.	-2163.5	265959.5	0.99	130.
suga	20122.4	0.	25.5	0.	18.7	17.5	20184.1	915.6	0.	-915.6	19268.5	0.95	208.
vege	12004.1	0.	9002.7	2747.2	2366.1	12.0	26132.1	0.	608.5	608.5	26740.5	1.02	1420.
bana	629.1	0.	0.	0.	59.2	0.2	688.4	688.4	0.	-688.4	0.	0.	120.
citr	1979.1	0.	0.	0.	143.0	1.2	2123.3	1988.6	0.	-1988.6	134.7	0.06	218.
frui	36542.8	0.	155.5	0.	3591.2	20.8	40310.3	0.	6287.5	6287.5	46597.8	1.16	210.
vego	4615.1	1618.8	249.6	443.1	7.7	9.4	6943.8	0.	417.2	417.2	7361.0	1.06	760.
coco	475.6	0.	0.	0.	0.9	0.8	477.4	477.4	0.	-477.4	0.	0.	1421.
coff	407.0	0.	0.	0.	0.	0.9	408.0	408.0	0.	-408.0	0.	0.	1586.
teas	227.7	0.	0.	0.	0.	0.3	228.0	70.6	0.	-70.6	157.4	0.69	1200.
cott	0.	10049.7	0.	0.	0.	9.2	10058.9	0.	2045.7	2045.7	12104.6	1.20	420.
o.nf	0.	1779.2	0.	0.	0.	2.7	1781.9	0.	1322.6	1322.6	3104.5	1.74	1130.
rubb	0.	748.0	0.	0.	0.	0.3	748.3	748.3	0.	-748.3	0.	0.	656.
fodd	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	91.
beef	11148.1	0.	0.	0.	26.8	9.7	11184.6	0.	3560.0	3560.0	14744.5	1.32	1200.
mutt	1385.0	0.	0.	0.	1.6	1.4	1388.1	0.	603.4	603.4	1991.4	1.43	1108.
pigm	11017.3	0.	0.	0.	116.7	13.0	11147.0	0.	4669.5	4669.5	15816.4	1.42	1626.
poul	4793.7	0.	0.	0.	24.8	11.7	4830.1	0.	212.2	212.2	5042.4	1.04	1144.
milk	88120.2	3107.6	95616.3	0.	7557.3	19.4	194420.8	0.	27099.3	27099.3	221520.1	1.14	209.
eggs	6488.7	0.	0.	324.1	381.5	3.2	7197.5	0.	2029.1	2029.1	9226.6	1.28	902.
cgrn	19287.4	6437.2	193106.7	25435.0	23780.7	75.9	268123.0	2163.5	0.	-2163.5	265959.5	0.99	
cere	80827.8	7478.7	268223.2	42863.7	41035.7	129.1	440558.2	3427.6	519.1	-2908.5	437649.7	0.99	
meat	28344.1	0.	0.	0.	169.9	35.8	28549.7	0.	9045.0	9045.0	37594.8	1.32	
cer$	12714.2	1002.8	37047.4	6100.3	5846.8	19.4	62730.8	572.0	82.5	-489.5	62241.4	0.99	
fod$	30328.9	1230.3	13006.2	4237.8	4159.5	31.9	52994.5	1926.3	2501.5	575.2	53569.7	1.01	
nfd$	0.	6722.1	0.	0.	0.	7.1	6729.2	490.9	2353.7	1862.8	8592.0	1.28	
liv$	62580.3	649.5	19983.8	292.3	2175.6	54.6	85736.2	0.	20269.8	20269.8	106006.0	1.24	
tfo$	105623.4	2882.6	70037.4	10630.4	12181.9	105.9	201461.5	2498.3	22853.8	20355.6	221817.1	1.10	
gvp$	105623.4	9604.7	70037.4	10630.4	12181.9	113.0	208190.7	2989.2	25207.6	22218.4	230409.1	1.11	

gdp 1799781.5 tot pop 433663.0 lab for 215672.0 ag lab 20614.0

notes

TABLE D.2 Free Trade Scenario (note: in our computations this scenario was called a Normative Medium Scenario).

IIASA - FAP agriculture programming system - basic data set

Normative Medium Scenario

sua for CMEA 1975

	food	industry	feed	seed	waste	stocks	demand	import	export	trade	output	ssr	price
whea	51157.3	647.3	43950.2	10854.9	12209.5	-1870.8	116948.4	8080.5	0.	-8080.5	108867.9	0.93	159.
rice	2646.4	31.0	0.	134.8	74.7	-26.9	2860.0	724.7	0.	-724.7	2135.3	0.75	230.
c.gr	18440.7	3657.3	110143.2	11955.8	13218.6	-2324.9	155090.7	11725.0	0.	-11725.0	143365.6	0.92	130.
suga	15684.7	0.	11.7	0.	14.1	-78.5	15632.0	3833.5	0.	-3833.5	11798.5	0.75	208.
vege	9461.5	0.	5450.1	1879.5	1547.7	-361.9	17976.9	129.4	0.	-129.4	17847.5	0.99	1420.
bana	207.8	0.	0.	0.	21.8	-0.3	229.3	229.3	0.	-229.3	0.	0.	120.
citr	1154.7	0.	0.	0.	99.5	-1.7	1252.5	1117.8	0.	-1117.8	134.7	0.11	218.
frui	22510.9	0.	82.7	0.	2109.1	-144.6	24558.1	0.	2194.7	2194.7	26752.8	1.09	210.
vego	3028.2	1005.6	123.6	301.0	102.4	-105.3	4455.5	0.	481.3	481.3	4936.8	1.11	760.
coco	295.9	0.	0.	0.	0.6	-1.5	295.0	295.0	0.	-295.0	0.	0.	1421.
coff	195.8	0.	0.	0.	0.	-1.0	194.8	194.8	0.	-194.8	0.	0.	1586.
teas	150.9	0.	0.	0.	0.	-0.8	150.1	63.7	0.	-63.7	86.4	0.58	1200.
cott	0.	7803.0	0.	0.	0.	-174.6	7628.4	0.	33.6	33.6	7662.0	1.00	420.
o.nf	0.	1271.3	0.	0.	0.	-11.0	1260.3	125.0	0.	-125.0	1135.4	0.90	1130.
rubb	0.	474.0	0.	0.	0.	-0.7	473.3	473.3	0.	-473.3	0.	0.	656.
fodd	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	91.
beef	8603.1	103.6	0.	0.	16.6	-69.8	8653.5	102.3	0.	-102.3	8551.2	0.99	1200.
mutt	1149.3	0.	0.	0.	0.9	-8.2	1142.0	0.	17.5	17.5	1159.5	1.02	1108.
pigm	8484.6	114.9	0.	0.	66.7	-223.4	8442.8	0.	2121.4	2121.4	10564.2	1.25	1626.
poul	2512.9	3.2	0.	0.	13.0	-31.3	2497.8	0.	172.8	172.8	2670.6	1.07	1144.
milk	70468.7	1555.0	53276.8	0.	4408.4	-249.0	129459.9	0.	47.5	47.5	129507.4	1.00	209.
eggs	4277.8	0.	0.	169.3	187.1	-19.2	4615.0	0.	105.8	105.8	4720.8	1.02	902.
cgrn	18440.7	3657.3	110143.2	11955.8	13218.6	-2324.9	155090.7	11725.0	0.	-11725.0	143365.6	0.92	
cere	72244.4	4335.6	154093.4	22945.5	25502.8	-4222.6	274899.1	20530.2	0.	-20530.2	254368.8	0.93	
meat	20749.9	221.7	0.	0.	97.2	-332.7	20736.1	102.3	2311.7	2209.4	22945.5	1.11	
cer$	11140.0	585.5	21306.7	3311.2	3676.9	-605.9	39414.4	2975.7	0.	-2975.7	36438.6	0.92	
fod$	21652.8	764.3	7850.4	2897.6	2743.6	-629.2	35279.6	1259.7	826.7	-433.0	34846.6	0.99	
nfd$	0.	5024.8	0.	0.	0.	-86.2	4938.6	451.7	14.1	-437.6	4501.0	0.91	
liv$	46854.4	639.8	11134.9	152.7	1234.4	-561.2	59454.9	122.8	3771.8	3649.0	63103.9	1.06	
tfo$	79647.2	1989.6	40292.0	6361.5	7654.9	-1796.3	134148.9	4358.2	4598.5	240.3	134389.1	1.00	
gvp$	79647.2	7014.3	40292.0	6361.5	7654.9	-1882.5	139087.4	4809.9	4612.6	-197.3	138890.1	1.00	
gdp	602717.0			tot pop	360566.0			lab for	0.	ag lab	0.		

notes

TABLE D.2 *Continued.*

IIASA - FAP agriculture programming system - basic data set

Normative Medium Scenario

sum for CMEA

1980

	food	industry	feed	seed	waste	stocks	demand	import	export	trade	output	ssr	price
whea	53822.7	702.9	51372.4	12595.7	12547.4	198.4	131239.5	7776.3	0.	-7776.3	123463.2	0.94	159.
rice	2745.8	3.5	0.	135.6	75.1	3.0	2963.1	764.2	0.	-764.2	2198.8	0.74	230.
c.gr	19390.7	4078.0	132521.7	16620.2	15888.8	449.3	188948.7	15868.6	0.	-15868.6	173080.1	0.92	130.
suga	16201.6	0.	17.5	0.	15.2	15.8	16250.2	3922.6	0.	-3922.6	12327.6	0.76	208.
vege	9918.8	0.	6733.1	2019.6	1661.7	27.2	20360.6	1156.3	0.	-1156.3	19204.2	0.94	1420.
bana	364.7	0.	0.	0.	34.1	1.1	399.9	399.9	0.	-399.9	0.	0.	120.
citr	1185.6	0.	0.	0.	91.5	0.8	1277.9	1143.2	0.	-1143.2	134.7	0.11	218.
frui	23286.9	0.	107.0	0.	2232.1	12.3	25638.3	0.	3170.3	3170.3	28808.6	1.12	210.
vego	3203.9	1128.0	160.2	281.5	5.9	8.3	4787.9	0.	66.6	66.6	4854.5	1.01	760.
coco	306.7	0.	0.	0.	0.6	0.5	307.8	307.8	0.	-307.8	0.	0.	1421.
coff	209.0	0.	0.	0.	0.	0.7	209.7	209.7	0.	-209.7	0.	0.	1586.
teas	156.7	0.	0.	0.	0.	0.2	156.9	57.0	0.	-57.0	99.9	0.64	1200.
cott	0.	8256.0	0.	0.	0.	9.5	8265.5	0.	1534.6	1534.6	9800.0	1.19	420.
o.nf	0.	1349.5	0.	0.	0.	1.6	1351.1	0.	22.1	22.1	1373.2	1.02	1130.
rubb	0.	549.0	0.	0.	0.	0.4	549.5	549.5	0.	-549.5	0.	0.	656.
fodd	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	91.
beef	8924.6	0.	0.	0.	18.5	12.6	8955.8	0.	1277.5	1277.5	10233.3	1.14	1200.
mutt	1149.1	0.	0.	0.	1.1	0.7	1151.0	0.	231.6	231.6	1382.6	1.20	1108.
pigm	8669.5	0.	0.	0.	80.3	11.9	8761.7	0.	3181.2	3181.2	11942.9	1.36	1626.
poul	2529.2	0.	0.	0.	18.3	5.5	2553.0	0.	559.6	559.6	3112.6	1.22	1144.
milk	73869.2	1834.4	72193.1	0.	5246.9	232.8	153376.3	0.	306.4	306.4	153682.7	1.00	209.
eggs	4437.0	0.	0.	199.5	215.0	2.0	4853.6	0.	628.6	628.6	5482.2	1.13	902.
cgrn	19390.7	4078.0	132521.7	16620.2	15888.8	449.3	188948.7	15868.6	0.	-15868.6	173080.1	0.92	
cere	75959.2	4784.4	183894.1	29351.5	28511.3	650.7	323151.3	24409.1	0.	-24409.1	298742.2	0.92	
meal	21272.4	0.	0.	0.	118.2	30.8	21421.5	0.	5249.9	5249.9	26671.4	1.25	
cer$	11710.1	642.7	25396.0	4194.5	4077.9	90.7	46111.9	3475.1	0.	-3475.1	42636.8	0.92	
fod$	22667.5	857.3	9705.3	3081.8	2857.8	49.9	39219.7	2777.5	716.4	-2061.2	37158.5	0.95	
nfd$	0.	5352.6	0.	0.	0.	6.1	5358.7	360.4	669.5	309.1	5667.8	1.06	
liv$	48413.7	383.4	15088.4	179.9	1465.5	92.2	65623.0	0.	8233.5	8233.5	73856.5	1.13	
tfo$	82791.3	1883.4	50189.7	7456.3	8401.1	232.8	150954.6	6252.7	8949.9	2697.2	153651.8	1.02	
gvp$	82791.3	7236.0	50189.7	7456.3	8401.1	238.8	156313.3	6613.1	9619.4	3006.3	159319.5	1.02	
gdp	718309.5			tot pop	376707.0			lab for	193002.0	ag lab	38771.0		

notes

IIASA - FAP agriculture programming system - basic data set

Normative Medium Scenario

sua for CMEA 1985

	food	industry	feed	seed	waste	stocks	demand	import	export	trade	output	ssr	price
whea	55465.4	780.0	61276.3	13911.9	13858.7	277.0	145569.3	9208.1	0.	-9208.1	136361.2	0.94	159.
rice	3739.0	4.0	0.	128.8	101.6	86.9	4060.3	1956.8	0.	-1956.8	2103.4	0.52	230.
c.gr	19939.1	4663.0	157810.5	19197.5	18341.9	633.7	220585.7	20699.6	0.	-20699.6	199886.1	0.91	130.
suga	16966.5	0.	20.5	0.	17.4	12.4	17016.8	3657.9	0.	-3657.9	13358.9	0.79	208.
vege	10479.4	0.	7702.8	2130.2	1776.8	34.5	22123.7	1761.4	0.	-1761.4	20362.2	0.92	1420.
bana	524.8	0.	0.	0.	49.4	0.3	574.5	574.5	0.	-574.5	0.	0.	120.
citr	1275.7	0.	0.	0.	93.7	-0.9	1368.5	1233.8	0.	-1233.8	134.7	0.10	218.
frui	25422.7	0.	124.9	0.	2732.8	15.3	28295.7	0.	6769.5	6769.5	35065.2	1.24	210.
vego	3569.6	1250.5	186.9	311.0	6.3	20.5	5344.8	21.9	0.	-21.9	5322.9	1.00	760.
coco	335.1	0.	0.	0.	0.7	0.6	336.4	336.4	0.	-336.4	0.	0.	1421.
coff	249.3	0.	0.	0.	0.	1.0	250.3	250.3	0.	-250.3	0.	0.	1586.
teas	168.9	0.	0.	0.	0.	0.3	169.1	43.1	0.	-43.1	126.0	0.74	1200.
cott	0.	8739.0	0.	0.	0.	10.1	8749.1	0.	3812.5	3812.5	12561.6	1.44	420.
o.nf	0.	1437.9	0.	0.	0.	1.8	1439.7	0.	331.8	331.8	1771.5	1.23	1130.
rubb	0.	599.0	0.	0.	0.	0.3	599.3	599.3	0.	-599.3	0.	0.	656.
fodd	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	91.
beef	9193.5	0.	0.	0.	21.5	-23.9	9191.1	0.	3155.6	3155.6	12346.8	1.34	1200.
mutt	1131.4	0.	0.	0.	1.3	-5.2	1127.5	0.	543.9	543.9	1671.4	1.48	1108.
pigm	8566.9	0.	0.	0.	93.7	-56.6	8604.1	0.	4956.3	4956.3	13560.4	1.58	1626.
poul	2802.0	0.	0.	0.	21.8	6.4	2830.2	0.	905.7	905.7	3735.9	1.32	1144.
milk	77998.4	2217.2	82965.6	0.	6343.1	113.6	169638.0	0.	15367.6	15367.6	185005.6	1.09	209.
eggs	4789.5	0.	0.	239.4	259.5	2.5	5290.9	0.	1303.5	1303.5	6594.4	1.25	902.
egrn	19939.1	4663.0	157810.5	19197.5	18341.9	633.7	220585.7	20699.6	0.	-20699.6	199886.1	0.91	
cere	79143.5	5447.0	219086.7	33238.2	32302.1	997.6	370215.2	31864.5	0.	-31864.5	338350.7	0.91	
meal	21693.9	0.	0.	0.	138.4	-79.3	21753.0	0.	9561.5	9561.5	31314.5	1.44	
cer$	12271.1	731.1	30258.3	4737.3	4611.3	146.4	52755.5	4605.1	0.	-4605.1	48150.4	0.91	
fod$	24347.8	950.4	11106.3	3261.2	3129.0	70.3	42865.0	3782.6	1421.6	-2361.0	40504.0	0.94	
nfd$	0.	5688.2	0.	0.	0.	6.5	5694.6	393.1	1976.2	1583.0	7277.6	1.28	
liv$	50042.9	463.4	17339.8	216.0	1764.4	-93.2	69733.4	0.	17872.1	17872.1	87605.5	1.26	
tfo$	86661.8	2144.9	58704.4	8214.5	9504.8	123.6	165353.9	8387.7	19293.7	10906.0	176259.9	1.07	
gvp$	86661.8	7833.1	58704.4	8214.5	9504.8	130.0	171048.5	8780.8	21269.8	12489.0	183537.5	1.07	
gdp	938663.1			tot pop	393096.0			lab for	199843.0	ag lab	34368.0		

notes

TABLE D.2 *Continued.*

IIASA - FAP agriculture programming system - basic data set

Normative Medium Scenario

sua for CMEA 1990

	food	industry	feed	seed	waste	stocks	demand	import	export	trade	output	ssr	price
whea	55146.4	887.1	68891.4	15114.8	15063.5	150.3	155253.4	7284.2	0.	-7284.2	147969.3	0.95	159.
rice	4473.8	4.7	0.	105.0	120.6	14.9	4719.0	2996.8	0.	-2996.8	1722.2	0.36	230.
c.gr	19650.7	5269.1	177917.5	22062.1	21098.9	400.1	246398.4	17349.7	0.	-17349.7	229048.8	0.93	130.
suga	18214.2	0.	23.4	0.	19.9	24.1	18281.6	3571.5	0.	-3571.5	14710.1	0.80	208.
vege	11041.1	0.	8531.7	2345.8	1969.2	27.5	23915.3	1502.4	0.	-1502.4	22412.8	0.94	1420.
bana	564.8	0.	0.	0.	53.1	0.2	618.2	618.2	0.	-618.2	0.	0.	120.
citr	1539.4	0.	0.	0.	112.5	1.5	1653.5	1518.8	0.	-1518.8	134.7	0.08	218.
frui	29520.5	0.	142.7	0.	3129.2	25.2	32817.6	0.	7256.6	7256.6	40074.2	1.22	210.
vego	3958.0	1384.9	204.9	345.0	6.8	11.0	5910.6	76.8	0.	-76.8	5833.8	0.99	760.
coco	386.8	0.	0.	0.	0.8	1.0	388.5	388.5	0.	-388.5	0.	0.	1421.
coff	306.7	0.	0.	0.	0.	1.1	307.8	307.8	0.	-307.8	0.	0.	1586.
teas	190.6	0.	0.	0.	0.	0.4	191.0	44.9	0.	-44.9	146.1	0.76	1200.
cott	0.	9164.1	0.	0.	0.	8.9	9173.0	0.	6264.1	6264.1	15437.1	1.68	420.
o.nf	0.	1524.2	0.	0.	0.	1.8	1526.0	0.	720.7	720.7	2246.7	1.47	1130.
rubb	0.	639.0	0.	0.	0.	0.2	639.2	639.2	0.	-639.2	0.	0.	656.
fodd	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	91.
beef	10030.1	0.	0.	0.	24.6	16.1	10070.8	0.	3930.8	3930.8	14001.6	1.39	1200.
mutt	1234.7	0.	0.	0.	1.5	2.0	1238.2	0.	656.5	656.5	1894.8	1.53	1108.
pigm	9561.6	0.	0.	0.	107.1	19.6	9688.3	0.	5285.9	5285.9	14974.1	1.55	1626.
poul	3560.5	0.	0.	0.	24.5	15.2	3600.3	0.	572.7	572.7	4173.0	1.16	1144.
milk	81895.1	2592.9	91519.2	0.	7190.7	79.5	183277.5	0.	26608.4	26608.4	209885.9	1.15	209.
eggs	5416.0	0.	0.	267.4	288.6	3.8	5975.9	0.	1377.0	1377.0	7352.9	1.23	902.
cgrn	19650.7	5269.1	177917.5	22062.1	21098.9	400.1	246398.4	17349.7	0.	-17349.7	229048.8	0.93	
cere	79270.8	6160.9	246808.9	37281.9	36283.0	565.3	406370.8	27630.6	0.	-27630.6	378740.2	0.93	
meat	24386.9	0.	0.	0.	157.7	53.0	24597.6	0.	10446.0	10446.0	35043.5	1.42	
cer$	12351.8	827.1	34083.0	5295.5	5165.7	79.3	57802.5	4102.9	0.	-4102.9	53699.5	0.93	
fod$	26553.9	1052.5	12300.7	3593.3	3490.5	56.7	47047.7	3691.3	1523.9	-2167.5	44880.2	0.95	
nfd$	0.	5990.5	0.	0.	0.	5.9	5996.4	419.3	3445.3	3026.0	9022.3	1.50	
liv$	55025.8	541.9	19127.5	241.2	1996.5	91.0	77024.0	0.	21497.7	21497.7	98521.7	1.28	
lfo$	93931.6	2421.6	65511.2	9130.0	10652.7	227.0	181874.1	7794.2	23021.6	15227.3	197101.5	1.08	
gvp$	93931.6	8412.0	65511.2	9130.0	10652.7	233.0	187870.5	8213.6	26466.9	18253.3	206123.8	1.10	
gdp	1202590.6			tot pop	408116.0			lab for	205573.0	ag lab	29746.0		

notes

IIASA - FAP agriculture programming system - basic data set

Normative Medium Scenario

sua for CMEA 1995

	food	industry	feed	seed	waste	stocks	demand	import	export	trade	output	ssr	price
whea	55125.1	961.5	75343.2	15831.2	15782.0	114.9	163157.9	8297.4	0.	-8297.4	154860.4	0.95	159.
rice	5202.6	5.1	0.	81.0	139.4	14.7	5442.8	4110.6	0.	-4110.6	1332.2	0.24	230.
c.gr	19389.9	5853.1	194966.8	23895.9	22826.0	299.7	267231.5	18537.9	0.	-18537.9	248693.6	0.93	130.
suga	19227.5	0.	26.2	0.	22.3	19.6	19295.5	3375.0	0.	-3375.0	15920.5	0.83	208.
vege	11529.3	0.	9217.7	2441.0	2090.1	21.3	25299.4	1962.6	0.	-1962.6	23336.8	0.92	1420.
bana	599.1	0.	0.	0.	56.3	0.2	655.6	655.6	0.	-655.6	0.	0.	120.
citr	1774.6	0.	0.	0.	129.0	1.3	1905.0	1770.3	0.	-1770.3	134.7	0.07	218.
frui	33221.1	0.	159.6	0.	3410.7	22.6	36814.0	0.	6859.4	6859.4	43673.4	1.19	210.
vego	4300.2	1501.8	229.9	374.5	7.2	9.9	6423.5	163.5	0.	-163.5	6260.0	0.97	760.
coco	433.5	0.	0.	0.	0.8	0.9	435.3	435.3	0.	-435.3	0.	0.	1421.
coff	359.3	0.	0.	0.	0.	1.0	360.3	360.3	0.	-360.3	0.	0.	1586.
teas	210.1	0.	0.	0.	0.	0.4	210.4	50.0	0.	-50.0	160.5	0.76	1200.
cott	0.	9606.9	0.	0.	0.	9.2	9616.1	0.	8539.2	8539.2	18155.3	1.89	420.
o.nf	0.	1651.7	0.	0.	0.	2.7	1654.4	0.	1120.5	1120.5	2774.9	1.68	1130.
rubb	0.	693.5	0.	0.	0.	0.3	693.8	693.8	0.	-693.8	0.	0.	656.
fodd	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	91.
beef	10659.4	0.	0.	0.	27.5	12.0	10698.9	0.	4480.2	4480.2	15179.1	1.42	1200.
mutt	1317.0	0.	0.	0.	1.7	1.6	1320.3	0.	730.2	730.2	2050.5	1.55	1108.
pigm	10379.3	0.	0.	0.	119.8	15.8	10515.0	0.	5666.7	5666.7	16181.6	1.54	1626.
poul	4227.2	0.	0.	0.	26.5	13.2	4266.9	0.	465.3	465.3	4732.2	1.11	1144.
milk	85096.3	2850.3	97932.7	0.	7781.5	52.0	193712.8	0.	34285.2	34285.2	227998.0	1.18	209.
eggs	5979.2	0.	0.	303.5	335.9	3.4	6622.1	0.	1806.6	1806.6	8428.7	1.27	902.
cgrn	19389.9	5853.1	194966.8	23895.9	22826.0	299.7	267231.5	18537.9	0.	-18537.9	248693.6	0.93	
cere	79717.5	6819.7	270310.0	39808.2	38747.4	429.3	435832.1	30945.9	0.	-30945.9	404886.2	0.93	
meat	26582.9	0.	0.	0.	175.5	42.7	26801.1	0.	11342.4	11342.4	38143.4	1.42	
cer$	12482.2	915.0	37325.2	5642.3	5508.8	60.6	61934.0	4674.7	0.	-4674.7	57259.4	0.92	
fod$	28512.8	1141.4	13297.3	3750.9	3725.8	46.3	50474.5	4625.7	1440.5	-3185.2	47289.3	0.94	
nfd$	0.	6356.3	0.	0.	0.	7.1	6363.4	455.2	4852.6	4397.5	10760.8	1.69	
liv$	59141.5	595.7	20467.9	273.8	2189.4	71.1	82739.3	0.	24726.8	24726.8	107466.1	1.30	
tfo$	100136.5	2652.0	71090.5	9666.9	11423.9	177.9	195147.8	9300.3	26167.3	16866.9	212014.8	1.09	
gvp$	100136.5	9008.3	71090.5	9666.9	11423.9	185.0	201511.2	9755.5	31019.9	21264.4	222775.6	1.11	
gdp	1492642.3			tot pop	420890.0			lab for	210623.0	ag lab	25225.0		

notes

TABLE D.2 *Continued.*

IIASA - FAP agriculture programming system - basic data set

Normative Medium Scenario

sua for CMEA 2000

	food	industry	feed	seed	waste	stocks	demand	import	export	trade	output	ssr	price
whea	55541.9	1036.0	79101.5	16228.5	16267.0	63.7	168238.6	9799.9	0.	-9799.9	158438.7	0.94	159.
rice	5947.3	5.5	0.	58.0	158.7	15.0	6184.5	5229.4	0.	-5229.4	955.1	0.15	230.
c.gr	19252.6	6437.2	205337.9	24997.1	23818.6	159.1	280002.5	18686.5	0.	-18686.5	261316.0	0.93	139.
suga	20136.1	0.	28.5	0.	24.3	17.8	20206.6	3238.3	0.	-3238.3	16968.3	0.84	203.
vege	12365.8	0.	9657.8	2461.6	2180.7	16.3	26322.2	2867.5	0.	-2867.5	23454.7	0.89	1420.
bana	629.6	0.	0.	0.	59.2	0.2	689.0	689.0	0.	-689.0	0.	0.	120.
citr	1984.7	0.	0.	0.	143.5	1.2	2129.4	1994.7	0.	-1994.7	134.7	0.06	218.
frui	36633.2	0.	174.0	0.	3505.9	20.5	40333.6	0.	4643.9	4643.9	44977.6	1.12	210.
vego	4620.8	1618.8	255.4	402.2	7.7	9.5	6914.3	278.0	0.	-278.0	6636.3	0.96	760.
coco	476.7	0.	0.	0.	0.9	0.8	478.5	478.5	0.	-478.5	0.	0.	1421.
coff	407.8	0.	0.	0.	0.	0.9	408.8	408.8	0.	-408.8	0.	0.	1556.
teas	228.1	0.	0.	0.	0.	0.4	228.5	63.6	0.	-63.6	164.9	0.72	1200.
cott	0.	10049.7	0.	0.	0.	9.2	10058.9	0.	10620.6	10620.6	20679.6	2.06	420.
o.af	0.	1779.2	0.	0.	0.	2.7	1781.9	0.	1591.9	1591.9	3373.8	1.89	1130.
rubb	0.	748.0	0.	0.	0.	0.3	748.3	748.3	0.	-748.3	0.	0.	655.
fodd	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	91.
beef	11163.6	0.	0.	0.	30.0	9.7	11203.3	0.	4378.0	4378.0	15581.3	1.39	1203.
mutt	1386.9	0.	0.	0.	1.8	1.4	1390.1	0.	707.2	707.2	2097.3	1.51	1108.
pigm	11055.9	0.	0.	0.	130.6	13.2	11199.7	0.	5824.4	5824.4	17024.1	1.52	1626.
poul	4815.7	0.	0.	0.	27.7	11.8	4855.2	0.	439.9	439.9	5295.1	1.09	1144.
milk	88125.9	3107.6	100923.1	0.	7956.5	31.0	200146.0	0.	34860.6	34860.6	235006.7	1.17	203.
eggs	6501.5	0.	0.	346.0	389.2	3.2	7233.9	0.	2335.7	2335.7	9569.6	1.32	902.
cgrn	19252.6	6437.2	205337.9	24997.1	23818.6	159.1	280002.5	18686.5	0.	-18686.5	261316.0	0.93	
cere	80741.8	7478.7	284439.3	41283.5	40244.3	237.9	454425.6	33715.7	0.	-33715.7	420709.8	0.93	
meat	28422.0	0.	0.	0.	190.1	36.1	28648.2	0.	11349.6	11349.6	39997.8	1.40	
cer$	12701.9	1002.8	39271.1	5843.3	5719.4	34.3	64572.7	5190.2	0.	-5190.2	59382.5	0.92	
fod$	30359.2	1230.3	13944.7	3601.1	3878.4	38.1	53251.8	6205.2	975.2	-5230.0	48021.9	0.90	
nfd$	0.	6722.1	0.	0.	0.	7.1	6729.2	490.9	6259.5	5768.6	12497.8	1.86	
liv$	62701.6	649.5	21092.9	306.7	2296.5	57.5	87104.6	0.	25403.6	25403.6	112508.3	1.29	
tfo$	105762.7	2882.6	74308.7	9951.1	11894.3	129.8	204929.1	11395.4	26378.9	14983.5	219912.6	1.07	
avp$	105762.7	9364.7	74308.7	9951.1	11894.3	136.9	211658.3	11886.3	32638.4	20752.1	232410.4	1.10	

gdp 1807776.9 tot pop 433653.0 lab for 215672.0 ag lab 20614.0

notes

APPENDIX E Commodity Projections for the Smaller CMEA Countries

TABLE E.1 Projections for wheat production in the smaller CMEA countries (10^3 t).

	Production				SSR			
Scenario	1975	1985	1990	2000	1975	1985	1990	2000
FAO/1	26,528	43,935	50,330	–	1.00	0.98	0.98	–
FAO/2	26,528	47,488	63,063	104,149	1.00	0.99	1.10	1.17
A/1	26,528	42,741	52,407	87,868	1.00	0.98	0.98	1.73
A/2	26,528	42,767	52,448	87,215	1.00	0.98	0.98	1.73
A/3	26,528	47,741	52,407	88,026	1.00	0.98	0.98	1.72
A/4	26,528	34,807	47,074	43,063	1.00	0.97	1.10	0.98
A/I	26,528	42,741	52,407	87,830	1.00	0.98	0.98	1.73
A/II	26,528	48,305	60,620	101,928	1.00	0.98	0.97	1.83
A/III	26,528	40,240	47,970	73,652	1.00	0.99	0.98	1.57
A/IV	26,528	38,284	44,637	64,492	1.00	0.99	0.98	1.37
A/a	26,528	42,596	51,969	85,196	1.00	0.98	0.98	1.77
A/b	26,528	42,354	51,549	84,699	1.00	0.98	0.98	1.77
A/c	26,528	42,078	52,606	86,118	1.00	0.98	0.98	1.77
A/d	26,528	42,838	52,332	85,680	1.00	0.98	0.98	1.77
A/A	26,528	42,837	52,332	85,680	1.00	0.98	0.98	1.77
A/T	26,528	42,995	52,688	86,762	1.00	0.99	0.98	1.42
B/1	26,528	45,343	59,375	94,450	1.00	0.98	1.06	1.09
B/2	26,528	41,738	50,713	81,541	1.00	0.98	0.98	1.50
C/1	26,528	42,542	53,677	91,361	1.00	0.98	1.00	1.76
C/2	26,528	40,998	49,507	77,913	1.00	0.98	0.98	1.53
C/3	26,528	40,898	49,041	76,432	1.00	0.98	0.98	1.46
C/4	26,528	40,997	49,507	75,538	1.00	0.98	0.98	1.16
C/M	26,528	42,209	48,488	74,158	1.00	0.99	0.98	1.12

TABLE E.2 Projections for coarse grain production in the smaller CMEA countries (10^3 t).

	Production				SSR			
Scenario	1975	1985	1990	2000	1975	1985	1990	2000
FAO/1	48,713	68,049	69,182	–	0.90	0.92	0.78	–
FAO/2	48,713	75,346	93,384	135,664	0.90	1.01	1.01	1.02
A/1	48,713	67,036	75,552	111,952	0.90	0.95	0.97	1.00
A/2	48,713	67,068	75,596	111,262	0.90	0.95	0.97	1.00
A/3	48,713	67,036	75,552	112,135	0.90	0.95	0.97	1.00
A/4	48,713	73,040	69,563	64,730	0.90	0.89	1.01	0.91
A/I	48,713	67,036	75,552	111,879	0.90	0.95	0.97	1.00
A/II	48,713	73,861	84,994	127,879	0.90	0.93	0.98	1.00
A/III	48,713	63,976	70,580	95,582	0.90	0.95	0.97	1.00
A/IV	48,713	61,483	66,763	84,527	0.90	0.95	0.97	1.00

TABLE E.2 *Continued.*

	Production				SSR			
Scenario	1975	1985	1990	2000	1975	1985	1990	2000
A/a	48,713	66,918	75,106	109,675	0.90	0.95	0.96	1.00
A/b	48,713	66,603	74,714	109,181	0.90	0.98	0.96	1.00
A/c	48,713	67,547	75,839	110,541	0.90	0.95	0.97	1.00
A/d	48,713	67,233	75,536	110,138	0.90	0.95	0.97	1.00
A/A	48,713	67,233	75,536	110,138	0.90	0.95	0.97	1.00
A/T	48,713	67,573	76,239	111,701	0.90	0.90	0.89	1.02
B/1	48,713	72,164	88,120	122,326	0.90	1.00	1.01	1.03
B/2	48,713	65,043	72,480	100,558	0.90	0.93	0.96	1.01
C/1	48,713	62,267	74,980	110,356	0.90	0.92	1.02	1.00
C/2	48,713	63,495	69,965	93,881	0.90	0.92	0.97	1.00
C/3	48,713	63,382	69,466	92,576	0.90	0.92	0.96	1.00
C/4	48,713	63,494	69,964	89,400	0.90	0.92	0.97	1.00
C/M	48,713	62,598	68,868	88,253	0.90	0.90	0.94	1.00

TABLE E.3 Projections for meat production in the smaller CMEA countries (10^3 t).

	Production				SSR			
Scenario	1975	1985	1990	2000	1975	1985	1990	2000
FAO/1	8984	14,257	18,743	–	1.47	1.85	2.23	–
FAO/2	8984	14,508	19,443	33,183	1.47	1.88	2.30	3.44
A/1	8984	13,330	16,384	16,020	1.47	1.76	2.04	1.77
A/2	8984	13,340	16,399	15,880	1.47	1.76	2.04	1.76
A/3	8984	13,330	16,384	16,053	1.47	1.76	2.01	1.78
A/4	8984	12,758	10,261	10,997	1.47	1.68	1.28	1.23
A/I	8984	13,330	16,384	16,018	1.47	1.76	2.04	1.77
A/II	8984	15,478	18,442	17,625	1.47	2.09	2.32	1.99
A/III	8984	12,364	14,886	14,306	1.47	1.67	1.89	1.63
A/IV	8984	11,636	13,682	13,715	1.47	1.57	1.74	1.57
A/a	8984	13,259	16,255	15,206	1.47	1.78	2.06	1.73
A/b	8984	13,170	16,141	15,086	1.47	1.76	2.05	1.71
A/c	8984	13,436	16,445	15,471	1.47	1.82	2.08	1.75
A/d	8984	13,347	16,355	15,339	1.47	1.80	2.07	1.74
A/A	8984	13,347	16,355	15,338	1.47	1.80	2.07	1.74
A/T	8984	13,318	16,266	15,359	1.47	1.80	2.06	1.74
B/1	8984	13,807	18,367	30,615	1.47	1.83	2.27	3.32
B/2	8984	13,058	15,618	15,408	1.47	1.73	1.94	1.71
C/1	8984	13,454	14,160	14,819	1.47	1.70	1.69	1.57
C/2	8984	12,828	14,571	13,499	1.47	1.69	1.81	1.50
C/3	8984	12,829	14,592	13,520	1.47	1.70	1.82	1.50
C/4	8984	12,828	14,571	14,902	1.47	1.69	1.81	1.66
C/M	8984	12,843	14,611	14,913	1.47	1.70	1.82	1.66

TABLE E.4 Projections for fruit production in the smaller CMEA countries (1972 US$ million).

	Production				SSR			
Scenario	1975	1985	1990	2000	1975	1985	1990	2000
FAO/1	9832	10,647	10,216	–	1.61	1.34	1.12	–
FAO/2	9832	11,255	11,984	13,255	1.61	1.41	1.29	1.14
A/1	9832	10,436	10,518	11,401	1.61	1.35	1.26	1.13
A/2	9832	10,439	10,521	11,358	1.61	1.35	1.26	1.12
A/3	9832	10,436	10,518	11,411	1.61	1.35	1.26	1.13
A/4	9832	8902	8084	8313	1.61	1.16	0.98	0.83
A/I	9832	10,436	10,518	11,399	1.61	1.35	1.26	1.13
A/II	9832	11,078	11,311	12,335	1.61	1.48	1.37	1.26
A/III	9832	10,137	10,077	10,374	1.61	1.36	1.25	1.09
A/IV	9832	9893	9733	9645	1.61	1.33	1.22	1.03
A/a	9832	10,422	10,477	11,250	1.61	1.39	1.29	1.17
A/b	9832	10,392	10,441	11,219	1.61	1.37	1.29	1.17
A/c	9832	10,480	10,540	11,306	1.61	1.41	1.30	1.17
A/d	9832	10,451	10,514	11,280	1.61	1.40	1.30	1.17
A/A	9832	10,451	10,514	11,280	1.61	1.40	1.30	1.17
A/T	9832	10,489	10,576	11,387	1.61	1.40	1.31	1.19
B/1	9832	10,836	11,374	11,856	1.61	1.40	1.34	1.14
B/2	9832	10,082	10,026	10,118	1.61	1.31	1.20	1.01
C/1	9832	9961	9938	9850	1.61	1.27	1.10	0.89
C/2	9832	9789	9529	8971	1.61	1.27	1.15	0.91
C/3	9832	9792	9539	8999	1.61	1.27	1.15	0.91
C/4	9832	9789	9529	8679	1.61	1.27	1.15	0.87
C/M	9832	9817	9550	8713	1.61	1.28	1.15	0.88

APPENDIX F Commodity Projections for the Soviet Union

TABLE F.1 Projections for wheat production in the Soviet Union (10^3 t).

	Production				SSR			
Scenario	1975	1985	1990	2000	1975	1985	1990	2000
FAO/1	82,340	103,712	108,082	108,545	0.97	0.98	0.99	1.00
FAO/2	82,340	101,636	105,137	109,403	0.97	0.98	0.99	1.12
FAO/3	82,340	100,424	103,306	103,105	0.97	0.98	0.99	1.01
A/1	82,340	107,558	116,164	125,716	0.97	0.98	0.98	0.99
A/2	82,340	103,410	110,612	117,385	0.97	0.98	0.98	0.99
A/3	82,340	99,767	105,700	111,295	0.97	0.98	0.98	0.99
A/4	82,340	97,821	102,935	107,758	0.97	0.98	0.99	0.99
A/5	82,340	110,233	119,173	126,747	0.97	0.98	0.98	0.99
A/6	82,340	111,924	121,379	129,015	0.97	0.98	0.98	0.99
A/I	82,340	107,687	115,669	122,942	0.97	0.98	0.98	0.99
A/II	82,340	98,338	103,515	109,169	0.97	0.98	0.98	0.99
A/III	82,340	105,586	112,147	117,290	0.97	0.98	0.98	0.99
A/IV	82,340	95,715	98,775	101,442	0.97	0.99	0.99	0.99
A/a	82,340	106,419	114,888	122,452	0.97	0.97	0.98	0.99
A/b	82,340	107,462	115,427	122,763	0.97	0.98	0.98	0.99
A/c	82,340	106,170	114,793	122,357	0.97	0.97	0.98	0.99
A/T	82,340	106,173	113,815	121,622	0.97	0.98	0.98	0.99

TABLE F.2 Projections for coarse grain production in the Soviet Union (10^3 t).

	Production				SSR			
Scenario	1975	1985	1990	2000	1975	1985	1990	2000
FAO/1	94,652	123,697	132,438	130,727	0.98	0.97	0.99	1.00
FAO/2	94,652	119,208	125,959	132,622	0.98	0.97	0.99	1.25
FAO/3	94,652	116,703	122,263	119,441	0.98	0.97	0.99	1.04
A/1	94,652	131,929	150,261	168,343	0.98	0.96	0.97	0.99
A/2	94,652	123,291	138,551	150,883	0.98	0.96	0.97	0.99
A/3	94,652	116,235	128,156	138,323	0.98	0.97	0.98	0.98
A/4	94,652	112,428	122,245	130,944	0.98	0.97	0.98	0.98
A/5	94,652	137,538	156,378	169,759	0.98	0.97	0.97	0.98
A/6	94,652	141,081	160,899	174,218	0.98	0.96	0.97	0.98
A/I	94,652	132,534	149,403	162,335	0.98	0.97	0.97	0.99
A/II	94,652	118,506	128,020	137,382	0.98	0.97	0.98	0.99
A/III	94,652	125,197	137,450	145,514	0.98	0.97	0.98	0.99
A/IV	94,652	115,506	121,171	123,849	0.98	0.98	0.98	0.99
A/a	94,652	129,344	147,319	161,087	0.98	0.96	0.97	0.99
A/b	94,652	132,009	148,875	161,972	0.98	0.97	0.97	0.98
A/c	94,652	129,017	147,023	160,837	0.98	0.96	0.97	0.98
A/T	94,652	129,083	145,446	160,020	0.98	0.97	0.97	0.99

TABLE F.3 Projections for meat production in the Soviet Union (10^3 t).

	Production				SSR			
Scenario	1975	1985	1990	2000	1975	1985	1990	2000
FAO/1	13,961	16,731	17,458	16,673	1.08	1.10	1.05	0.88
FAO/2	13,961	16,138	16,504	12,767	1.08	1.06	0.99	0.67
FAO/3	13,961	16,345	16,922	15,984	1.08	1.07	1.02	0.84
A/1	13,961	18,177	20,601	22,713	1.08	1.19	1.23	1.19
A/2	13,961	16,928	18,882	20,373	1.08	1.11	1.13	1.06
A/3	13,961	15,751	17,264	18,510	1.08	1.02	1.03	0.96
A/4	13,961	15,117	16,354	17,457	1.08	0.98	0.98	0.91
A/5	13,961	18,972	21,567	23,244	1.08	1.24	1.29	1.22
A/6	13,961	19,575	22,270	23,931	1.08	1.28	1.33	1.26
A/I	13,961	18,257	20,541	22,088	1.08	1.19	1.22	1.15
A/II	13,961	16,158	17,420	18,571	1.08	0.98	0.98	0.91
A/III	13,961	16,999	18,566	19,343	1.08	1.15	1.17	1.08
A/IV	13,961	15,683	16,422	16,822	1.08	0.91	0.87	0.77
A/a	13,961	17,939	20,246	21,889	1.08	1.18	1.21	1.15
A/b	13,961	18,129	20,448	22,039	1.08	1.18	1.22	1.15
A/c	13,961	17,884	20,176	21,852	1.08	1.57	1.21	1.14
A/T	13,961	18,405	21,063	23,802	1.08	1.21	1.26	1.24

TABLE F.4 Projections for fruit production in the Soviet Union (1972 US$ million).

	Production				SSR			
Scenario	1975	1985	1990	2000	1975	1985	1990	2000
FAO/1	16,921	25,220	31,137	43,448	1.23	1.62	1.73	1.93
FAO/2	16,921	24,474	29,696	33,050	1.23	1.58	1.66	1.53
FAO/3	16,921	24,555	30,001	41,005	1.23	1.58	1.67	1.83
A/1	16,921	26,860	35,146	54,195	1.23	1.71	1.90	2.28
A/2	16,921	27,791	37,283	61,298	1.23	1.76	1.99	2.51
A/3	16,921	26,245	34,236	54,405	1.23	1.65	1.86	2.28
A/4	16,921	25,421	32,606	50,668	1.23	1.59	1.78	2.15
A/5	16,921	30,601	42,705	73,445	1.23	1.91	2.23	2.90
A/6	16,921	31,585	44,285	76,585	1.23	1.96	2.30	3.01
A/I	16,921	29,823	40,608	68,306	1.23	1.86	2.12	2.73
A/II	16,921	26,733	34,362	54,149	1.23	1.48	1.66	2.03
A/III	16,921	28,037	36,915	58,223	1.23	1.87	2.16	2.71
A/IV	16,921	26,095	32,524	48,054	1.23	1.34	1.43	1.63
A/a	16,921	29,143	39,947	67,516	1.23	1.84	2.12	2.72
A/b	16,921	29,511	40,383	68,095	1.23	1.84	2.12	2.72
A/c	16,921	29,067	39,857	67,353	1.23	1.83	2.12	2.72
A/T	16,921	26,935	35,398	55,362	1.23	1.71	1.90	2.31

A GENERAL REGIONAL AGRICULTURAL MODEL (GRAM) APPLIED TO A REGION IN POLAND

Murat Albegov, Janusz Kacprzyk, William Orchard-Hays, Jan W. Owsinski, and Andrzej Straszak
International Institute for Applied Systems Analysis, Laxenburg, Austria

SUMMARY

The General Regional Agricultural Model (GRAM) described in this report is the product of a case study of regional development in the Upper Notec region of Poland carried out collaboratively by IIASA and the Systems Research Institute in Warsaw, Poland. The purpose of this work was twofold: to assist Polish authorities in planning the development of agriculture in the region, and to create a universal methodology in the form of a model applicable to similar problems and settings in other countries. Thus, the methodological characteristics presented in this report are based on testing and implementing the model in the concrete situation of the Upper Notec region of Poland.

GRAM was developed using the so-called "bottom-up" approach, which consists of orienting the model toward technological interdependencies at the level of the agricultural areas in the region, and including a set of variables and parameters that enable this "bottom" model to be linked with those for other aspects of the regional economy.

The model deals with the following elements: a set of crops subject to rotation constraints; types of agricultural animals, types of livestock products, and feed components in forage; three types of market and three types of land ownership; different crop growing and livestock breeding technologies; and different soil qualities and types of fertilizer, according to the contents of the elements. The model incorporates space and can give solutions for a number of regions. Technically GRAM is a large linear programming model with static relations.

The purpose of the model is to derive a detailed specification for a production structure combined with a direct utilization of its products that is optimal for a predefined objective. The model can also be used to indicate essential bottlenecks, resource distribution inconsistencies, and so on. It allows the formulations of multiobjective optimization problems to consider conflicts between different groups of producers. It is solved under constraints on labor, machinery, fertilizers, and water availability at annual and two peak levels.

Two types of objective function are used: monetary (linked with cost–benefit analysis) and physical. Among specific objective functions for which the model has been solved there are: total net return or net production value from agricultural activities within the region; balance of regional agricultural production in monetary terms; regional agricultural production in terms of nutrition units; regional trade balances in livestock products in monetary terms and in nutrition units; and export production in monetary terms. In cooperation with other elements of the regional model system, two types of information are exchanged: dual prices and volume of output.

The model was implemented on an IBM 370/168 computer using the SESAME/DATAMAT LP system designed by William Orchard-Hays, which is operative in Pisa (Italy).

1 INTRODUCTION

The subject of regional development planning and management, taken up by IIASA as a universal issue, was first approached through a series of retrospective case studies of regional development undertakings, such as the Tennessee Valley Authority in the United States, the Bratsk–Ust'–Ilimsk territorial production complex in the Soviet Union, or the Shinkansen high-speed railway system in Japan (see Knop 1976, Knop and Straszak 1978, Straszak 1980). Having gathered experiences and identified the essential general features of these regional development activities, IIASA has turned to the analysis and design work that will be of use in the planning of ongoing regional programs. Three such joint ventures of IIASA and appropriate National Member Organizations (NMOs) were completed at the end of 1981, namely, the modeling projects for the Upper Notec watershed region in Poland (see Albegov and Kulikowski 1978a, b), for the Silistra region in Bulgaria (Andersson and Philipov 1979), and for the Southern Skåne region in Sweden (Andersson 1980). A fourth project for the Tuscany region in Italy is still under way.

The main input of IIASA to such studies is a methodological one. Owing to the generally analogous nature of problems encountered in various regional circumstances, IIASA is capable, through the work of its scholars, to develop formal systemic methods, mainly connected with modeling, which are applicable to a specific region, and which can also be applied to other regional development problems. These models are practically implemented; i.e., data are gathered, results are assessed, etc., by specialists from the appropriate NMOs.

Since the emphasis in the work on regional development planning is placed upon integration, care is taken that the models developed constitute segments of a system of models that will also be partly or totally transferable. The model whose formal description and implementation are presented in this report was proposed by Albegov (1979); this was then developed as a generalizable element of a model system, and its applicability was tested for a practical regional project planning case.

The main problem is to define the model in such a way that two requirements are simultaneously fulfilled:

(i) Representation of a real system with sufficient detail, so that specific features of a particular case can be made explicit, and that communication with other models in the system is meaningful; and, on the other hand,

(ii) representation of an adequate variety of possible system configurations, so that the model can be applied to various other circumstances.

Thus, the model should fulfill the conditions of representation, inter-model communication within a system, and generality. In the presence of another (technical) condition of flexibility and operativeness, however, the above requirements may conflict.

The present report shows to what extent the basic prerequisites generally formulated can be met by a regional agricultural model that encompasses technical, economic, and partly social aspects of a regional agricultural system.

2 NEED AND PURPOSE: BASIC PREREQUISITES

2.1 Regional Development Planning and Modeling Activities

When speaking of regional development planning, one has to make a clear distinction between this activity and a routine management practice, which is focused on the structural status quo. In stable situations it is justified to decouple subsystems and manage them separately via routine mechanisms. When essential structural changes are envisaged, however, the regional system should necessarily be regarded as a whole, since such changes in one subsystem can be transmitted and cause important repercussions in all subsystems.

In consideration of regional development plans, integration therefore plays a very important role. First, the considerations of development should be comprehensive, i.e., they should comprise all the essential elements of the regional socio-economic system. However, in order for the cognitive mapping of a regional development problem to be complete (i.e., ro reflect as well the intrinsic systemic features), there should follow an integration phase, in which all the elements are interlinked. This integration has two facets: material linkages (flows, common resources, productive activities, etc.), and value interrelations (various objectives and interests represented in the regional system and the relations between them), which are defined over physical activities and interrelations.

The necessity of regarding a regional system as a whole for development planning purposes led us to coin the term integrated regional development (IRD); this approach is justified by experience gained from case studies done and under way at IIASA (Knop 1976, Albegov 1978, Straszak 1980). In particular, comprehensiveness and integration with regard to the various regional sectors involved, both resources and activities, are required. Another essential comprehensiveness and integration cross section is operations management organization; both of these are taken into account in the cases studied. The value and interest cross section, however, was considered to a much smaller extent.

In the consideration of large, multidimensional complex systems such as the regional socio-economic ones it is necessary to utilize formalized methods based upon computer models of reality and of its possible changes. This necessity of model building and application results both from the need for precision and speed in handling large amounts of data, and from the need to test the mostly intuitive assumptions concerning causal relations in real socio-economic systems.

2.2 The System of Models

It is impossible to construct a single model that will serve all regional development needs, fulfilling the comprehensiveness and integration requirement. There do exist such frameworks, e.g., Input/Output, which are meant in principle to comprise all possible components of a (regional) socio-economic system in terms of commodities and production activities, with the exception of substitution, functional, and value interrelations. There is in practice, however, no experience of or capacity for implementing any all-embracing, comprehensive, and integrating model. It is therefore necessary to elaborate systems of partial models, where each model in the system highlights with adequate precision a portion of the real regional system. Simultaneously, interconnections between the models would ensure adequate reflection of the systemic behavior of the whole. Thus, the models entering the system should not only sufficiently describe/optimize their subsystems well, but should also provide for easy and meaningful connections with other models.

Positive experience in the construction of systems of models for regional purposes have already been gained during IIASA's work in the field in both retrospective (analysis) and prospective (design) case studies: Kinki in Japan (Ikeda *et al.* 1979); Silistra in Bulgaria (Andersson and Philipov 1979); Notec in Poland (Albegov and Kulikowski 1978a, b); and Bratsk–Ilimsk in the USSR (Knop and Straszak 1978).

There is a wide range of methodological possibilities in constructing a model for the model system. Models with regional connotations are being constructed according to such methodologically differing theories as, for example, control theory or factor analysis, but it should be remembered that each type of theoretical basis for modeling ought to be placed firmly against a broad spectrum of regional socio-economic issues, so as to ensure the most appropriate utilization of these theories in solving development problems. A possible "assignment" of model types to issues is shown in Table 1 (taken from Straszak and Owsinski 1980). This table assumes a number of issues, i.e., problem areas, that appear in regional analysis and planning, such as: regionalization, regional specialization, coordination, or regional structure. On the other hand, the classification presented refers to stages in decision-making (planning) processes, in which models can take on various roles. In such a two-way breakdown the model methodologies are chosen according to their purpose.

The structure of the model system should reflect the structure of the regional system on an aggregate level, while the internal structure of each model should reflect micro-level relations. This can be illustrated by a structure for the model system, proposed by Albegov (1978), presented in Figure 1. This particular structure is oriented towards normative planning applications related to regional development. When commenting on this diagram, a number of reservations should be made. First, this is only one of several possible structures; it results from the author's experiences in development plan modeling of territorial breakdown in the Soviet Union. The assumption behind this diagram is that a certain more general planning scheme – involving modeling – exists. In particular, aggregate marginal costs, related to resource uses, are given, obtained for various regions and for the main resource groups.

For a more general case, when the marginal opportunity costs for resources and commodities have not been determined beforehand via a nationwide procedure, one can

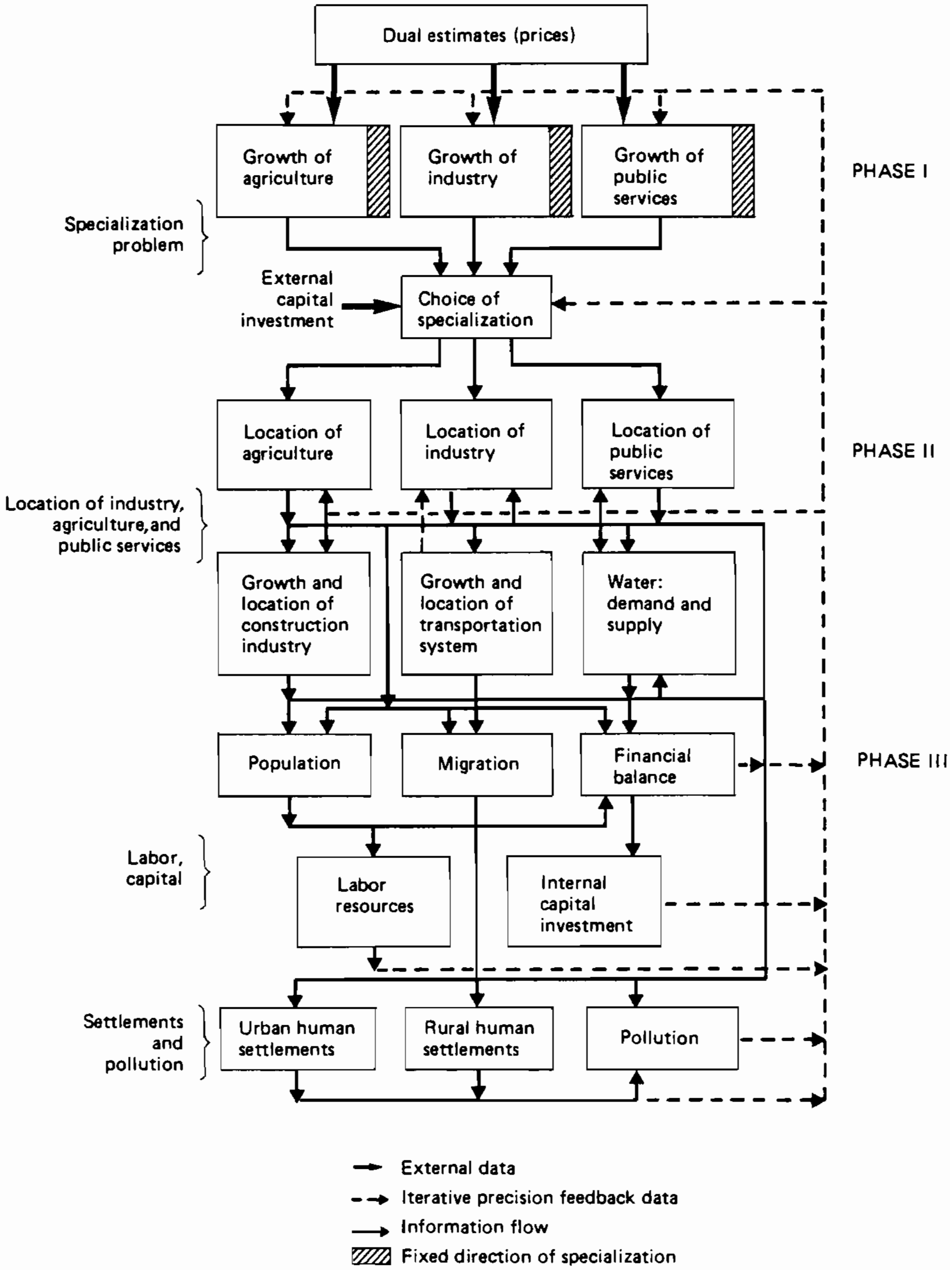


FIGURE 1 General scheme of the regional development model system structure. From Albegov (1978).

TABLE 1 Utilization of various model types and techniques according to their roles in the decision-making process, and issues considered. From Straszak and Owsinski (1980).

Issue	Role: Recognition	Debate	Pre-planning	Planning	Operational	Monitoring and control
Regionalization	Factor analysis Cluster analysis Connectivity analysis	Factor analysis Cluster analysis Connectivity analysis Structural anal.	Structural anal. Decomposition Multi-level optimization	Multi-level optimization Decomposition Tearing		Trending
Choice	Structural anal. Gaming	Gaming Decision anal.	Decision anal. Game theory	Decision anal. Game theory Multi-criteria assessment	Multi-criteria assessment Multi-objective programming	Polling
Specialization	Identification Structural modeling	Econometric Input/output Programming Structural models	Econometric Input/output Programming dual, nonlinear	Input/output Programming dual, nonlinear, dynamic	Dynamic programming Critical path Financial	Regulation Critical path Financial
Resource efficiency	Identification Input/output Structural models	Input/output Structural models Programming	Input/output Programming dual, nonlinear	Programming nonlinear, dual, dynamic Input/output Accounting	Dynamic programming Accounting	Accounting
Coordination	Gaming Structural models	Gaming Game theory	Game theory Decomposition Multi-level optimization	Decomposition Multi-level optimization Control theory	Dynamic programming Regulation	Interactive gaming Regulation Critical path

TABLE 1 *Continued.*

Issue	Role: Recognition	Debate	Pre-planning	Planning	Operational	Monitoring and control
Control	Identification Structural models Gaming Stochastic approximation	Structural models Control theory Game theory Econometric	Control theory Programming Econometric	Control theory Dynamic programming	Dynamic programming Regulation Critical path	Regulation
Stability	Identification Structural models Stochastic approximation	Structural models Control theory Catastrophe theory	Structural models Control theory Catastrophe theory	Control theory Structural models	Regulation Dynamic programming	Regulation
Structure	Structural analysis Structural models Identification	Structural analysis Structural models Catastrophe theory	Structural models Markov processes Catastrophe theory	Structural models Stochastic control theory		Trending
Characteristics	Survey Screening	Relational data base	Relational data base	Relational data base		Data acquisition

start the iterative working of the proposed system of models from the population, migration, and financial balance blocks (phase III), which determine the regional–exogenous trends. These trends can then be rectified for normative purposes, if needed, when the same blocks are "activated" again in a second iterative run of the system. Thus, the same system structure (same in the sense of intra-model structures and inter-model connections) can be used to work in various configurations. The alternative configuration proposed here, i.e., starting from population and consumption trends (phase III) and going to sectoral growth (phase I), is in fact one of the more popular ones, e.g., in the regional forecasting model elaborated by the TVA (Knop 1976).

On the other hand, the blocks of Figure 1 by no means have to be treated as separate models. In practice, the specialization and location problems (phases I and II) are quite often solved for a given sector (e.g., industry or agriculture) within one model. Similarly, the population and migration questions are usually contained within one model.

Evidently, for the working of such a model system it is necessary that some core models are operational, to provide sufficient data for other models and to make use of the information provided by them. Such core models should certainly account for the most important and dynamic sectors of the regional economy.

2.3 The Agricultural Core Model

The first two regions taken as the prospective regional case studies into which IIASA would have a positive modeling input were largely agricultural in character. Although agriculture plays an important role in almost any regional development venture – whether in connection with land-use problems, the environment, or for purely economic reasons – it unquestionably takes a leading role in the regions of Notec in Poland and Silistra in Bulgaria. Thus the model systems devised for these two cases necessarily included agricultural models. These systems and the models therein were developed on the basis of differing methodologies, but the contents of the systems on the level of blocks (modeling objectives) were similar.

According to the above, a regional agricultural model included in such a system would describe adequately the agricultural socio-economic regional subsystem and provide sufficient data for other models in the system. This places definite requirements on agricultural model representations of such resource subsystems as labor force, land, infrastructure, water, fertilizers, etc.

The model should therefore be limited to solving agricultural problems, but must also be able to include all significant feedbacks and results from other subsystems. It is generally assumed that a regional development problem should be separated according to its sectoral components, so that each component can be solved by the corresponding model within the framework of the set of regional models. Such an approach would allow each subproblem to be described in as much detail as is necessary, and would avoid the use of complicated "hybrid" models ("hybrid" in the sense that they include elements of several sectors, such as water, industry, and agriculture). During the interaction between the agricultural and the other regional models, it should be possible to change some coefficients in accordance with the results of the other models. Communication with other parts of the model system on various resources can be carried out by transmitting information on their absolute volumes and/or costs, values, and efficiencies, absolute or marginal.

In this way, information on specialization capacities is gathered. The model should account for both material and financial flows, since both these methods of measurement are perceived explicitly in the system. This also has a bearing on different values being sought in the region and with regard to the region to be operationalized in the model via quantitative objective functions. In particular, the interests of various groups (producers, administrators) within the regional agricultural system should be accounted for, as well as various types of values in general.

The principal purpose of the model is to achieve results that can be used in the formulation of policies regarding future regional agricultural production, structure, and specialization. These may depend on issues such as land use, present production structure, soils, farm types, animal feeding methods, technology choices, labor skills and their use, availability of resources, etc., all of which are examined in more detail below.

A model fulfilling the above requirements would constitute an effective core for a model system. In the work of IIASA as an international institution, however, there is still another essential requirement – generality. The construction of the model should therefore ensure that it can be used under changing conditions, i.e., that various aspects of the system be accounted for, even though they may not necessarily be present in all cases. The contents of these aspects should therefore not be overdefined, so as to allow a flexible fill-in procedure in particular implementations.

Such a model has been formulated and implemented at IIASA, and is called the generalized regional agriculture model (GRAM).

When looking at the experiences that could serve as a starting point in our work we found that quite a limited number of models had been developed that fulfilled to a reasonable degree the conditions set out here. Outstanding work in the field has been done by E.O. Heady and associates (see Nicol and Heady 1975, Heady and Srivastava 1975), for the United States. References to similar models in other countries can be found in Heady and Srivastava (1975). Relevant models for our purposes were also reported by von Sauer (1970) for Lower Saxony, by Egbert and Estacio (1975) for Portugal, and also by Semionova (1976) for the Soviet Union. Of earlier works one should mention here the Swedish model, as presented by Birowo and Renborg (1965), the Norwegian one by Langvath (1962), and the French method by Klatzmann (1965). It was mainly the question of transferability and adequate representation that made our search for an appropriate structure difficult.

3 MODEL STRUCTURE, CONTENTS, AND USE

In accordance with the previous remarks on the purposes that the model was intended to serve within the model system, and on its characteristics allowing for its generality, the prerequisites of the formulation of the model will now be presented in more detail.

3.1 The Structure of the Model

The structure of the system studied, i.e., regional agriculture, is schematically presented in Figure 2(a). The figure follows in outline the actual form of the model described below, but it contains certain elements that are as yet absent from the model, such as seed or livestock reproduction feedbacks.

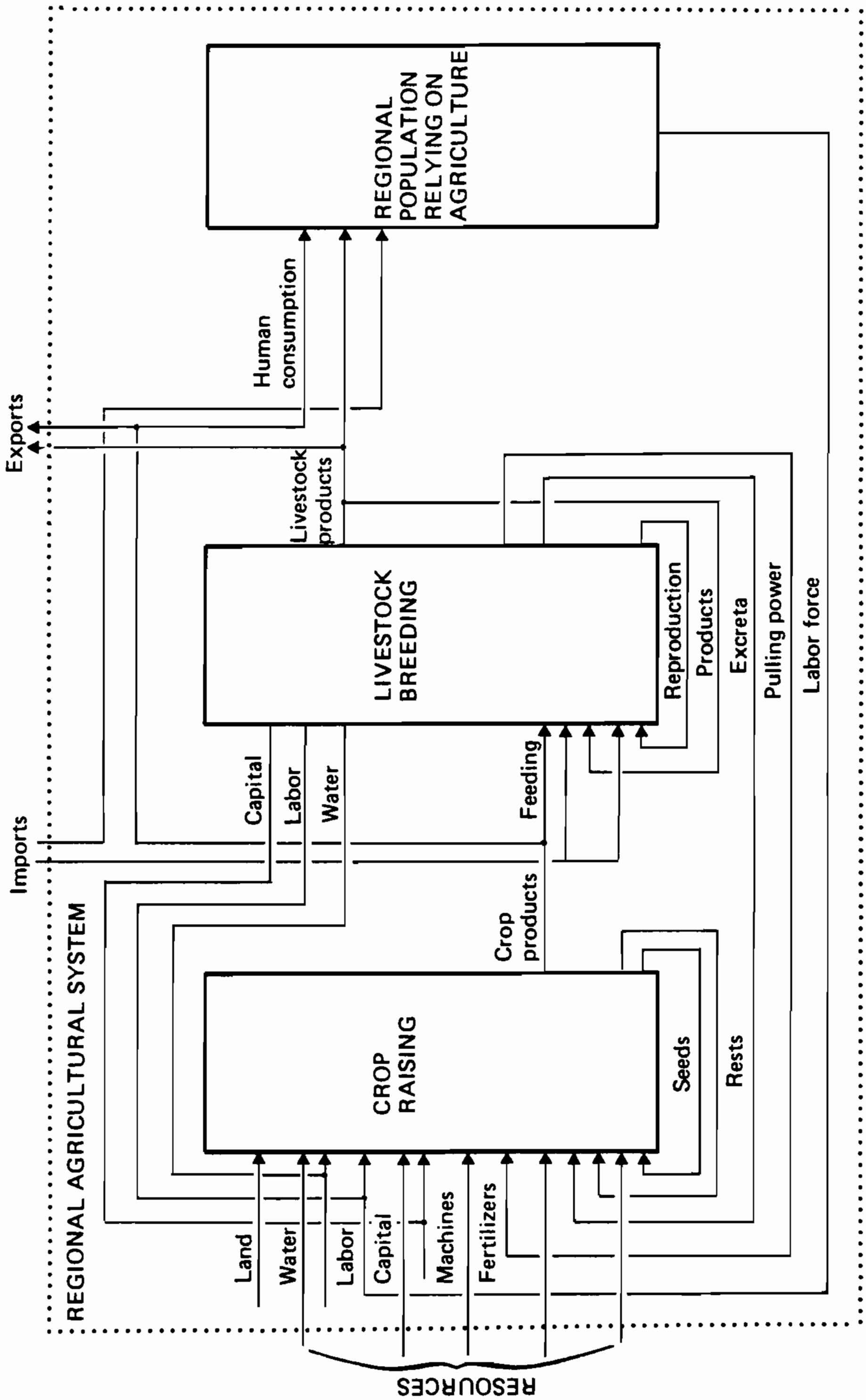


FIGURE 2(a) Structure of product and physical resource flows in the system under study.

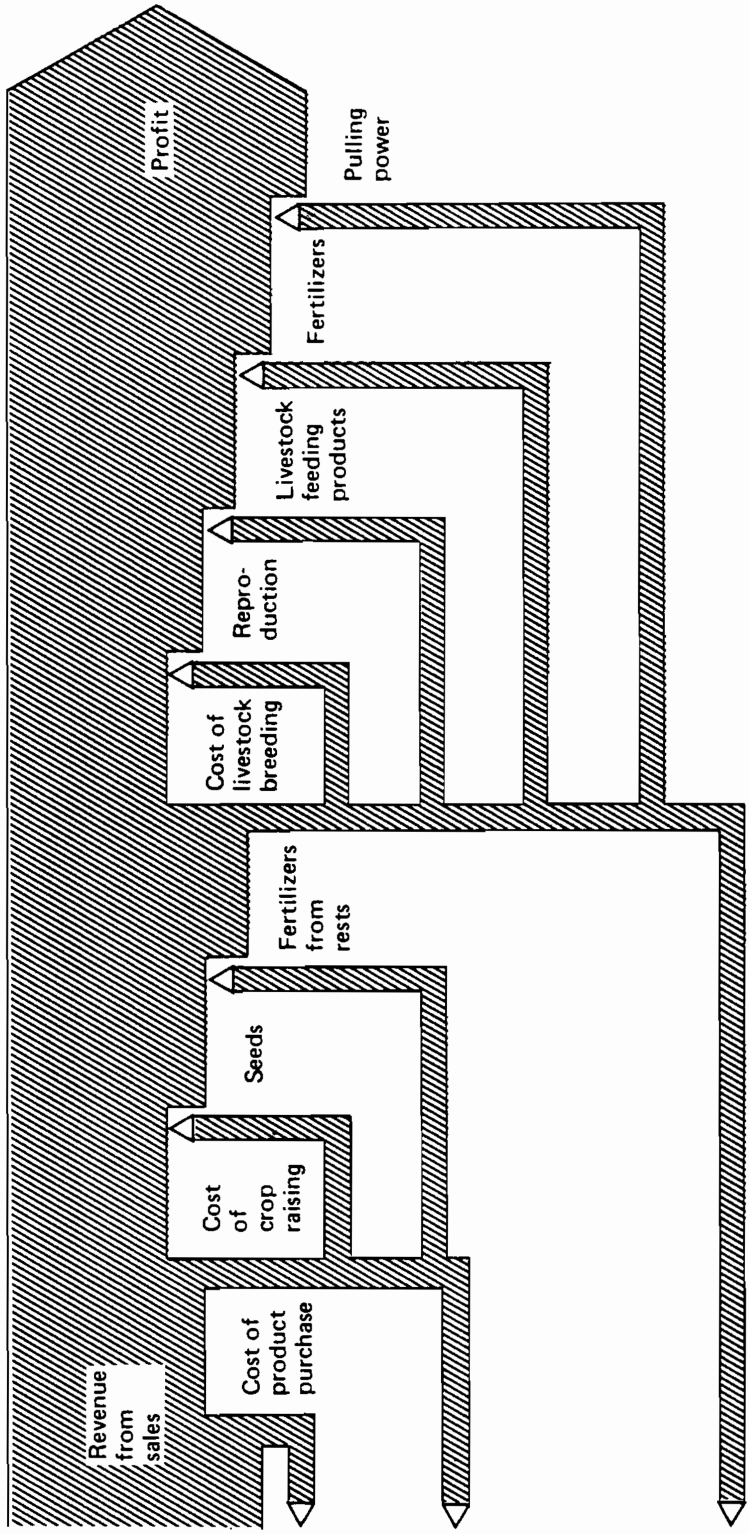


FIGURE 2(b) Structure of the financial accounting scheme for a farm in the system under study.

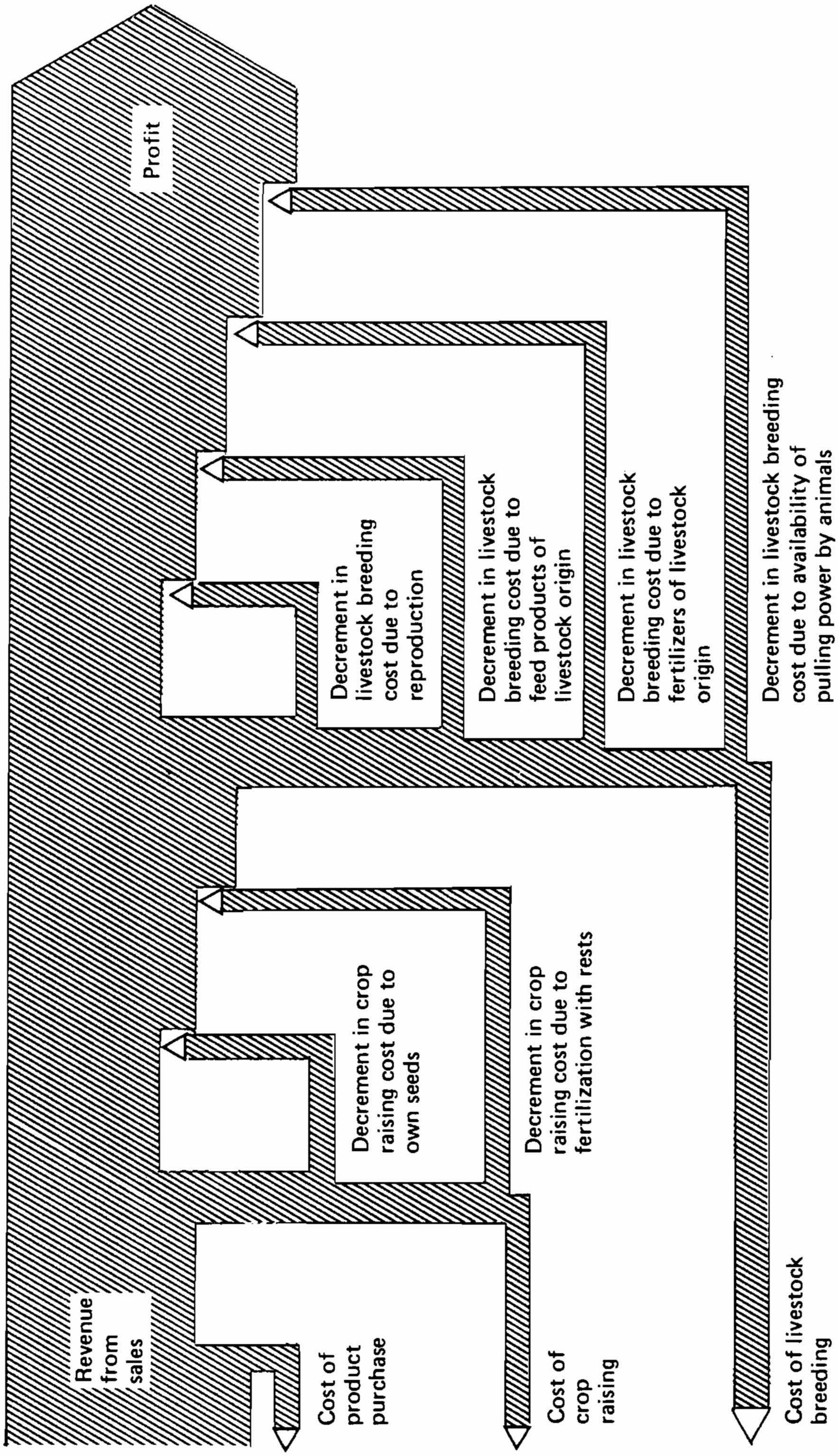


FIGURE 2(c) Structure of costs for crop raising and livestock breeding for the system under study.

As can be clearly seen from the figure, the main subject matter of the model is the description of various aspects of crop raising and livestock breeding activities. The more important items appearing in these activities will be commented upon in this section.

3.2 The Form of the Model

The individual elements and aspects of the agricultural system outlined in Figure 2, and the way they ought to be represented in the model, are discussed in the following section. Prior to these considerations, however, some general comments are necessary to justify the major choices made in model elaboration.

The model was intended to be a tool in development planning, whereby essential changes in the activity structure, etc. are implied. It was assumed that additional outlays and resource supplies would occur, and that conscious policies would be exerted to direct the use of additional resources and possibly ensure an effective course of development. Thus it was decided that the model would be normative and would provide a broad overview of potential controls, which could be operated by development centers (local administration, authority, corporation, etc.), depending upon the specific legal, administrative, and organizational conditions of a development undertaking. For each control instrument (such as prices, interest rates, subsidies, infrastructural investments, land-use regulations, supplies), there should be a way of assessing its efficiency in terms of its influence on producers' behavior. Furthermore, for each optimal structure and specialization obtained, the opportunity costs related to it for each producer group should be established. In this way the feasibility of an optimum can easily be assessed. As can be seen, these policy indication requirements necessitate from the model great facility of dual and marginal cost and price calculations. (Further details of the decision-making applications are given in Section 3.4.)

Since the model was intended for planning purposes in a changing environment it was deemed inappropriate to use aggregated magnitudes and relations, which are often quite abstract and rely on conditions that might totally change due to the development program itself. These include various production functions for agriculture as a whole, regardless of specific conditions, possibilities of activity reallocation, etc. Instead, it was decided to start with explicit consideration of various soils, producer types, climatic and hydrological areas, technologies, etc. Furthermore, an explicit solution to the diet problem was to be included in the model insofar as dramatic changes in crop production patterns may make the predefined diets not just suboptimal, but even obsolete. This variety, coupled with crop and animal types as well as product and monetary flows, results in a very complex picture.

Bearing in mind the requirements of normativeness and of facility in producing dual and marginal values for policy indication purposes, and also the assumed complexity of the model, it was decided to implement it as a linear programming (LP) model. This would also ensure that the model would be able to communicate with others in the system, and the simplicity of potential transfers.

Such a choice necessitated essential simplifications to some relations that were known to be highly nonlinear (e.g., discrete technological options rather than continuous production functions), and we did not find satisfactory the justification for actual forms of nonlinear relations accounting for bigger aggregates. On the other hand, empirically based production functions, which are defined for individual crops and resources in particular subregions (see Hexem and Heady 1978), would limit the model dimensions.

Some of the feedback effects shown in Figure 2, if appropriately accounted for, might ultimately lead to a dynamic model. It was anticipated, however, that the dimensions of the resulting LP model, in which spatial and productive aspects were assumed to be of major importance, could inhibit dynamic formulations; that is why at the present stage of work, a static LP model form was adopted. With a model size constraint resulting from the requirement of operativeness this aspect was chosen to be covered in more detail. Secondly, dynamics would not be a major problem for most of the elements accounted for in the model. Dynamics, in fact, enters mainly into the herd structure programming and into financial and investment considerations. For the aggregate, "comparative statics" type of analysis, the omission of these dynamic aspects does not introduce essential errors, provided the time horizon is not too long and a stable situation is envisaged.

For an LP model its communication with other elements of the system can be easily organized through the exchange of information concerning right-hand side (RHS) values in the constraints (Albegov 1978, Gutenbaum *et al.* 1980). Other models may specify resource availabilities, for example, which enter the agricultural model (GRAM) as RHS values, while the agricultural model, on the basis of either appropriate dual variables or absolute increments in the objective function, would specify relative or absolute sectoral costs/values of the resources in the region. In cases of more flexible software implementations it is feasible to exchange some information on coefficients of the objective functions or even of the constraint coefficient matrix. The organization of the appropriate iterative procedure then becomes more complicated.

3.3 The Content of the Model

In accordance with Figure 2(a), our comments start with the resource side of the system. Resource conditions are generally treated through appropriate requirement and availability balances.

3.3.1 Constraints

Land use. To obtain a comprehensive description of regional land use, the following points need to be examined when setting up land-use balances and availability constraints (care should also be taken of the areal changes due to urbanization, etc.):

(1) the possibility of implementing major land-improvement techniques such as irrigation, drainage, terracing, chemical applications;
(2) variations in the quality of land;
(3) the possibility of cultivating a second crop in some areas;
(4) the conditions for crop rotation.

The effectiveness of implementing land-improvement technologies depends on the quality of the land. Thus, the economic efficiency of capital investment and current expenditure in such undertakings is variable. The overall efficiency is also influenced by the situation of the land: for example, the closer an area requiring irrigation is to a river, the more economically effective an irrigation scheme will be. This aspect can, of course, be dealt with through appropriate cost coefficients. In general, GRAM should account for the land-improvement factor by including several different types of "technology" in the model description. These technologies should, in principle, represent vectors defined in a set of multifactor production functions. Since it is not feasible to use all these production functions, even in a linear form (there would have to be production functions, such as for crops, depending on labor, water, fertilizers, and machine energy, for each soil type, subregion, and producer type), only a limited number of such vectors should be used.

It should therefore be remembered when defining technologies and related coefficients describing resource use, costs, etc., what sort of (explicit) assumptions are made with respect to yields, capital, and running costs, their dependence on soils, technologies, and farm types, etc.

Crop production conditions cannot be considered uniform for all subregions because of the differences in soil quality and/or in cultivation traditions, and consequently in the results of land improvement. These differences can be described adequately by accounting for an appropriate number of subregions. In GRAM, the regions might be divided according to soil quality, farm type, and administrative divisions, and the model should be capable of handling up to 40–50 such subregions. In general, the division of space, and therefore also of agricultural land, must meet the modeling requirements not only of the agricultural sector but also of other sectors, such as industry, water supply, and settlement patterns. It is impossible to achieve a division of the land area of the region that is "ideal" for all sectors. Thus, the boundaries of the subregions should be defined by some factor of importance for the leading sector of the regional economy and should ensure feasibility of policy-making with regard to these entities.

It is essential – and of direct relevance to land use – that various types of farm economy be taken into account in consideration of technological and financial coefficients. Thus, land-use balances should also be made over farm types, since their shares must be considered relatively stable within the time horizon of the model. In some regions the distinction might be based upon farm size, while in others, on farm organization or specialization. Such distinctions are envisaged in GRAM. Because of the conditions of the first implementation, the types corresponded to land ownership (private, cooperative, or state), but this is by no means binding for other implementations. Having introduced the farm economy types these will now be referred to as "producer types". A further distinction could be a "producer group", which is a producer type spatially or otherwise located.

In some regions it may be possible to harvest a distinct second crop and this should also be represented in the model description. Similarly, crop rotation should also be accounted for. In the case of crop rotation schemes used as activities there is no need for appropriate land-use conditions. However, since the present model assumes consideration of real entities in all their potential configurations, crops are regarded as activities.

An important problem connected with land use is the question of how to define the ratio of perennial to annual crop production. It is possible to find the exact proportions for a particular year by using a longer-term model that describes an average annual harvest. Perennial production may change from year to year, but the way in which these changes occur (that is, the dynamics of production) can be assumed to be constant for any given five-year period. Thus, balances of land use (note being made of possible soil losses due to other activities) should take into account the following details:

(i) the availability of land of given soil type for a given producer group (subregion and producer type);

(ii) the feasibility of introducing given technologies on individual portions of land as defined above;

(iii) balance conditions for the second crop areas;

(iv) the land-use constraints for various crops resulting from crop rotation conditions and from the proportions of perennial and annual crops.

Use and supply of labor. The tendency for migration from rural to urban areas during certain stages of socio-economic evolution is a worldwide phenomenon, so that restrictions on the availability of labor merit some discussion. At this point, however, it is unnecessary to consider the coordination of labor distribution between the main economic sectors (industry, agriculture, and services). The inclusion of labor force constraints will enable information on marginal and total costs to be exchanged with other sectoral models.

If regional limits to the labor supply are accounted for in GRAM in a changeable way, it should be possible to determine the regional agricultural structure and output when employees change their field of work, or if the distribution of skills changes. Additional balances of labor supply between various types of farming, such as in the case of providing staff when required, should also be considered. This may be done by introducing variably tight constraints representing labor supply restrictions on various organizational and economic forms of farming for the region.

Water resources. The interdependence of agriculture and water supply is obvious, but the scale on which an irrigation scheme is introduced significantly affects the marginal costs of the water supply. Therefore, an optimal solution to the water supply problem in an agricultural region must be found. Our approach has been to separate water demand (described in the agriculture model) from supply (described in the water supply model), although in many agricultural regions conditions of water supply and demand are in fact determined internally. Information about the price of water and/or the limits of supply is obtained from the water supply model and included in the agriculture model.

However, the water shadow-pricing system could be complicated as a result of the irregularity of agricultural water demand, which is much higher in spring and summer than in autumn and winter. To avoid complications it can be assumed that for a given water resource system structure there is a constant cost of water entering the agricultural system. However, for a more precise calculation, several values for the cost of water might be introduced.

The same applies to water resource shadow prices, which can be defined for the all-year availability constraint, and/or for some shorter-period constraints. The exchange of information on water volumes, costs, shadow prices, etc., between supply and demand models should lead to a rationally balanced regional solution.

The supply of technological and technical resources. The general approach used in GRAM to solve the problem of the supply of technological and technical resources was to establish coefficients reflecting the requirements of the basic and additional supply of technological and technical resources, such as machinery and fertilizers. If supply restrictions on certain items exist, the corresponding constraints should be introduced into the model. These can also serve as accounting devices. The various unit volumes of additional supply and the corresponding costs are incorporated in the coefficients for appropriate technological variants.

It should be kept in mind, for fertilizers in particular, but also, as shown above, for water, and in fact for most of the physical resources, that the supply–demand approach has definite limits. Thus, as well as appropriate costs and prices, physical balances should also be taken into account. In a simplified model, this might also be a way around the essential nonlinearities of shadow prices. In the case of fertilizers, the physical balances are indispensable in view of environmental limitations.

Capital investment and incomes. The total capital investment required for regional agriculture has to be assessed. The investment needed by the various producer types for different activities carried out using various technologies should be estimated on an individual basis. Let us comment on the financial aspect for the distinction of three producer types on the basis of land ownership in a mixed economy: state, cooperative, and private. Capital investment conditions for collective and private farms may be assessed similarly, but a different approach should be used for state farms. The differences in farm organization are reflected in these two approaches. On state farms all income goes to the state, which pays the farmworkers a wage. The workers are thus not dependent on the results of production for their income, as are those on collective or private farms. The state also supplies the farms with all requirements such as seed, fertilizers, and the capital investment necessary to achieve the desired level of growth in output and expansion of activities. In the case of collective farms, it is the members who decide what proportion of the farm income should be spent on capital investment and what on consumption through disposable income. However, they are able to obtain some external funds for the expansion of activities, usually in the form of credits, loans, or subsidies from the local or central authorities. In the case of private farms, the owner is responsible for providing most of the capital investment necessary to increase his output or to expand his activities, which is thus closely connected with his current expenditure and revenue. In GRAM the capital investment constraints are therefore allowed to vary according to producer types, as are also constraints specifying minimum income levels per capita.

The availability of external capital investment funds is one of the main factors in determining the rate of regional agricultural growth. In this respect, constraints resulting from the addition of internal and external funds exist at the subregional as well as the regional level. It is possible to ascertain the degree of dependence of the regional agricultural structure, output, and income on the allocation of external finance by varying the level of external investment in agriculture. Furthermore, the efficiency of this investment can be measured and compared with the efficiencies achieved in other sectors of the economy.

Animal feeds. To achieve regional livestock growth, it is essential that livestock be provided with adequate and well balanced feeds. Thus, the following main issues should be examined.

(1) Is the region able to supply its livestock with a complete range of animal feedstuffs (a balance of feed types and elements, such as green or rough, and succulent or protein content, should be included in the model)?

(2) What possibilities exist to export excess feedstuffs produced?

(3) What influences do internal and external animal feed supplies have on regional livestock specialization and on the scale of future levels of feed production?

Some models (e.g., Gouevsky and Maidment 1977) treat animal feed supply alternatives as fixed; this has both advantages and disadvantages. Although it may simplify the model description, it can lead to errors in cases where the real situation is more complex (and changeable), so that even a great number of fixed "diets" would not suffice to define the effectively optimal diet and the related production structure. It can never be assumed a priori that an adequate precision of optimization can be achieved via the fixed diet approach in conditions of changing crop production structure, particularly insofar as it is impossible to know in advance what the dependence of the objective function will be upon the location of the program in the vertices in the vicinity of the optimal one. Therefore, the approach chosen for GRAM is free formation of animal feeding schemes, through (implicit) solutions of the optimal diet problem embedded in the whole LP problem. The diet problem is expressed through a set of constraints on minimal and maximal consumption of feed elements. This enables a choice to be made about optimal animal feed production according to regional specialization of crop cultivation and available external supplies. In most cases, such an analysis appears to be very important. It has been shown that in the USSR an economy of several million tons of crop could be achieved using optimal free balances of forage crops (Albegov 1975).

Because a significant part of crop production is required for feeding livestock, it is important that an optimal balance between crop and livestock production can be explicitly obtained. The problem of organizing the animal feed processing industry should be solved separately, analogously to food processing in general, and this is discussed below.

Product balance constraints. First, there are product balances in the form of equations that sum up all the products obtained on the one hand, and all the ways in which they are used on the other. In addition, there are internal production balances that express, for example, import quotas or capacities of storage and transportation facilities. These sales and purchases constraints, because of their simplicity, can also be used just for accounting purposes, even in cases when some or all of them are insignificant. Their importance is obviously greater in strictly controlled economies or in economies under stress.

3.3.2 Activities

As mentioned above, it was decided that in GRAM the activity variables should refer to crops and not to crop rotation schemes. Although this choice in fact determines only a small portion of the model (such as constraints defining crop rotation conditions), it has an important influence on data preparation and interpretation of results, and thus determines to a high degree the philosophy of the model. The justification for such a choice is analogous to that for the explicit diet problem solution for livestock feeding. First, a much greater number of crop rotation schemes than crops would usually be required. Furthermore, even for quite a large number of crop rotation schemes it is quite possible that the economically optimal one will not be among them. Another problem arises when there is a need to change the rotation scheme in the middle of the sequence.

Production structure. To obtain practical results, a detailed model is required in which all major agricultural products (about 20–30, including livestock and annual and perennial crops) are described. For instance, for the USSR (Albegov 1975) it has been shown that at the national level no fewer than 15 crop products should be described in the model (spring wheat, winter wheat, rye, oats, barley, maize, beans, potatoes, forage and sugar beets, annual and perennial grass, different types of animal feed products), and there should also be a place for fruit and vegetable production. At the regional level a similar number of crops is usually specified, although the types differ slightly from the aggregated ones specified at the national level.

The production structure in general should be defined, as indicated before, according to crops, subregions, producer types, soil quality, and technologies. Such a structure is shaped by all the resource availability and balance constraints mentioned above.

In principle, agricultural processes directly involve dynamics. However, when considering problems of a general nature, such as regional agricultural specialization, it is not necessary to specify details of the dynamics such as year-to-year changes in the area of land used for cultivation of a particular crop and in the livestock production structure. A detailed time-span analysis, however, is more important when a significant variation in the volume of production of some important crop or livestock product occurs, or when the amount of a resource increases or decreases dramatically over time.

The dynamics of regional livestock production is reflected directly in the herd structure, which in turn influences the structure and volume of livestock products. Thus, not only should these products be included in GRAM in an aggregate form, but also livestock specialization might be represented, e.g., cattle rearing for meat, milk, or both; sheep rearing for meat or wool; poultry breeding for meat or eggs. The model (if compared with that of Gouevsky and Maidment 1977) could therefore describe the structure of future regional livestock production, taking into account all available alternatives. The above points are included in GRAM by the use of indices representing appropriate technology and specialization in the variables concerning livestock production. The herd structure, however, is not described directly, but has to be determined exogenously or through appropriate cost-and-price coefficients, reflecting average reproduction parameters and animal prices.

Since the tendency to organize agriculture on the basis of agro-industrial integration is becoming more widespread, the agricultural product processing industry needs to be briefly discussed. Once the optimal volumes and locations of crops and livestock are defined the problem of where the processing plants should be located and at what capacities can be solved. Location depends to a large extent on the transport infrastructure, since for many products rapid transportation of the products to users and consumers within and outside the region is essential. The separation of the procedure into two stages, as proposed above, could introduce errors, although these can be diminished through use of production and sale limits, whose values are based upon certain predefined feasible configurations and capacities of processing plants, transportation facilities, etc., for which aggregate shadow prices could thereafter be obtained. Thus, an iterative procedure leading to a globally optimal location and capacity program can be established.

Errors resulting from separation would therefore not be as significant as in the case when a detailed description of the processing industry is included in the model. For this latter case, the description of crop and livestock production would have to be simplified because the size of the model is restricted and decisions would have to be made about the geographical extent of processing, storage, and transport facilities to be taken into account.

Another way around this question could be to introduce just a few additional aggregate activity variables for processed food, making it possible to assess the efficiency of processing in a crude fashion.

Choice of technology. When developing a regional agriculture model, it is essential to examine the various types of agricultural technology that can appear in the system. These should be evaluated in relation to the particular conditions of the subregion, such as the availability of capital investment, the cost of water and fertilizers, and the labor supply. Thus the determination of an optimal set of technologies to be considered in the model requires some preliminary calculations, which should be carried out during the establishment of the data base. The results should be combined with a variety of possible technology options and then included in the appropriate version of GRAM.

When preparing the resource use and cost coefficients for various technologies, extensive use should be made of the data specifying explicit production-function-type relations. (Implicit marginal substitution relations can be obtained through optimal characteristics for a given regional setting.)

The choice and parameters of a technology depend on many features of the farms in the area, such as size, which in turn depend on the type of property ownership. As a preliminary calculation, it is therefore necessary to assume the future size of each type of farm (by, for example, determining the optimal farm size if analyzed in a normative framework). The optimization method presented by Kulikowski (1978) could for instance be used for this purpose. For such a forecast, one should have some idea of possible technologies that depend on machinery, fertilizers, water, use of manual labor, and so on, although these dependences could be presented in a more explicit production function form.

The farmer's real response to modern technology is an important factor governing the success of the implementation of the model. The farmer must be convinced that new technology will significantly improve his output in the long term before he replaces his old machinery and methods, and so the model should determine conditions for such a situation. Thus, for example, in order for the farmer to use water the price of water (for a certain volume meant for irrigation) coupled with unit cost of irrigation structures on the farm should be less than the marginal value of water. In this case it would be necessary to investigate the water pricing system since the inducing price may be below the supply cost level. GRAM should then be constructed in such a way that it is possible to account for the influences of water cost as an element of technology on the structure and volume of regional agricultural output.

Product flows. Since the model will explicitly establish the balance between crop and livestock production, and will account for financial relations within the system, it is necessary to introduce activity variables connected with the origins and destinations of product flows. Flows of produce meant for livestock, for local human consumption, and for export, as well as the appropriate flows of imported products, should all be distinguished.

Additionally, it was assumed necessary, because of the variety of prices and of differing sale and purchase conditions, to distinguish markets on which appropriate transactions are made. Thus, the markets might be export/import and internal, wholesale and retail, etc. Such distinctions make it easy to account for sales and purchases with appropriate prices in financial constraints and in objective functions.

3.3.3 Objective Functions

The type of objective function used is primarily dependent on the policy defining the agricultural development of the particular region. Thus objective functions should in principle be custom-made, although a small number of general objective functions could be formulated to fit most regional development cases.

Hence, the major types of objective function that should be included in the model are: monetary net output and monetary (or physical) gross output. For the former, a direct cost–benefit comparison is made, while for the latter, some policy-oriented objectives are sought, such as maximization of a certain predefined product or product contents. Usually an equivalence coefficient vector has to be introduced in physical objective functions for purposes of aggregating various commodities. Such coefficients may be based on the protein content, for example, on the protein content weighted with some other elements, or just upon a previously defined "optimal" element mix ("diet"). These coefficients play the role of prices used in monetary objective functions. Non-monetary objective functions are not often used, so the monetary type will be described in more detail. The prices applied change according to the destination and origin of the products, or to variations in the structure of the model, i.e., the interpretation of flows in the objective function. The various product uses, and the potential sales and purchasing of products via various markets should be explicitly considered.

Actual expressions of monetary objective functions first have to include income from agriculture, i.e., full accounting of revenues and expenses on primary agricultural products, with alternative treatment of capital and current expenditures and wages in various producer groups. Another objective function of the accounting type is the balance of regional trade. There may also be monetary objective functions of gross output type, which may account for the whole productive output or for portions of it.

It should be emphasized that for each case considered the specification of objective functions and their interpretation should be given over to appropriate decision-makers, interest groups, and other participants in regional development. As already mentioned, the duty of the modeler in this respect is to determine the feasibility and scope of control, and also to coordinate achievements that will satisfy all interested parties.

3.4 Uses of the Model

The main output of the model is a detailed specification of the production structure, together with the pattern of direct utilization of production. The structure obtained is optimal with respect to a predefined objective. By parametrizing the main resource constraints, the model can be used to indicate essential bottlenecks, distribution inconsistencies, etc. When appropriately wide ranges of dual variables are obtained, they can be used for intersectoral efficiency studies within the region, and for interregional assessments of agricultural efficiency. Simultaneously, the information thus acquired is sufficient for communication with other models in a regional development model system.

The model is intended to be used in decision- or policy-making, and that is what the information gained with it should be used for. As far as real policy-making is concerned, the situations theoretically range from a strict government taking into account the interests of direct producers merely through appropriate constraints, to an "invisible hand" directing the rational behavior of seemingly uncontrolled producers. In practice, there is always an "intelligence" and decision center whose capacities may vary; and there are always interest groups that can more or less effectively influence the policies and their outcomes by shaping the policy instruments themselves, and then by behaving more or less according to a "central decision-maker's" anticipations. Let us begin by looking at the possibilities of policy-making with the help of GRAM that the decision center has.

Policies can be determined by optimizing the model for objectives of all involved groups of producers, and comparing the shadow prices for the distribution-prone resources (capital investment funds, water projects, etc.) thus obtained with those for global objective functions. When this information has been obtained, one can optimize the efficiency of the resources used as control devices. (The use of resources can be optimized based uniquely on values of their shadow prices for one global objective function, but only where the agricultural system is assumed to be wholly under one management.) Such a procedure should not be confused with the standard price coordination technique since in this case the full model is solved explicitly and no regularizing assumptions are made.

Another multi-criteria approach, which also refers to producer groups or types as seen from the regional decision center, has been proposed by Seo and Sakawa (1979). This approach postulates the construction of a utility function based on resource shadow prices for different producers, and then proceeds to their aggregation for the whole system.

Thus, if the initial problem is

$$\max_{x_i \in X} \{f_1(x_1), \ldots, f_m(x_m)\}$$

where x_i is an n-dimensional decision vector of the ith producer group ($i = 1, \ldots, m$), then this problem is transformed into another:

$$\max_{x_i \in X} U\{f_1(x_1), \ldots, f_m(x_m)\}$$

where U is a multi-attribute utility function. In fact, U is not directly defined over f_i, as will be seen below. The procedure starts with the producer group problems

$$\max_{x_i \in X_i} f_i(x_i)$$

for which dual solutions λ_i are obtained. Values of λ_{ij} for individual resources j are used to construct the subsystem's utility functions. Since, provided certain standardization assumptions hold true, the numerical values of the shadow prices λ_{ij} correspond to a local decision-maker's preference ordering, the utility is determined by a linear transformation. The subsystem utility functions are then nested into a global, multi-attribute utility function, which can be optimized while keeping track of the satisfaction of the producer types. The method outlined is fully feasible with a well programmed LP model.

Either of these two methods can handle a compromise between a global objective and the objectives of producers. On the one hand, this compromise can be observed via dual values, and on the other simply via income levels (in the minimal income constraints) for producer groups. Such a mechanism enables an explicit compromise to be made between all the elements involved over the values represented in the model.

In addition to this question of inter-actor coordination with respect to a given objective there is also the problem of goal structure stemming from the fact that usually a number of goals are pursued at each level. In many cases special studies are required in order to establish the goal structure within a development program. In this situation coordination or compromise should be performed among goals or goal achievement measures.

For an explicit solution of the essentially multi-objective problem (i.e., not a coordination with respect to a higher-level objective or an aggregation) the interactive technique proposed by Wierzbicki (1979) can be used. Suppose we have an initial multi-criteria problem

$$\max(C_i^T x = q_i) \qquad i \in \{1, \ldots, p\}$$

subject to $\Omega x = \gamma$ and $x \geqslant 0$, where x is an n-dimensional decision variable vector, C_i are vectors of the criterion coefficients, Ω is the matrix of technical coefficients, γ is the vector of the right-hand sides, and p is the number of criteria.

The method proceeds by specifying the aspiration levels, referred to as "reference points": $\bar{q}_i$, $\bar{q} = (\bar{q}_1, \ldots, \bar{q}_p)$. For the vector reference point $\bar{q}$ and the vector of actual values q, a scaling function $s(q - \bar{q})$ has to be defined. A proposed function is

$$s(q - \bar{q}) = s(w) = -\min\left(\min_i gw_i, \sum_i w_i\right) - ew$$

where $g \geqslant p$, $e \geqslant 0$, $w = q - \bar{q}$. With this "distance" function one can formulate a uni-criterion LP program, which is solved instead of the initial problem. The reformulated LP problem yields a Paretian solution $\hat{q}$ with regard to $\bar{q}$ (see Kallio *et al.* 1980), which is a very strong and important property.

An interactive procedure can be organized for obtaining successive $\hat{q}_k$ that correspond to $\bar{q}_k$ given by the decision-maker on the basis of previous results. From the conceptual point of view, the method makes it possible to reflect the very nature of the situation considered. Namely, there exist definite requirements of the aspiration level (reference point) type, e.g., to produce a certain amount of grain, sugar beet, etc. or to attain a certain income level per capita, etc. The use of explicit reference points is much more adequate than weighting or trade-off coefficients, which in any case may be obtained with this method a posteriori. The interactive mode of operation is helpful in the solution search.

The software for the technique outlined, i.e., for the transformation of the LP problem, has been developed and is available at IIASA.

It should be remembered, however, that the reference point technique provides Paretian solutions with regard to $\bar{q}$, and not to initial $C_i^T x$. In fact, the distance function $s(q - \bar{q})$ refers to $w = q - \bar{q}$, and not explicitly to q. To obtain Paretian solutions for the initial problem one would have to utilize a sort of goal-programming approach, which is much less numerically acceptable. Hence, by combining these two types of multi-criteria assessment techniques one can obtain balanced policy proposals. According to previous indications these may address various types of decision-making situations.

As indicated above, the model is meant to cooperate with other elements of the regional model system. Two predominant types of information will be exchanged in the coordination process: shadow prices (dual variables) used hereafter as cost coefficients, and output volumes used hereafter as constraints. It is certainly much easier to deal with the latter since they do not require intervention in the coefficient matrix. Such changes are, however, in general unavoidable, and they should be provided for via appropriate software procedures. Some resource distribution models may require knowledge of the whole optimal characteristic function for a number of resources being distributed, in order to dispose of an efficiency indicator hypersurface of use of a resource, whether on a subregional, regional, or interregional level (see Kulikowski and Krus 1980 for the application of a net production efficiency indicator function in a regional distribution problem). This would necessitate a number of model runs for each function through parametrization of the right-hand sides, but should not represent a serious difficulty.

It should be kept in mind when devising model coordination schemes that shadow prices can be treated merely as indices for iterative procedures and that their economic significance, though sometimes important, is quite limited. Sounder conclusions can only be drawn from the full shadow price optimal characteristics, from which real costs could also be inferred.

There may be a number of other particular problems connected with model coordination, such as consistency of regional breakdown or correspondence of constraints to limits and limits to costs, but these should be solved separately for each case.

4 MODEL FORMULATION

The model has the standard LP form:

$$\Omega \widetilde{X} \left\{ \begin{matrix} \leqslant \\ = \\ \geqslant \end{matrix} \right\} \Gamma$$

$$\omega_\eta \widetilde{X} \rightarrow \max,$$

where Ω represents the matrix of coefficients, $\widetilde{X}$ is the vector of all decision variables (activity values), Γ is the vector of constraining values (mostly resource limitations, requirements, or balance conditions), and ω_η are the objective function cost-and-income coefficients for the activity variables. It has multiple objective functions $\eta = 1, 2, \ldots,$ and is complemented with some additional procedures, described below. The model, as described here, represents the implementation valid as of January 1980. Further improvements have been made since then.

An overview of the constraints Ω, $\widetilde{X}$, and Γ is given in Table 2, where all coefficient subtables and their correspondence to appropriate portions of $\widetilde{X}$ are indicated. The table also gives the nature of the constraints and bounds, i.e., constraining values. The details and complexity of the model are, however, not fully revealed by the table, since summations

TABLE 2 Schematic GRAM model constraints. GRAM-Gen mnemonics refer to the software implementation explained in Section 5.

GRAM No.	GRAM-Gen mnemonic	Lower limit[a]	GRAM variable classes X	Y	Z	U	V	W	O	P	Q	R	S	T	Con. type	Right side	Index subsets
(1)	EL.PR.		U												$=$	L^{pr}	$w = m^b$
(2)	BL.PRA	$L^{min}_{pr\alpha}$	U												$\leqslant$	$L^{max}_{pr\alpha}$	
(3)	BL.PR.	L^{min}_{wpr}	U												$\leqslant$	L^{max}_{wpr}	$w = m^b$
(4)	BLSPRA	$L^{min}_{prs\alpha}$	U												$\leqslant$	$L^{m}_{prs\alpha}$	particular s
(5)	AM.PR.		U												$\leqslant$	L^{m}_{pr}	$w = m^b$
(6)	CIYPR.		$-U$	U^1											$\leqslant$	$\emptyset$	
(7)	LIIPR.		1	1	-1		-1						-1		$=$	$\emptyset$	
(8)	LJMPR.					0		-1	-1					-1	$=$	$\emptyset$	
(9L)	CNNPR.N				$-M$	R			$-N$	$-M$					$\leqslant$	$\emptyset$	according to pr
(9R)	CNNPR.M				M	$-T$			N	M					$\leqslant$	$\emptyset$	according to pr
(10L)	CNNP. .N				$-M$	R			$-N$	$-M$					$\leqslant$	$\emptyset$	according to p
(10R)	CNNP. .M				M	T			N	$-M$					$\leqslant$	$\emptyset$	according to p
(11)	BII. . .	F^{min}_{i}					1				1				$\leqslant$	F^{max}_{i}	
(12)	BJM. . .	F^{min}_{m}						1				1			$\leqslant$	F^{max}_{m}	
(13)	AB.PR.		B	B		G									$\leqslant$	B_{pr}	
(14)	AB. . . .		B	B		G									$\leqslant$	B	
(15)	AD.PR.		D	D		I									$\leqslant$	D_{pr}	
(16)	AD. . . .		D	D		I									$\leqslant$	D	
(17)	AK.PR.		J	J		K									$\leqslant$	$\hat{D}^1_{pr}$	
(18)	AK. . . .		J	J		K									$\leqslant$	$\hat{D}^1$	
(19)	AY.PR.		S	S		Y									$\leqslant$	$\hat{D}^2_{pr}$	
(20)	AY. . . .		S	S		Y									$\leqslant$	D^2	
(21)	AE.PR.		E	E		$-W$									$\leqslant$	E_{pr}	

TABLE 2 *Continued.*

GRAM No.	GRAM-Gen mnemonic	Lower limit[a]	GRAM variable classes X	Y	Z	U	V	W	O	P	Q	R	S	T	Con. type	Right side	Index subsets
(22)	AE. . . .		E	E		$-W$									$\leqslant$	E	
(23)	BFF. . .	M_f	A	A		$-F$									$\leqslant$	G_f	
(24)	BFFPR.	M_{fpr}	A	A		$-F$									$\leqslant$	G_{fpr}	
(25)	KPI. .L									1					$\leqslant$	H_{il}	
(26)	KQI. .L										1				$\leqslant$	I_{il}	
(27)	KRM. .L											1			$\leqslant$	I_{ml}	
(28)	KSI. .L												1		$\leqslant$	$\bar{I}_{il}$	
(29)	KTM. .L													1	$\leqslant$	$\bar{I}_{ml}$	
(30)	AC.PR.		H	H'		L									$\leqslant$	C_{pr}	
(31)	AC. . . .		H	H'		L									$\leqslant$	C	
(32)	DW.PR.		$-SX$	$-SU$		$-SU$				$-\$P$	$-\$Q$	$-\$R$	$\$S$	$\$T$	$\geqslant$	$W_p B_{pr}$	

[a]Omitted when all zero.
[b]$w = m$ means pasture land.

over various subsets of indices in coefficient tables and in decision variables may occur. It is therefore necessary to present the model explicitly. The following items will be specified: indices used; coefficients (hence coefficient tables); bounds (i.e., constraining values); and decision variables. Also, formulae for constraints and objective functions are presented.

Indices. The indices used in the model are as follows:

i = type of crop, e.g., wheat, sugar beet;
$I = \{i\}$, set of all crop indices;
ω = index of crop rotation group I^{ω}, where $\cup_{\omega} I^{\omega} = I$, $I^{\omega'} \cap I^{\omega''} = \emptyset$, $\omega' \neq \omega''$, e.g., grains or starchy root crops;
j = type of livestock, e.g., milk cows, sows;
k = specialization of livestock production, e.g., meat, dairy products;
m = type of livestock product, e.g., meat, milk;
r = number of subregion corresponding, for example, to an administrative division;
n = feed component for livestock, e.g., nutrition units, dry mass;
l = type of market for purchasing/selling commodities, such as internal state market;
p = type of farm (producer), e.g., private, state-owned;
s = technology of crop raising, e.g., presently used, intensive with sprinkling;
α = land quality, e.g., weak and light, or weak and heavy soils;
s' = breeding technology, related for example to size of herd or stable;
f = type of fertilizer, e.g., containing nitrogen or phosphorus, or mixed artificial, natural;
β_i = second crop, the best or only successor to the first crop i.

Coefficients. The following coefficients are included, forming appropriate tables (the letters in parentheses indicate notations from Table 2):

(A) $a_{fiprs\alpha}$ = demand of fertilizer f to produce unit of crop i on land α in subregion r by producers p with technology s;
(F) $\hat{a}_{fjks'}$ = production of manure fertilizers per unit of livestock raised;
(B) $b_{iprs\alpha}$ = labor requirement in crop production;
(G) $b_{jkprs'}$ = labor requirement in livestock breeding;
(H) $c_{iprs\alpha}$ = capital (investment) demands in crop raising without technology transformation;
(H′) $\bar{c}_{iprs\alpha}$ = as above, with technology transformation;
$c_{jkprs'}$ = capital (investment) demand in livestock breeding without technology transformation;
(L) $\bar{c}_{jkprs'}$ = as above, with technology improvement;
(D) $d_{iprs\alpha}$ = water demand for crop raising (annual total);
(J) $\hat{d}^{1}_{iprs\alpha}$ = as above, for the first peak period;
(S) $\hat{d}^{2}_{iprs\alpha}$ = as above, for the second peak period;
(I) $d_{jkprs'}$ = water demand for livestock breeding (annual total);

(K) $\hat{d}^1_{jkprs'}$ = as above, for the first peak period;

(F) $\hat{d}^2_{jkprs'}$ = as above, for the second peak period;

(E) $e_{iprs\alpha}$ = machinery demand for crop production;

(W) e_{jkp} = equivalent pulling power of animals jk in farm p;

(R, T) $f^{\min,\max}_{njk}$ = minimum and maximum demand for feed components for livestock;

(M) g_{in} = contents of feed components in crops;

(N) g_{mn} = contents of feed components in livestock products;

(O) $h_{mjkps'}$ = livestock product yields per unit of livestock bred;

n_i = contents of nutrition units in crops;

n_m = contents of nutrition units in livestock products;

($S) P_{il} = unit price of home-produced crops on market l;

($T) P_{ml} = unit price of home-produced livestock products on market l;

($P) P^{imp}_{il} = unit price of crops purchased for livestock feeding on market l;

($Q) $\bar{P}^{imp}_{il}$ = as above, for human consumption;

($R) P^{imp}_{ml} = unit price of livestock products purchased for human consumption on market l;

($X) $s_{iprs\alpha}$ = cost of crop production with seeds and fertilizers;

($U) $s_{jkprs'}$ = cost of livestock production, without forage;

(U) $u_{iprs\alpha}$ = yield of crops;

(U^1) $u^1_{iprs\alpha}$ = yield of crops raised as secondary crops.

Bounds. The following lower and upper bounds are used:

B = labor force, total in the region;
B_{pr} = as above, for producer types and subregions;
C = maximum external and internal capital (investment) funds available in the region;
C_{pr} = as above, for producer types and subregions;
D = total annual water volume available;
$\hat{D}^1$ = as above, for the first peak period;
$\hat{D}^2$ = as above, for the second peak period;
D_{pr} = annual water volume available, for producer types and subregions;
$\hat{D}^1_{pr}$ = as above, for the first peak period;
$\hat{D}^2_{pr}$ = as above, for the second peak period;
E = total available machinery;
E_{pr} = machines available for producer types and subregions;

$F_i^{\min,\max}$ = minimum and maximum human consumption of crops i;

G_f = maximum available amount of fertilizer f;

G_{fpr} = as above, for producer types and subregions;

H_{il} = maximum crop purchases for livestock feeding from market l;

I_{il} = maximum crop purchases for human consumption from market l;

I_{ml} = maximum purchases of livestock products from market l;

$L_{wpr}^{\min,\max}$ = minimum and maximum area for crop group w (due to crop rotation conditions);

$L_{pr\alpha}^{\min,\max}$ = minimum and maximum area of given soil quality;

$L_{prs\alpha}^{\min,\max}$ = minimum and maximum area of land transformable with technology s;

L_{pr} = area of arable land;

L_{pr} = area of meadows and pastures;

M_{fpr} = environmental bounds on fertilizers and manure;

W_{pr} = minimal income per capita.

Decision variables. The following decision variables are included in the model (the letters in parentheses denote abbreviations used in Table 2):

(X) $X_{iprs\alpha}$ = volume of primary crop i produced by producers p of subregion r, using technology s, on soil α;

(Y) $Y_{iprs\alpha}$ = as above, for secondary crops;

(V) W_{ipr} = own consumption of crop i produced by producers p of subregion r by population connected with producers p in subregion r;

(Z) Z_{ipr} = as above, consumed by own livestock;

(U) $X_{jkpr'}$ = number of livestock j bred in specialization k and technology s', by farms p in subregion r (producer groups pr);

(W) W_{mpr} = own consumption of livestock products produced in a pr by population related to that pr;

(O) Z_{mpr} = as above, for human consumption within pr;

(P) P_{iprl} = purchase of crop i for forage from market l by producers p of subregion r;

(Q) Q_{iprl} = as above, for human consumption within pr;

(R) Q_{mprl} = purchase of livestock product m for human consumption within pr from market l;

(S) R_{iprl} = sale of crop i to market l by producer group pr;

(T) R_{mprl} = as above, sale of livestock product m.

Constraints. The description of constraints is divided into the following groups concerning particular aspects:

1. *Land use*

(a) Availability of arable land:

$$\sum_{\substack{i \in I - I^m \\ s, \alpha}} \frac{X_{iprs\alpha}}{u_{iprs\alpha}} = L_{pr} \tag{1}$$

where $m = \omega$ for meadows and pastures.

(b) Availability of land of a particular quality:

$$L_{pr\alpha}^{\min} \leqslant \sum_{i,s} \frac{X_{iprs\alpha}}{u_{iprs\alpha}} \leqslant L_{pr\alpha}^{\max} \tag{2}$$

(c) Availability of arable land for crops I^{ω} due to crop rotation:

$$L_{\omega pr}^{\min} \leqslant \sum_{\substack{i \in I^{\omega} \\ s, \alpha}} \frac{X_{iprs\alpha}}{u_{iprs\alpha}} \leqslant L_{\omega pr}^{\max} \tag{3}$$

(d) Availability of transformable land, i.e., for a particular technology s:

$$L_{prs\alpha}^{\min} \leqslant \sum_{i} \frac{X_{iprs\alpha}}{u_{iprs\alpha}} \leqslant L_{prs\alpha}^{\max} \tag{4}$$

(e) Availability of meadows and pastures:

$$\sum_{\substack{i \in I^m \\ s, \alpha}} \frac{X_{iprs\alpha}}{u_{iprs\alpha}} \leqslant L_{pr}^{m} \tag{5}$$

where $m = w$ for meadows and pastures.

(f) Availability of land for secondary crops:

$$\sum_{\substack{i^* \in \beta_i \\ s, \alpha}} \frac{Y_{i^*prs\alpha}}{u^1_{i^*prs\alpha}} - \sum_{s,\alpha} \frac{X_{iprs\alpha}}{u_{iprs\alpha}} \leqslant 0 \tag{6}$$

2. *Crop and livestock product balances*

(a) Crops:

$$\sum_{s,\alpha} (X_{iprs\alpha} + Y_{iprs\alpha}) - W_{ipr} - Z_{ipr} - \sum_{l} R_{iprl} = 0 \tag{7}$$

(b) Livestock products:

$$\sum_{j,k,s'} h_{mjkps'} X_{jkprs'} - W_{mpr} - Z_{mpr} - \sum_{l} R_{mprl} = 0 \tag{8}$$

3. *Forage balances*

(a) For a particular pr:

$$\sum_{j,k,s'} f_{njk}^{\min} X_{jkprs'} \leqslant \sum_{i} g_{in} Z_{ipr} + \sum_{i,l} g_{in} P_{iprl} + \sum_{m} g_{mn} Z_{mpr} \leqslant \sum_{j,k,s'} f_{njk}^{\max} X_{jkprs'} \tag{9}$$

(b) For the whole region but possibly also according to p:

$$\sum_{j,k,r,s'} f_{njk}^{\min} X_{jkprs'} \leqslant \sum_{i,r} g_{in} Z_{ipr} + \sum_{i,r,l} g_{in} P_{iprl} + \sum_{m,r} g_{mn} Z_{mpr} \leqslant \sum_{j,k,r,s'} f_{njk}^{\max} X_{jkprs'} \tag{10}$$

4. *Limits of agricultural product consumption by local population*

(a) Crops:

$$F_i^{\min} \leqslant \sum_{p,r} W_{ipr} + \sum_{p,r,l} Q_{iprl} \leqslant F_i^{\max} \tag{11}$$

(b) Livestock products:

$$F_m^{\min} \leqslant \sum_{p,r} W_{mpr} + \sum_{p,r,l} Q_{mprl} \leqslant F_m^{\max} \tag{12}$$

5. *Resource constraints*

(a) Labor:

For a particular pr,

$$\sum_{i,s,\alpha} b_{iprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) + \sum_{j,k,s'} b_{jkprs'} X_{jkprs'} \leqslant B_{pr} \tag{13}$$

For the whole region,

$$\sum_{i,p,r,s,\alpha} b_{iprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) + \sum_{j,k,p,r,s'} b_{jkprs'} X_{jkprs'} \leqslant B \tag{14}$$

(b) Annual water availability:

For a particular pr,

$$\sum_{i,s,\alpha} d_{iprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) + \sum_{j,k,s'} d_{jkprs'}X_{jkprs'} \leqslant D_{pr} \tag{15}$$

For the whole region,

$$\sum_{i,p,r,s,\alpha} d_{iprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) + \sum_{j,k,p,r,s'} d_{jkprs'}X_{jkprs'} \leqslant D \tag{16}$$

(c) Water availability in the first peak period:

For a particular pr,

$$\sum_{i,s,\alpha} \hat{d}^1_{iprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) + \sum_{j,k,s'} d^1_{jkprs'}X_{jkprs'} \leqslant \hat{D}^1_{pr} \tag{17}$$

For the whole region,

$$\sum_{i,p,r,s,\alpha} \hat{d}^1_{iprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) + \sum_{j,k,p,r,s'} d^1_{jkprs'} \leqslant \hat{D}^1 \tag{18}$$

(d) Water availability in the second peak period:

For a particular pr,

$$\sum_{i,s,\alpha} \hat{d}^2_{iprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) + \sum_{j,k,s'} \hat{d}^2_{jkprs'}X_{jkprs'} \leqslant \hat{D}^2_{pr} \tag{19}$$

For the whole region,

$$\sum_{i,p,r,s,\alpha} \hat{d}^2_{iprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) + \sum_{j,k,p,r,s'} \hat{d}^2_{jkprs'}X_{jkprs'} \leqslant \hat{D}^2 \tag{20}$$

(e) Pulling power:

For a particular pr,

$$\sum_{i,s,\alpha} e_{iprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) - \sum_{j,k,s'} e_{jkp}X_{jkprs'} \leqslant E_{pr} \tag{21}$$

For the whole region,

$$\sum_{i,p,r,s,\alpha} e_{iprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) - \sum_{j,k,p,r,s'} e_{jkp}X_{jkprs'} \leqslant E \tag{22}$$

(f) Fertilizers:

For a particular pr,

$$M_{fpr} \leqslant \sum_{i,s,\alpha} a_{fiprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) - \sum_{j,k,s'} \hat{a}_{fjks'} X_{jkprs'} \leqslant G_{fpr} \tag{23}$$

For the whole region,

$$M_f \leqslant \sum_{i,p,r,s,\alpha} a_{fiprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) - \sum_{j,k,p,r,s'} \hat{a}_{fjks'} X_{jkprs'} \leqslant G_f \tag{24}$$

6. *Purchase limits*

(a) Crops for livestock (may not concern all i):

$$\sum_{p,r} P_{iprl} \leqslant H_{il} \tag{25}$$

(b) Crops for human population (will concern a limited number of i):

$$\sum_{p,r} Q_{iprl} \leqslant I_{il} \tag{26}$$

(c) Livestock products for human population:

$$\sum_{p,r} Q_{mprl} \leqslant I_{ml} \tag{27}$$

7. *Sale limits*

(a) Crops (may not concern all i):

$$\sum_{p,r} R_{iprl} \leqslant \bar{I}_{il} \tag{28}$$

(b) Livestock products:

$$\sum_{p,r} R_{mprl} \leqslant \bar{I}_{ml} \tag{29}$$

8. *Financial limits*

(a) Capital investments:

For a particular pr,

$$\sum_{i,s,\alpha} (c_{iprs\alpha} + \bar{c}_{iprs\alpha})(X_{iprs\alpha} + Y_{iprs\alpha}) + \sum_{j,k,p,r,s'} (c_{jkprs'} + \bar{c}_{jkprs'}) X_{jprs'} \leqslant C \tag{30}$$

For the whole region,

$$\sum_{i,p,r,s,\alpha} (c_{iprs\alpha} + \bar{c}_{iprs\alpha})(X_{iprs\alpha} + Y_{iprs\alpha}) + \sum_{i,j,s'} (c_{jkprs'} + \bar{c}_{jkprs'})X_{jkprs'}$$

$$\leqslant C_{pr} \tag{31}$$

(b) Minimal income for particular types of farms:

$$\sum_{i,l} P_{il}R_{iprl} + \sum_{m,l} P_{ml}R_{mprl} - \sum_{i,s,\alpha} s_{iprs\alpha}X_{iprs\alpha} - \sum_{j,k,s'} s_{jkprs'}X_{jkprs'}$$

$$-\sum_{i,l} P_{il}^{\mathrm{imp}}P_{iprl} - \sum_{i,l} \bar{P}_{il}^{\mathrm{imp}}Q_{iprl} - \sum_{m,l} P_{ml}^{\mathrm{imp}}Q_{mprl} \geqslant W_p B_{pr} \tag{32}$$

Objective functions. The objective functions specified below represent some aggregate activity indicators, related either to financial flows or to production volumes.

(a) Total net return or net production value resulting from agricultural activities within the region:

$$\sum_{i,p,r,l} P_{il}R_{iprl} + \sum_{m,p,r,l} P_{ml}R_{mprl} - \sum_{i,p,r,s,\alpha} s_{iprs\alpha}X_{iprs\alpha}$$

$$- \sum_{j,k,p,r,s'} s_{jkprs'}X_{jkprs'} - \sum_{i,p,r,l} P_{il}^{\mathrm{imp}}P_{iprl} - \sum_{i,p,r,l} \bar{P}_{il}^{\mathrm{imp}}Q_{iprl} \tag{33}$$

$$- \sum_{m,p,r,l} P_{il}^{\mathrm{imp}}Q_{mprl}$$

(b) Balance of regional agricultural production expressed in monetary terms, i.e., according to unified prices and without costs:

$$\sum_{i,p,r,s,\alpha} P_{il}X_{iprs\alpha} + \sum_{m,j,k,p,r,s'} P_{ml}h_{mjkps'}X_{jkprs'} - \sum_{i,p,r,l} P_{il}^{\mathrm{imp}}P_{iprl}$$

$$- \sum_{i,p,r,l} \bar{P}_{il}^{\mathrm{imp}}Q_{iprl} - \sum_{m,p,r,l} P_{ml}^{\mathrm{imp}}Q_{mprl} \tag{34}$$

(c) Regional agricultural production expressed in nutrition units:

$$\sum_{i,p,r} n_i \left(\sum_{s,\alpha} X_{iprs\alpha} - \sum_{l} (P_{iprl} + Q_{iprl}) \right)$$

$$+ \sum_{m,p,r} n_m \left(\sum_{j,k,s'} h_{mjkps'}X_{jkprs'} - \sum_{l} Q_{mprl} \right) \tag{35}$$

Objective functions (b) and (c) are applied in cases when there are important deviations from cost structure in the price system and when agricultural commodities are obviously in short supply.

(d) Regional trade balance of livestock products in monetary terms:

$$\sum_{m,p,r,l} P_{il}R_{mprl} - \sum_{m,p,r,l} P_{ml}^{\mathrm{imp}} Q_{mprl} \tag{36}$$

(e) Production of livestock products in nutrition units:

$$\sum_{m,j,p,r,s'} n_m \left(h_{mjkps'} X_{jkprs'} - \sum_l Q_{mprl} \right) \tag{37}$$

(f) Export production in monetary terms:

$$\sum_{\substack{i,p,r\\ l=3}} (P_{il}R_{iprl} - \bar{P}_{il}^{\mathrm{imp}} Q_{iprl} - P_{il}^{\mathrm{imp}} P_{iprl})$$
$$+ \sum_{\substack{m,p,r\\ l=3}} (P_{ml}R_{mprl} - P_{ml}^{\mathrm{imp}} Q_{mprl}) \tag{38}$$

Since for particular purposes it may prove necessary to construct special problem-oriented functions, (33) to (38) should be treated as an initial proposition.

5 IMPLEMENTATION: GRAM-GEN

The purpose of this section is to present briefly the computer implementation of GRAM as it was carried out at IIASA – the generation of the model, basic options of the LP system, etc. The text is far from exhaustive; its aim is merely to show the reader some basic principles, modes of operation, etc.

5.1 Computer and System Environment

The dimensions of GRAM (about 3000 variables, and about 11 000 rows for the application described in the present report), and its density (*ca.* 2%) do not imply a need to use a special LP system and an extremely powerful computer. However, due to the anticipated "tightness" of the model and the need to obtain results in a very short time period, an advanced interactive LP system was considered to be very important.

Such a system, which fulfilled the above requirements and was easily accessible, was the SESAME/DATAMAT LP system designed by William Orchard-Hays (1977). This system is operating in Pisa, Italy, on the CNUCE's IBM Series 370 computer, which is connected with IIASA through a telex line. The computer is an IBM 370/168, working under a system that provides virtual machine and interactive mode of operation. Therefore, any user (usually about 100) logged in would appear to have all the computer facilities (disks, core, output devices, etc., except for tapes) at his disposal. The normal core allocation of IIASA is 500 or 680 kbytes, and this may be extended to 2000 kbytes.

The Pisa installation is connected with IIASA through a leased two-channel telex line. The first channel of 2400 baud transmission speed is intended for data transmission (output printing files), and is controlled by a TPA-70 minicomputer. The second, low-speed channel of 112 baud transmission speed is used for the interactive communication and is connected to a display terminal at IIASA. Some basic information about the software organization will be of use for understanding better the place and operation of SESAME/ DATAMAT. The basic operating system is CP (control program), which runs the real computer.

Generally speaking, the CP system enables the user to log into (or off) the installation, enter his password to be verified, send a message to the Pisa operator, display states of the system's facilities, etc. The next higher-level operating system is the CMS, which handles the *virtual* machine. Its basic tasks are to define an appropriate core storage allocation, attach disks to the virtual machine, specify the files to be used, manipulate the files, compile and run programs, carry out text editing (change of characters, deletion or addition of lines, sorting of files, etc.), and so on.

The SESAME mathematical programming system is a program in CMS, and, in turn, DATAMAT is a part of it – or better still, its extension. Since they are both crucial in the generation and running of GRAM, they will thus be described in more detail below. However, we will begin with DATAMAT and then proceed to SESAME.

5.2 DATAMAT and the Generation of GRAM

DATAMAT, an interactive data management system for linear programming applications, is a part of the SESAME LP system. The primary purposes of DATAMAT are as follows: (1) to create and maintain primary data in the form of arrays containing numerical values, symbolic values, or strings; (2) to generate, revise, and manipulate models; (3) to generate reports (including the calculations, arranging the print-outs into appropriate formats); (4) to perform additional calculations with some data; and (5) to inspect and display various quantities. The first three points will be described in more detail.

(1) In the creation and maintenance of primary data, the main possibilities are as follows: (a) construction (masking, extending, filing, etc.) of tables identified by column and/or row; (b) construction of empty tables with proper masking, selection, etc.; (c) input and updating of card-image files; (d) filing tables; (e) listing tables; (f) erasing tables; (g) deleting tables; (h) naming tables; and (i) arithmetical calculation tables.

(2) In generating, revising, and manipulating models, the main possibilities are as follows: (a) access to any coefficient in an existing model for testing or changing; (b) recall of an existing model for revision (the whole model or a submodel can be dealt with; merging of different models is possible); and (c) creation and change of new and/or existing model components.

More specifically, the main creation and change possibilities are as follows: (i) definition of row and column identifiers; (ii) definition of right-hand side identifiers; (iii) definition of range sets; (iv) definition of bound sets; (v) insertion of new columns, rows, right-hand sides, etc.; (vi) creation of linear combinations of two rows, columns, etc.

(3) The main possibilities are as follows: (a) definition of a suitable output format; and (b) definition of headings and footnotes.

DATAMAT is called from SESAME and is controlled by statements typed at the user's terminal. The following types of programmed subroutines may also be used:

(i) *Macros.* These are composed of strings of ordinary DATAMAT statements with the provision of argument substitution, looping, and branching. Macros make it possible to build highly specialized functions of great complexity. They are called by names. The main macros used concern: (a) definition of specified columns; (b) searching for a variable class name; (c) filling specified rows, columns, and tables; and (d) generation of specified parts of the model.

(ii) *DATARUN deck.* Here the whole DATAMAT program is read from a file. To run such a program, the file and deck names are specified. The main decks concern: (a) definition of appropriate set-up (file names, storage, etc.); (b) setting up parameters and files for merging; (c) preparation for solving the model by SESAME; (d) preparation for a modification or revision; and (e) extraction of submodels.

The DATAMAT data base consists of five main components (plus CR – the SESAME communication region):

1. The SESAME model whose name is in the CR file given in SDDMODEL. This model may be revised in DATAMAT and then refiled.
2. One or more SESAME LP result cases whose names are specified within DATAMAT. The result file is never changed by DATAMAT.
3. The SESAME file MAPSFILE, which is only read and only used for limited purposes related to models and results.
4. A table file, which contains the primary data on which DATAMAT operates. Its name is specified within DATAMAT. This file is created and used by DATAMAT only.
5. A working data base (WDB), which is either in the core storage or on scratch file. It disappears upon exit from DATAMAT.

Moreover, DATAMAT can read or write some additional data tables.

We shall now briefly show the use of DATAMAT in the case of generating GRAM. First, a diagram is devised corresponding to Table 2, which shows the general structure of the model in terms of row and column tables, left-hand sides, objective functions, etc. The names here are specific to the model generation program – GRAM-Gen – and correspond to the original GRAM notation given in Section 4, as follows:

1. Sets of indices:

GRAM-Gen	GRAM
I	i
I^{ω}	I^{ω}
J	j
K	k
M	m
R	r
N	n
L	l
P	p
S	s
A	α

GRAM-Gen (*continued*)	GRAM (*continued*)
T	s'
F	f
BETA	β_i

2. Decision variables:

GRAM-Gen	Table 2	GRAM
XI.PRSA	X	$X_{iprs\alpha}$
YY.PRSA	Y	$Y_{iprs\alpha}$
ZI.PR. .	Z	Z_{ipr}
UJKPRT.	U	$X_{jkprs'}$
VI.PR. .	V	W_{ipr}
W.MPR. .	W	W_{mpr}
O.MPR. .	O	Z_{mpr}
PI.PR.L	P	P_{iprl}
QI.PR.L	Q	Q_{iprl}
R.MPR.L	R	R_{mprl}
SI.PR.L	S	R_{iprl}
T.MPR.L	T	R_{mprl}

3. Constraints:

GRAM-Gen	GRAM bounds
EL.PR.	L_{pr}
BL.PRA	$L_{pr\alpha}^{\min,\max}$
BL.PR.	$L_{wpr}^{\min,\max}$
BLSPRA	$L_{prsx}^{\min,\max}$
AM.PR	L_{pr}^{m}
CIYPR.	ϕ
LIIPR.	ϕ
LJMPR.	ϕ
CNNPR.N	ϕ
CNNPR.M	ϕ
CNNP. .N	ϕ
CNNP. .M	ϕ
BII. . .	$F_{i}^{\min,\max}$
BJM. . .	$F_{m}^{\min,\max}$
AB.PR	B_{pr}

GRAM-Gen (*continued*)	GRAM bounds (*continued*)
AB. . . .	B
AD.PR.	D_{pr}
AK.PR.	$\hat{D}^1_{pr}$
AY.PR.	$\hat{D}^2_{pr}$
AD. . . .	D
AK. . . .	$\hat{D}^1$
AY. . . .	$\hat{D}^2$
BFF. . .	M_f, G_f
BFFPR.	M_{fpr}, G_{fpr}
KPI. .L	H_{il}
KQI. .L	I_{il}
KRM. .L	I_{ml}
KSI. .L	$\bar{I}_{il}$
KTM. .L	$\bar{I}_{ml}$
AC.PR.	C_{pr}
AC. . . .	C
DW.PR.	$W_p B_{pr}$

Other corresponding tables of coefficients, lower and upper bounds, etc., may be found in Orchard-Hays (1979). An example of the DATAMAT generation program is shown in Appendix A.

As can be seen from this condensed description of DATAMAT, it is a really powerful system and its availability has contributed to some extent to the short time devoted to numerical implementation.

5.3 SESAME LP System and its Potential

SESAME is an interactive system for solving large linear programming problems. The system is highly sophisticated, but in the description below, only those issues of interest to readers are mentioned, namely: (1) SESAME command language; (2) SESAME procedures; (3) SIMPLEX algorithm and parametric solutions; (4) solution print-outs.

(1) The SESAME command language is a simple language to control the run of the system. The main command groups concern: (a) entitling the outputs; (b) determination of proper output form and contents; (c) display of specified cell(s); (d) starting, finishing, etc., the run; and (e) reporting and correction of errors.

(2) The main SESAME procedures concern: (a) on-line browsing through the model; (b) specification of values of symbolic coefficients for studying nonlinearities or sensitivity; (c) static sensitivity; (d) file maintenance; (e) model input and output; (f) model set-up; (g) solution (primal and dual simplex algorithm, basis reinversion); (h) parametric simplex algorithms; (i) LP solution and tableau generation; and (j) LP basis and map manipulation.

Most of the above procedures are interactive for greater flexibility and convenience.

(3) The main simplex algorithms are evidently the most crucial part of SESAME. The system provides both primal and dual solutions. Moreover, the following parametric solution options are available: (a) parametrization of right-hand sides with a specified base column, change column parameter; (b) parametrization of objective function with a specified change row and parameter; (c) both (a) and (b); (d) parametrization of a specified structural column with a specified change column and parameter; (e) parametrization of a specified structural row, with a specified change row and parameter.

The above parametrization facilities are very powerful.

(4) The following basic selection options for the solution print-outs are available: (a) full solution; (b) solely basic variables; (c) solely nonbasic variables; (d) no listing; (e) infeasibilities. These differ considerably in volume, and hence should be chosen carefully.

The purpose of this short description of SESAME has been to give some insight into its potential. As can be seen, the system has great capacity and flexibility, and – extended with DATAMAT – it is a valid procedure to facilitate effective, efficient implementation of large and complicated linear programs, as was the case with GRAM.

6 APPLICATION: THE UPPER NOTEC REGIONAL AGRICULTURAL POLICY ANALYSIS AND DESIGN

The model, whose general form and software implementation were described above, was first applied to the agriculture of the Upper Notec watershed region in central-northwestern Poland. In fact, the work on this application has had an essential influence on the final outlook of both the general model (Albegov *et al.* 1980) as presented in Section 4, and its software implementation (Section 5).

Before describing the model version for the Upper Notec region and the results obtained therewith, a brief outline of the first object of the application will be given.

6.1 The Upper Notec Watershed Region and its Agriculture

The region in question (see Figure 3) is located somewhat to the northwest of the center of Poland, and encompasses the watershed of the upper part of the Notec River, i.e., down to its confluence with the old Bydgoszcz Channel (Figure 4). The Notec River belongs to the Odra watershed system, although it runs relatively close to the Vistula River. The Bydgoszcz Channel, linking the middle of Notec with the Vistula, therefore links the two main river systems of Poland, those of the Odra and the Vistula (Wisla).

The Upper Notec watershed region coincides largely with the historically important region of Kujawy (Cuiavia) and contains the smaller traditional area of Pakuly. Owing to the long tradition of social organization and cultivation of crops in this area, a number of characteristics have evolved which distinguish it from others in Poland. For example, the forest cover is significantly lighter than elsewhere in the country, the quality of agricultural expertise of farmers is higher than average, and the region has a long tradition of dealing with water economy in agriculture. As early as the beginning of the eighteenth century important drainage works were carried out.

FIGURE 3 Location of the Upper Notec watershed region (the area is denoted by cross-hatching) in Poland. The watershed overlaps the Cuiavia region. From Albegov and Kulikowski (1978a).

In connection with the above characteristics, but also related to more general climatic changes, there has for several decades been a growing awareness that the region has been becoming drier, or more steppe-like (Kostrowicki 1978). Because of the relatively high quality of soils in the area, the experience of farmers, and a large proportion of cultivable land, the regional agriculture has a high productive potential.

The realization of this potential has to a large degree been hindered by the need to economize water resources, however. The region contains a large number of natural water bodies such as post-glacial ribbon lakes. There are also some areas where humidity is too high, but because of the generally low level of precipitation (as low as about 450 mm per annum in Pakosc, in the center of the region), there is an essential water deficit for most of the potential crops.

The Upper Notec watershed region was therefore included as the site for a prototype water and agriculture system in the Polish government's research and development program

FIGURE 4 The Upper Notec watershed region. From Albegov and Kulikowski (1978a): —·—·— watershed region boundary; – – – – voivodship boundaries; ——— artificial waterways.

for water resources (Somorowski 1978). The work aimed to design and implement a prototype system, including studies of the water resource system in the area, as well as of its agriculture and its needs. This work was complemented by a modeling project (see Gutenbaum *et al.* 1980) comprising models of water system expansion, of agriculture, and of general resource distribution. Since industry is not greatly developed within the Upper Notec region and the demographic situation is fairly stable, it was not deemed necessary to proceed with these models in the first stage of the work.

Precise delineation of the Upper Notec region for the purposes of systems analysis and design followed the existing administrative boundaries. Thus, the region as the object of the study encompassed 32 of the lowest administrative divisions (*gminas*) and was therefore not identical to the hydrographic watershed region, but the differences were not vital. These 32 gminas constituting the Upper Notec region belong to three higher administrative divisions (*voivodships*), although they do not make up the major portion of these three voivodships (see Figure 5). Such a situation certainly posed difficult

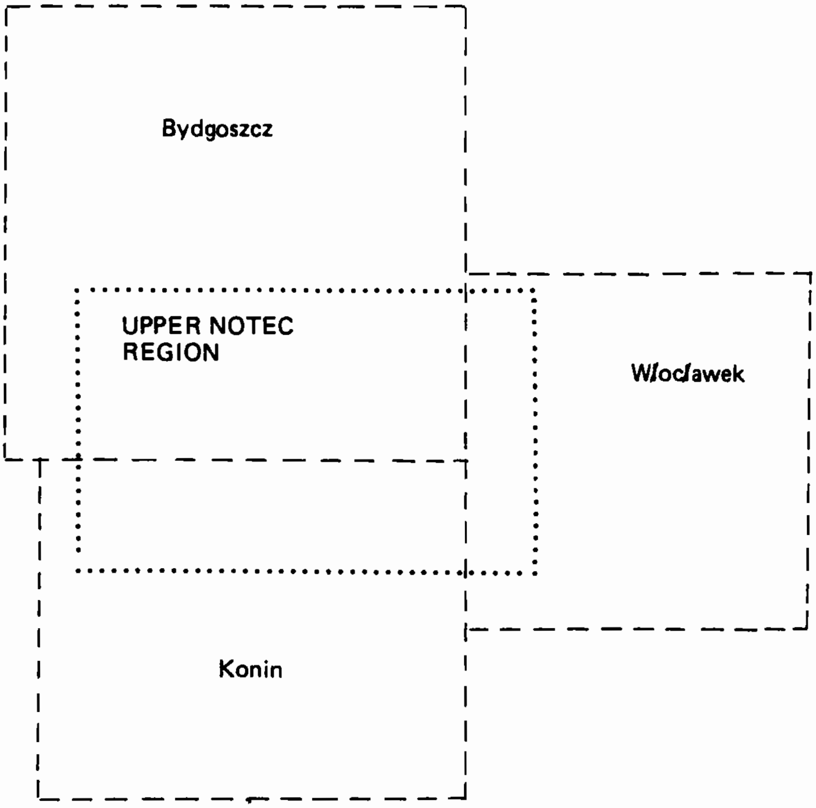


FIGURE 5 Relation of the Upper Notec delimitation to the boundaries of the voivodships involved: – – – –, voivodships; . . . . . . , Upper Notec watershed region.

decision-making problems, which were additionally aggravated by the organization of agricultural activities.

Three forms of land ownership coexist in Poland, particularly in the Upper Notec region: large state farms, usually covering several thousand hectares each, accounting for about 15% of the agricultural land; somewhat smaller cooperative farms, accounting for about 5% of the agricultural land area; and small private farms, averaging 5–7 ha, which together account for about 75% of the land area. Thus, decision-making in agriculture occurs within a very intricate set-up, whose structure is schematically shown in Figure 6.

Even if the models proposed for such agricultural systems cannot take into account all aspects of the decision-making organization, they should at least show differences between the three types of agricultural economy, so that decisions can be made after consideration of all of these differences.

The main goal is to obtain from the region the optimal production of the most essential agricultural goods with the most efficient utilization of available resources, while simultaneously ensuring adequate incomes for producers. Such a formulation does not, of course, preclude a specific form of the objective function; it defines, however, the

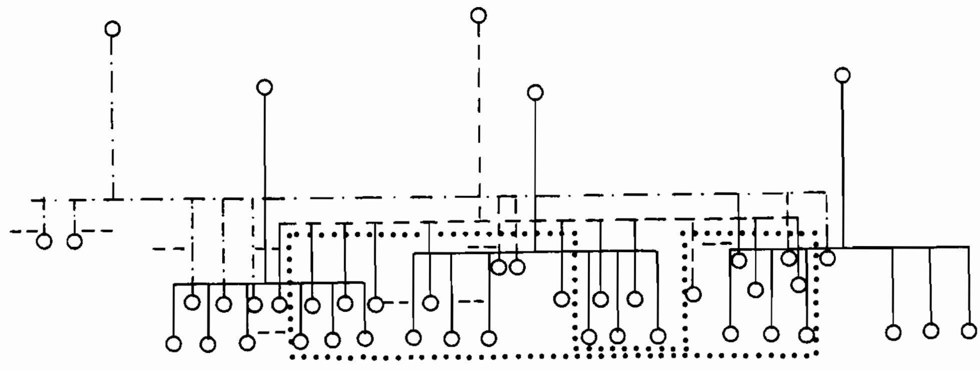


FIGURE 6 Illustration of the overlapping of some of the various managerial levels pertaining to the region. o—o, administrative; o– – – –o, state farm board and individual state farms; o–·–·–, water system cooperatives' management and cooperatives; . . . . , boundary of the regional system.

perspective form in which the various results obtained, using various objective functions, should be viewed.

As far as specific farming activities were concerned, fruits and vegetables were deemed to be marginal for the regional agriculture. The three land-ownership types, the feasibility of irrigation, the variety of soil types, and the different purchase and sale markets were seen as the most important aspects of the regional agricultural economy. The potential limitations of some of the resources (labor force, capital, but also fertilizers) necessitated a precise analysis of the impact of these resources on agricultural production.

6.2 Specification of the Model for the Upper Notec Region

The particular form of the general model that was applied to the Upper Notec region will now be described in terms of concrete sets of items – mainly indices – appearing in the model, and the concrete formulation of constraints therein.

Indices

$i \in I = \{1, \ldots, 13\}$: crops:

$i = 1$, wheat
2, rye
3, barley
4, oats
5, other grains
6, sugar beets
7, potatoes
8, maize
9, forage root crops
10, beans, etc.
11, clover, lucerne, etc.
12, industrial crops for oil and fiber
13, meadows and pastures (grasslands)

$\omega : \{\omega\} = \{1, \ldots, 6\}$: crop rotation groups:

$I^1 = \{i \mid i = 1, 2, 5\}$
$I^2 = \{i \mid i = 3, 4, 12\}$
$I^3 = \{i \mid i = 7, 8\}$
$I^4 = \{i \mid i = 6, 11\}$
$I^5 = \{i \mid i = 9, 10\}$
$I^6 = \{i \mid i = 13\}$

$j : \{j\} = \{1, \ldots, 7\}$: animal type:

$j = 1$, milk cows
2, other cattle
3, sows
4, other pigs
5, horses
6, sheep
7, poultry (X 100)

k : livestock breeding specialization (undifferentiated), i.e., there is only one k for each j; say, $k = 1$

$m : \{m\} = \{1, \ldots, 5\}$: type of livestock product:

$m = 1$, meat
2, leather
3, milk
4, eggs
5, wool

$r : \{r\} = \{1, 2, 3\}$: subregions, In the version implemented as of January 1980, there are three subregions corresponding to portions of voivodships belonging to the Upper Notec region (see Figure 5):

$r = 1$, Bydgoszcz voivodship
2, Włocławek voivodship
3, Konin voivodship

$n : \{n\} = \{1, \ldots, 11\}$: feed components in forage:

$n = 1$, grain units
2, proteins
3, dry mass
4, volume
5, fodder
6, preserved
7, straw and other rests
8, starchy root crops, other than potatoes
9, potatoes
10, other crop components
11, milk

$l : \{l\} = \{1, 2, 3\}$: type of market:

$l = 1$, internal state market (prices totally controlled by the state, the products are usually ordered from producers prior to the season)
2, internal private market
3, world (export/import) market

$p : \{p\} = \{1, 2, 3\}$: type of farm (according to land ownership):

$p = 1$, state-owned farms
2, cooperative farms
3, private farms

$s : \{s\} = \{1, 2, 3\}$: technology of crop raising:

$s = 1$, present, good
2, intensified – more fertilizers, machines, etc.
3, as above, with irrigation

$\alpha : \{\alpha\} = \{1, 2, 3, 4\}$: soil quality:

$\alpha = 1$, weak (light)
2, medium light
3, medium heavy
4, good

s' : technology of livestock breeding (undifferentiated), i.e., there is one livestock breeding technology, $s' = 1$

$f : \{f\} = \{1, 2, 3, 4\}$: type of fertilizer, according to element contents:

$f = 1$, nitrogen
2, phosphorus
3, potassium
4, calcium

β_i : index of crop which may follow the ith one in the same year

$\beta_1 = 11$
$\beta_2 = 11$
$\beta_3 = 2$
$\beta_4 = 2$
$\beta_5 = 11$
$\beta_6 =$ none
$\beta_7 =$ none
$\beta_8 = 5$
$\beta_9 \div \beta_{13} =$ none

The tables of coefficients and the left- and right-hand sides of constraints were formed in accordance with the above specification of items. However, since several of these tables were too large and too detailed to be formed directly on the basis of existing agrotechnical or agroeconomic data (see, for example, $\{a_{fiprs\alpha}\} = A$, containing in this case 5616 coefficients), they were formed indirectly. First, smaller tables of existing initial data were formed and then, based on them, the tables as appearing in the model were set up. Thus, in order to produce a tape containing all model-ready data, another tape containing initial data and the program of data preparation was needed. The data preparation program was carried out, as well as multiplication of elements in the initial tables, and aggregation over geographical space. This was necessary insofar as all data specified geographically were determined for the 32 lowest administrative units, gminas. This breakdown of data made it possible to proceed with further division of geographical space as represented in the model into more than the three voivodship-related areas.

Hence, for instance, the creation of Table A proceeded according to the formula:

$$a_{fiprs\alpha} = a^1_{fi\alpha} a^2_{fs} \frac{1}{\bar{\bar{R}}(r)} \sum_{r' \in R(r)} a^3_{fpr'}$$

where r' are indices of gminas, $R(r)$ are sets of indices of gminas belonging to subregions r, and $\bar{\bar{R}}(r)$ are numbers of gminas in the respective subregions. In this way a crude estimation, but the only one available, is obtained. Utilizing such approaches for setting up the coefficient matrices one should be aware of the risk of degeneracy (i.e., linear dependence), and provide a fair check against it.

In relation to the description of constraints and objective functions, the following remarks should be made here:

superscript $\omega = m$ used for grasslands now takes the value 6;
inequalities (3) hold for $\omega = 1, \ldots, 5$;
inequalities (4) hold for $s = 3$;
inequalities (9) hold for all $r, p = 2, 3$;
inequalities (21) hold for all $r, p = 2, 3$;
inequalities (32) hold for all $r, p = 2, 3$;

otherwise, constraints are in force for all appropriate indices.

Three types of data can in general be distinguished:

(1) constants that are valid over much greater areas than just the particular region (e.g., livestock feed requirements, nutrient and water requirements of plants, prices, minimum income levels);

(2) constants that are valid for the given region only (e.g., crop yields, soil nutrient content, precipitation, population);

(3) magnitudes that are subject to policy decisions (e.g., investment projects, supplies, some prices).

The data of the first type were taken directly from national statistics, agrotechnical tables, etc. The second and largest group of data was obtained from studies made by local design organizations involved in the development project work, and farm records gathered by the Institute of Agricultural Economics in Warsaw. In fact, although these data were not exactly fitted to the model structure outlined, as already mentioned, they turned out to be quite reliable, even after the expansion described above. For example, for crop yield values, a three-year comparative basis was used since it was considered to be more important to preserve inter-coefficient magnitude relations than to try to obtain precise absolute values, which are anyway subject to stochastic fluctuations. As to the third group of data the model's functioning started with the actual values, taken from the official statistical sources. In subsequent runs these values were changed according to needs.

The LP model thus implemented was quite large, comprising approximately 3500 decision variables (columns) and 1100 constraints (rows). The number of elementary nonzero datum items specified for purposes of this implementation was about 55 000.

The final version of the model for the Upper Notec region was run approximately 40 times, for various objective functions and resource limits, as well as for some minor modifications to the coefficients. This number of runs enabled the characteristic features of this particular implementation case, and also to some extent the model itself, to be assessed.

It has proven possible to perform quite a large number of test runs because once an initial optimal solution was obtained starting from scratch, the subsequent solutions could be obtained in no more than 3–4% of the time needed to obtain the initial one, and quite often as little as 1%. This applied equally to constraint parametrization and to changes in the objective functions. Although these statements only pertain to this particular implementation it can safely be assumed that there would be no major differences in other cases, provided the data and model structures were retained and no degeneracy was introduced. The initial optimal solution was usually obtained in 10 000 iterations (major + minor). Approximately the same time was required to generate the model, i.e., to set up the coefficient matrix, variables, right-hand sides, and objective functions.

An example of the SHORT-LIST print-out of a solution is given in Appendix B, together with clarifying comments.

6.3 Results

With regard to the model itself, its application to the Upper Notec watershed region was simply a test of adequacy with respect to the prerequisites presented at the beginning of this report: generality, communication capacities, and representation. Thus, presentation and analysis of the results are not the main purpose of this report. The results will be shown and commented on in relation to the main prerequisites of the model construction.

Some essential features. An example of the results for an optimal point is summarized in Table 3 to give an idea of the production structures and specialization patterns obtained. Such aggregate data are the most important for regional agricultural development planning. It is therefore essential to look at the changes these structures undergo with shifts in availability of resources and for different objective functions. Thus, for instance, a number of runs were performed for various labor and capital availabilities with the net return/net production objective function thus yielding a global quasi-production function* for optimal conditions whose approximate shape is shown in Figure 7. Such analyses were aimed at determining the essential properties of the regional agricultural system, related to resource utilization, efficiency, specialization, bottlenecks, production capacities, etc.

*To obtain the actual production function, the model should be used as a simulation device, i.e., real objectives existing within the system should be identified and applied (see the next section).

TABLE 3 Aggregate illustration of a solution.

(a) Arable land in the region (ha).

	Subregions		
Producer types	1. Bydgoszcz	2. Włocławek	3. Konin
1. State	59 654	3 173	4 133
2. Cooperative	9 630	278	1 093
3. Private	147 240	38 016	40 961

(b) Crop production and specialization.

Crop	Volume (tonnes)	Producer types	Subregions	Soils	Technologies
1. Wheat	95 000	1	1, (2, 3)	1, (2, 3)	1
2. Rye	115 000	2, 3	1, 2, 3	1, (2, 3)	1
3. Barley	72 000	2, (3)	1, (3)	2, (3, 4)	1
4. Oats	35 000	1, 3	1, 3	1, (2)	1
5. Other grains	38 000	1	1	1	1
6. Sugar beet	710 000	1, 2, 3	1, 2, 3	4	3
7. Potatoes	725 000	1, 2, 3	1, 2, 3	1, 2, 4	1, 2
8. Maize (grain)	35 000	(1, 2), 3	1, 2, 3	3, 4	1
9. Forage root crops	140 000	2, 3	1, (2), 3	3, 4	1
10. Beans, etc.	45 000	2, 3	1, (2, 3)	1, 2	1
11. Clover, etc.	150 000	1	1, (3)	1	1
12. Flax, etc.	65 000	2, 3	1, 2, 3	2, 3, 4	1
13. Grassland	230 000	1, 2, 3	1, 2, 3	4	2, 3

(c) Livestock production and specialization.

Livestock	Number	Producer types	Subregions
Milk cows	140 000	(1, 2), 3	1, (2, 3)
Other cattle	360 000	(1, 2), 3	1, (2, 3)
Pigs	630 000	2, 3	1, 2, 3
Horses[a]	38 000	3	1, 2
Sheep	22 000	3	1, 3
Poultry	4 300 000	1, 2, 3	1, 2, 3

(d) Uses of crops produced.

Product	Total volume	For forage	For human consumption	Sales	Purchases[b]
1. Wheat	95 000	0	45 000	50 000	0
2. Rye	115 000	500	45 000	70 000	0
3. Barley	72 000	20 000	12 000	40 000	0
...					
6. Sugar beet	710 000	215 000[c]	75 000[d]	420 000	0
7. Potatoes	725 000	75 000	100 000	550 000	0
...					

[a]Still in use as pulling power.
[b]This particular solution was obtained for constraining conditions forcing maximum self-sufficiency.
[c]In terms of rests.
[d]In terms of sugar.

Although the model was run for various objective functions, as will be shown and discussed later on, the main bulk of the analyses was performed for the net return/net production objective illustrated in Figure 7 for capital and labor.

This objective was deemed to enforce the clearest picture of efficiencies, specializations, and resource requirements in the solutions obtained therewith. The optimal characteristics shown in Figure 7 can be communicated to higher-level resource distribution models. From the numerous results, the invariant features were extracted, and these can be summarized together with their causes as follows.

(i) There is a low tendency towards innovation connected with capital investment (technologies 2 and 3 do not exceed 10–15% of total area); i.e., for many runs the capital available was unused, because of the price and repayment structure, which favors industrial goods rather than agricultural products.

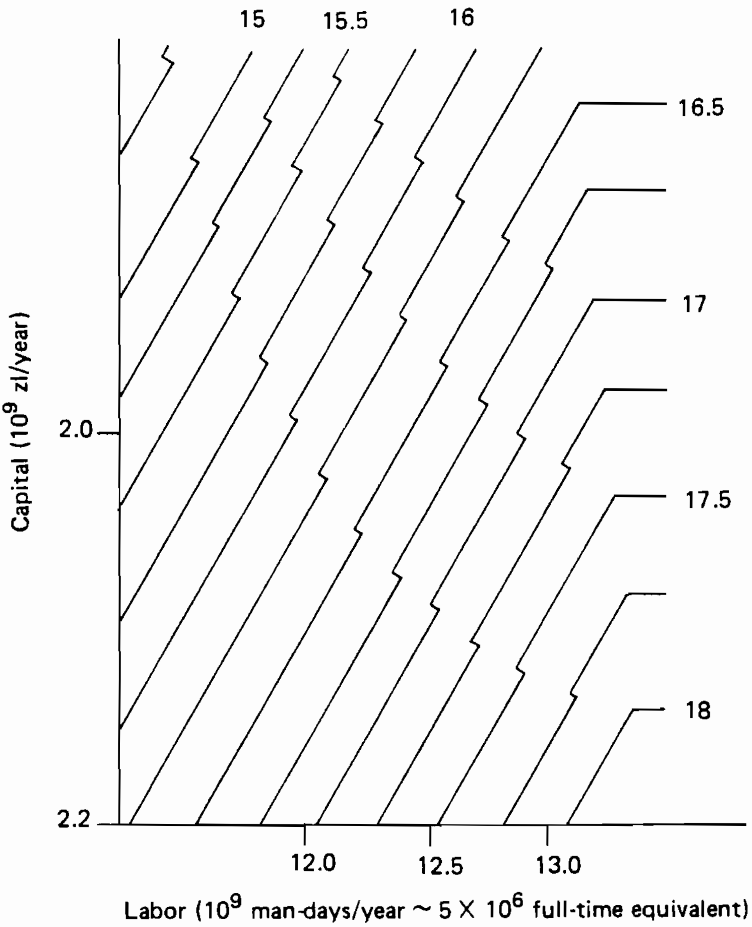


FIGURE 7 Efficiency function for Notec agriculture. Isolines indicate net production value levels in billion zloty/year. Capital is expressed in annual repayments at 3% interest.

(ii) There is a clear specialization among producer types, e.g., state farms grow much more wheat than cooperatives or private farms, mainly because of much higher yields, while private farms specialize, for example, in sugar beet, in the cultivation of which they show higher efficiency, as well as easily providing adequate labor for that crop.

(iii) Inter-subregional specialization is not distinctly pronounced, primarily because the soil and climatic conditions are virtually the same in all subregions; any specialization results mainly from differences in cultivation traditions and various distributions of the three producer types in these subregions.

(iv) There is a fairly high level of intra-regional exchange of commodities, which is not in opposition to the previous statement, since the exchange occurs mainly between and among the producer types (possible exchanges within the producer types not being made explicit in the model), and transfers over subregional "borders" occur mainly when there are imbalances in the production capacities of ownership types in particular subregions.

(v) The region is an important net exporter with only some livestock products being imported. This indicates the large productive capacity of the region when compared with the needs of its small population, the main cause of animal product imports being, again, the price structure.

(vi) There is very little poultry production, which is a direct consequence of the previous result insofar as this phenomenon is also caused by the price structure, this time mainly with regard to preprocessed food for poultry.

(vii) Irrigation is almost entirely limited to sugar beet and grassland, which offer the highest monetary yield value increases in response to irrigation, as measured through overall output, including livestock production, with relaxation of financial constraints, although other crops do enter the irrigated technology.

(viii) An advanced technology with irrigation ($s = 3$) is preferred to advanced technology without irrigation ($s = 2$), when credit repayment conditions only allow for that, technology 3 being much more capital-intensive. This indicates that there is a real water need in the region.

The above results were found to be in general in agreement with the expectations of agricultural planners and decision-makers in the region, although a number of particular phenomena were quite different in their scope and influence than was anticipated. The primary merit was the formulation of a consistent overall picture. The results and their causes pointed out the necessity for modifications in regional agricultural policy.

In the analyses performed, resource limits other than labor and capital were also examined for their influence on the objective function values and on structures. This was done for water resources, and it was shown, in accordance with the conclusion previously formulated, that additional water was necessary for agricultural development in the region. The dimensions of the water system expansion project would have to be carefully assessed, however, since, according to GRAM, the additional water volumes needed varied from approximately 40×10^6 m^3 yr^{-1} for the net production objective to 200×10^6 m^3 yr^{-1} for the maximum output objective.

Another constraint analyzed was the sales and warehouse infrastructure insofar as it is expressed in the inequalities on maximum sales. It turned out that by raising these limits by 30–50% with regard to the actual ones, depending on the commodity, a 50–70% increase in the net production objective was obtained! For the influence of this factor on some features of the optimal solutions see Table 4.

Stability of optimal structures. When performing analyses leading to conclusions on some important features of the system optimized, attention should be paid to the changeability of the optimal production structures obtained. While the optimal characteristic function of Figure 7 is relatively smooth and its shape ensures the expected concavity properties, one is obliged to look at the production structures that correspond to points

TABLE 4 (a) Shares of various technologies in production of individual crops for various solutions (%).

		Objective functions (%)			
		Net production value		Gross production value	
Crop	Technology s	Solution no. 1	Solution no. 2	Solution no. 1	Solution no. 2
Wheat	1	100	100	78	99.3
	2	0	0	4	0
	3	0	0	18	0.7
Rye	1	100	100	41	100
	2	0	0	4	0
	3	0	0	55	0
Potatoes	1	99.7	99.8	99	98
	2	0.3	0.2	1	2
	3	0	0	0	0
Sugar beet	1	0	45	0	56
	2	0	0	0	0
	3	100	55	100	44
Grassland	1	0	0	0	35
	2	0	14	0	51
	3	100	86	100	14
(b) Amount of water needed in optimal solutions ($m^3 yr^{-1}$).		26×10^6	23×10^6	123×10^6	32×10^6

Solution no. 1: Sales-limitations-related storage and transportation capacities increased by 30–50%.
Solution no. 2: Present sales capacities.

on this surface. In general, the smooth changes in the objective function may be accompanied by numerous and essential switches in the structure. Such behavior is often regarded as unstable, and is a cause for indicating inadequate conditioning of the coefficient matrix (see Gutenbaum *et al.* 1980). Arguments can be raised against such inferences, since this "instability" may well reflect the actual state of the technical and economic agricultural system. Suspicions can only be justified when there are returns to the vicinity of previous structures over a straight-line path in the optimal characteristic surface. Aggregate results referring to structure and specialization are shown for three important points in Table 5. As can be seen there are no dramatic differences, which is also true for other points

TABLE 5 Characterization of crop production structures and specializations for three points of the labor and capital optimal characteristic function.

Subregion	Producer type	Technologies 1	2 (Areas/soils)	3	Volume of crops (10^6 tonnes) Wheat	Rye	Sugar beet (volume/technologies/soils)	Potatoes	Clover	Grassland
Point 1. Labor: 12.5 × 10^6 man-days/year; Capital; 1800 × 10^6 zl/year at 3% interest/year.										
Value of net production: 15 503 × 10^6 zl/year.										
B	1	57925/all	2419/4	665/4	94/1/1,2,3	0	0	0	18/3/4	16.5/1/2
	2	9668/all	404/4	199/4	0	6.1/1/1,2,3	14.1/3/4	19.4/1/2	0	14.7/1,2/2,4
	3	140604/all	1031/2	13096/4	0	53.6/1/2,3	935/3/4	501/1/2	225/1/4	161/1,2/2,4
W	1	2543/all	830/2,3,4	0	5.3/1/1,2,3	1/2/4	0	0	13.3/1,2,3/1,4	4.2/1,2/2,3
	2	273/all	0	8/1,4	0.1/1/3	0.4/1,2,3/1,4	0.2/3/4	3.3/1/1,3,4	0.1/2/4	0.2/3/1,4
	3	38344/all	880/2,4	462/4	16/1/4	0	41/3/4	153/1/2	0	53.4/1,2/2,4
K	1	4049/all	112/4	7/4	7.3/1/2,3	0.5/3/4	0.5/3/4	0	12/3/4	0.5/1/2
	2	1078/all	76/2,3	31/4	0	2/1,3/1,3,4	2.2/3/4	6.8/1/2,4	1/3/4	2.3/2/2,3
	3	40791/all	1369/2	564/4	0	33.3/1/1,2,3,4	49/3/4	98/1/2	0	54/1,2/2,4
Point 2. Labor: 11.25 × 10^6 man-days/year; capital: as before.										
Value of net production: 14 356 × 10^6 zl/year.										
B	1	54364/all	0	5228/4	110/1/1,2,3,4	0	0	0	0	0
	2	9668/all	437/4	143/4	0	5.1/1/1,2	10.2/3/4	0	0	14.8/1,2/2,4
	3	140680/all	1238/2	13020/4	0	100/1/1,2,3	928/3/4	226/1/2	269/3/4	167/1,2/2,4
W	1	2380/all	382/4	79/4	5.4/1/1,2,3	0	0	0	5.8/3/4	7.8/2/1,2,3
	2	276/all	0	8/1,4	0.1/1/3	0.1/1/1	0.2/3/4	0.7/1/2	0	0.2/3/1,4
	3	38345/all	710/2,4	524/4	0	0	47/3/4	153/1/2	0	48.3/1,2/2,4
K	1	4038/all	275/2,4	112/4	73/1/2,3	0	0	0	0	6.3/1,2/2
	2	1099/all	84/2,3,4	0	0	0.3/1/1	0	6.2/1/2	0	2.4/2/2,3,4
	3	40774/all	1303/2	581/4	0	29/1/1,2,3	50/3/4	99/1/2	0	51.8/1,2/2,4
Point 3. Labor: 13.4 × 10^6 man-days/year; capital: 2200 × 10^6 zl/year at 3% interest/year.										
Value of net production: 17 825 × 10^6 zl/year.										
B	1	54362/all	0	7497/4	98.5/1/2,3,4	7.8/1/1	38.3/3/4	0	20.4/1,3/4	74.1/3/4
	2	9522/all	475/4	175/4	0	7/1/1,2	12.4/3/4	38.8/1/2	0	14.2/1,2/4
	3	141912/all	0	11789/4	11/1/4	45/1/3,4	790/3/4	678.5/1/2	223.7/1/4	164.6/1,3/4
W	1	2931/all	4/3	548/1,2,4	5.9/1/all	4.1/3/4	18.1/3/4	0	8.7/1,3/4	12.5/all/1,2,4
	2	187/all	76/4	20/4	0	0	0.9/3/4	2.9/1,2/1,2,4	0	0.2/3/4
	3	37946/all	0	790/4	0	0	182/1,3/2,3,4	85.5/1/2	0	44/3/4
K	1	4020/all	18/4	422/1,2,4	7.3/1/2,3	4.7/1/4	8/3/4	0	11.7/1,3/4	11.1/2,3/1,2,4
	2	1039/all	34/2,3	118/1,2,4	0	1.1/3/4	1.6/3/4	11.8/1/1,2	0	2/all/1,2
	3	39716/all	0	2209/1,4	0	28.4/1/1,2	47.8/3/4	90.6/1/2	0	49.6/1/4

obtained, and there is therefore no need to admit that there could be more important structural changes over shorter segments in the surface. In order to account for the varying importance of structural differences across various indices, a measure of "structure distance" could be introduced, here formulated for crops:

$$D(X^t, X^u) = \frac{1}{Ind} \sum_{i \in I_1} \gamma_1 \sum_{i \in I_2} \gamma_2 \cdots \sum_{i \in I_W} \gamma_W \sum_p \gamma_p \sum_r \gamma_r \sum_s \gamma_s \sum_\alpha \gamma_\alpha$$

$$\times \frac{|X^t_{iprs\alpha} + Y^t_{iprs\alpha} - X^u_{iprs\alpha} - Y^u_{iprs\alpha}|}{X^t_{iprs\alpha} + Y^t_{iprs\alpha} + X^u_{iprs\alpha} + Y^u_{iprs\alpha}}$$

where γ's are weighting coefficients, $\gamma \in [0, 1]$, showing the relative importance of differences attached to various index categories (for example, γ_α would obviously be much less than γ_p or γ_r); $I_1, \ldots, I_W$ are subsets of I accounting for equal γ's. $I = I_1 \cup I_2 \cup \ldots \cup I_W$, $I_v \cap I_w = \emptyset$ and t, u are indices of two different solutions for some resource availability. *Ind* is the product of the numbers of items in each of the index sets involved, in this case 8640. As can easily be seen, for all $\gamma = 1$, and no coincidences in the structures, there is $D(X^t, X^u) = 1$, or 100%. Differences between neighboring points in the case considered did not exceed 2–3%, and between the extreme points (90% and 110% of the assumed resource availability) it merely approached 10%. In order to relate $D(X^t, X^u)$ to corresponding changes in the resource availability and/or objective function value, one should apply certain common measures, but such an approach was not attempted here.

Thus, certain relatively invariant features of structures corresponding to the net return/net production objective could be justly formulated.

Multi-criteria analysis. Table 6 presents the action introduced by application of different objective functions. A major shift can be observed where the net production objective is replaced by global, physical or monetary, output indices. This applies especially to investment and innovation issues. In the production of individual commodities, important differences also occur between the global output indices. These results again indicate the necessity of precise specification of the development goals and their structure, as mentioned in Section 3.4.

The question of differing interests within the system is illustrated in the lower portion of Table 6. When an overall objective is optimized, the efficiency aspect prevails and the initial inter-subregional differences tend to sharpen. The question of internal objectives applies not only to subregions but, equally, to producer types. An illustration of different situations of such producer types is given in Table 7. Because of such pronounced differences, the technique proposed by Seo and Sakawa (1979) was applied. The first step in this technique, i.e., decomposition of the overall model into submodels *pr*, corresponding to producer (land ownership) type *p* and subregion *r*, was executed and some of the results, showing differences in resource utilization, are given in Table 8. These differences are due to specific conditions of this subsystem (*pr* = 11), as well as to isolation of this subsystem within the whole system, and therefore the impossibility of internal commodity/financial exchange.

TABLE 6 Some results for various objective functions.

		Objective function			
Subject	Specification	Profit/net production	Production value	Physical output	Livestock product output
Areas under technologies (%)	Present	96	52	50.9	49.3
	Fertilized	0.1	6.7	7.2	9.4
	Irrigated	3.9	41.4	41.9	41.3
Crop production (10^6 kg)	Grain	347	332	378	377
	Starchy + clover	300	337	332	303
	Grassland	233	350	453	453
	Sugar beet	712	809	814	830
Livestock (10^3 head)	Milk cows	138	211	242	242
	Other cattle	356	451	450	445
	Pigs and sows	642	1018	1002	1043
	Poultry (× 100)	43	9	53	34
Income per capita in subregions (zl/month)	I Bydgoszcz	6484	5583	5732	5731
	II Włocławek	4387	3106	3105	3004
	III Konin	1500[a]	1500[a]	1500[a]	1500[a]

[a]1500 zl/month was the minimal income bound for these runs.

TABLE 7 Average land shadow prices for various producer groups.

	Producer types		
Subregion	Private farms	Cooperatives	State farms
I	58	114	127
II	83	194	112
III	42	80	∅

TABLE 8 Use of resources in the solution of the whole regional system and for an isolated producer group subsystem ($pr = 11$).

	Total GRAM		GRAM submodel	
Resource	Use (%)	Dual price (zl)	Use (%)	Dual price (zl)
Arable land	100	319	100	7750
Labor force	88	0	100	1665
Water, total[a]	12	0	25	0
Water, I peak[a]	22	0	25	0
Water, II peak[a]	1	0	34	0

[a]Water bounds in these runs were taken to be very high, to assess maximum consumption.

6.4 Policy Analysis

The various results of the optimization model, exemplified above, can serve as a basis for broader policy analysis considerations. Structure and specialization solutions can therefore be treated as planning indications, while analyses of causes making these optimal structures/specializations appear and of possibilities of changing them, belong to the policy analysis domain.

Regarding the relatively invariant features of structures/specializations reported earlier, several inferences as to their causes and means of dealing with them can be made.

(i) Low levels of investment and innovation for the net production objective are caused mainly by the price and credit structure. This is advantageous for industrial goods and disadvantageous for agricultural goods and for repayment of agricultural infrastructure, so that an essential increase could be obtained if only the repayment conditions were changed appropriately.

(ii) With modern technology the region has a large production capacity, which can be made to work provided the infrastructure and supply conditions are generally improved.

(iii) The narrow and relatively rigid specialization of producer types results from the economic and organizational conditions in which they act, related not only to the price structure, but also to repayment schemes, credit conditions, land appropriations, labor costs, etc. Depending on the objectives to be attained, these conditions would have to be operated differently: for net return/net production the objective should be towards unification of conditions with regard to producer types, while for maximum output some differences should be maintained, whereby unprofitable products would be produced in adequate quantities.

(iv) There may be individual producer types for whom some resources might be essentially limiting (e.g., the labor force), which postulates an analysis of such resources in the surrounding systems as well as a substitution analysis within the system studied.

Besides this, the results again point out the necessity of multi-criteria analysis if an internally feasible policy were to be defined and implemented. Thus, by analyzing the influence of factors relevant to policy-making, one can arrive at values that define the direction of policy improvements, e.g., price levels and repayment schemes that will allow the innovation process to accelerate; infrastructure improvements that are necessary to utilize fully other resources available; suitable scales of activities to ensure maximum efficiency; and minimal incomes of producers ensured by appropriate specialization to balance the effects of differences in efficiency. Furthermore, the substitution conditions for limiting resources need to be established. This would have to be done in the framework of an explicit analysis of the overall goals of the system.

Any policy should explicitly take into account or start from the existing and potential inter-producer-group differentials indicated here. While minimal income constraints can make some equalization analysis possible, deeper insights and policy decisions are required to ensure viable development. It should be noted that redistribution policies could also be addressed with GRAM.

In the elaboration of policies, GRAM was deemed to cooperate with other models in a regional development planning model system, although it was assumed that it could

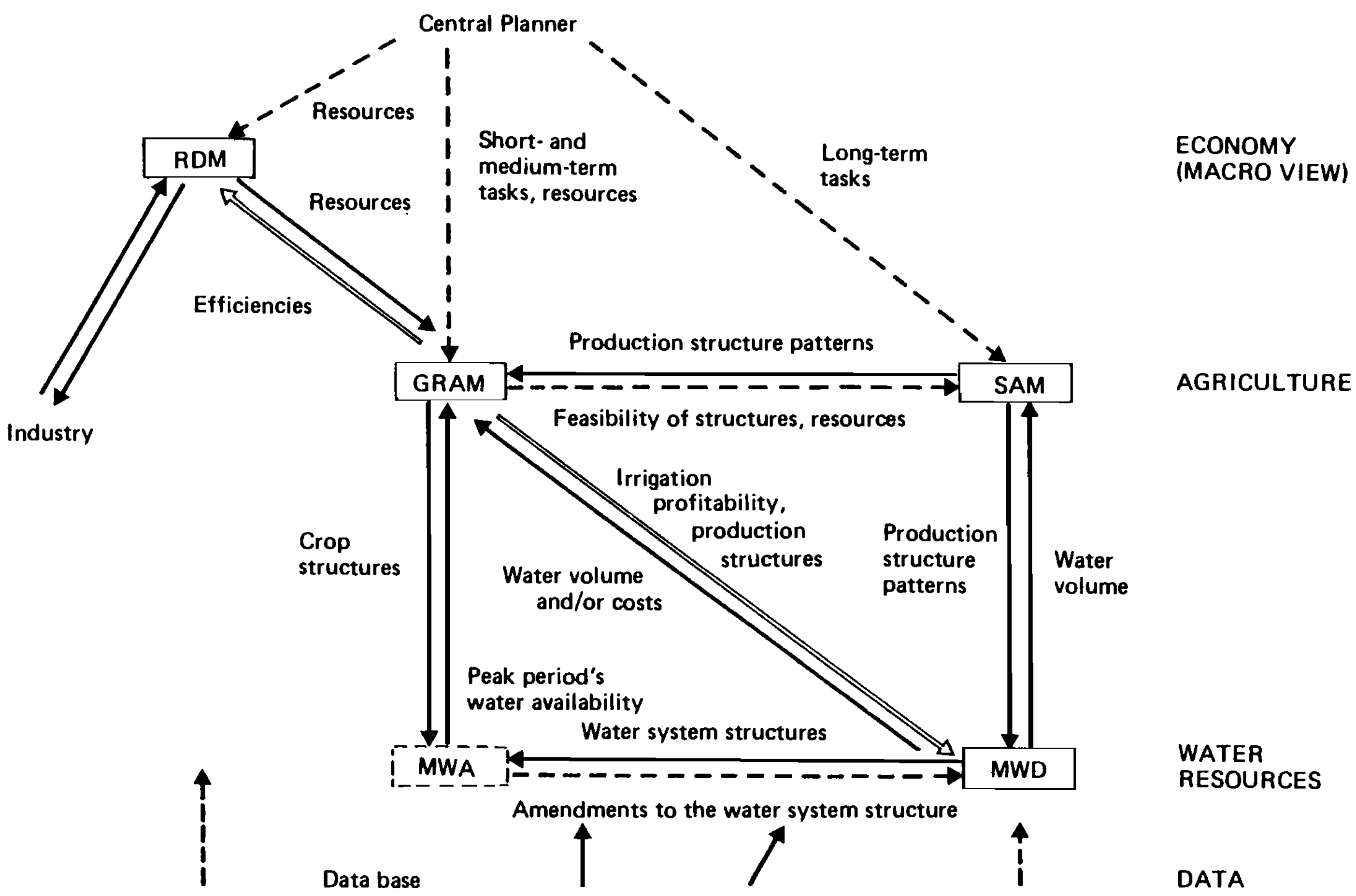


FIGURE 8 Outline of a system of models for a regional agriculture-based development program. ▭, models tested for the Upper Notec region; ⟶, connections necessary for the functioning of the system; ⟹, connections tested for the Upper Notec region.

be an independent planning tool for narrower purposes. Such a system, differing somewhat from the one presented earlier (Figure 1) was proposed for the existing set of models in Gutenbaum *et al.* (1980). It is quoted here with some modifications in Figure 8, together with clarifications as to the functioning of the system.

As can be seen, the agricultural model described here acts as a core. Another core model, on an aggregate level, is the (mainly) capital and labor distribution model (RDM), whose potential cooperation with other models is presented in Kulikowski and Kruś (1980).

GRAM was tested for its role as a core model by indirect utilization of the optimal characteristic function of Figure 7 in RDM and by trying out the MWD model optimizing the water system expansion with agricultural data from GRAM. Its feasibility as an integral part of a model system was thus fully established. GRAM can provide useful information for models whose policy and planning scopes lie outside agriculture.

7 CONCLUSIONS

The purpose of the work described in this report was to test whether a simple and flexible model structure can be developed and implemented to provide, simultaneously, sufficiently detailed information on a regional sector, be able to interact with other regional and inter-regional socio-economic models, and have such general features as would make it possible to apply it to different cases. It was intended that the test should be a difficult one, and the results obtained show that this was passed quite successfully by the model.

GRAM can, in fact, play the role of an independent planning and policy analysis and design tool, when equipped with data preparation and post-optimal analysis software. It can also work as an element of a model system, even in an interactive mode, provided the interaction process does not involve major changes in model coefficients, and that an initial solution is given. These properties of GRAM have been proven by a series of optimal solutions and sensitivity analyses, which provided information on optimal activity directions, limiting factors, and bottlenecks. The information thus obtained was checked with local decision-makers and planners for its validity and it was found to be in reasonable accordance with their experience. (Were it in complete accordance, then might the model perhaps not have been necessary?) The model's main merit was related to its capacity to provide a consistent, holistic quantitative numerical basis for comparing roles of factors and alternatives generated for various objective functions, as well as contributions and situations of various producer groups. It was very important to demonstrate that the model could be made operational even on a relatively small computer. In fact, the most difficult time is the preparatory phase, which would be better carried out on a bigger, faster computer. Once the model is set up, it can be run on a smaller one.

It should be emphasized that although GRAM tries to show the interrelations of the regional agricultural system with other systems, it cannot be extended so far as to comprise all the elements or processes of these other systems. Thus, if one wants to have a thorough review of the situation with a model like GRAM, there should be alternative scenarios generated by other models fed to GRAM. This considers first of all the population and labor force, water, land, and other resources, as well as costs, prices, and technologies, all of which require that GRAM be considered as an integral part of a system of regional models.

REFERENCES

Albegov, M.M., ed. (1975) Modeli Razmeshcheniya Proizvodstva (Models of Production Location). Moscow: Nauka. pp. 19–38.

Albegov, M.M. (1978) Guidelines for the Elaboration of the Subsystem: Regional Water Supply. WP-78-09. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Albegov, M.M. (1979) Generalized Regional Agriculture Model GRAM: Basic Version. WP-79-93. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Albegov, M.M., J. Kacprzyk, J.W. Owsinski, and A. Straszak (1980) Regional Agricultural Policy Design on the Basis of a Detailed Linear Economic and Agrotechnical Model. WP-80-18. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Albegov, M.M. and R. Kulikowski, eds. (1978a) Notec Regional Development – Proceedings of Task Force Meeting I on Notec Regional Development. RM-78-40. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Albegov, M.M. and R. Kulikowski, eds. (1978b) Notec Regional Development – Proceedings of Task Force Meeting II. Warsaw: Systems Research Institute.

Anderson, A.E. (1980) The Swedish Case Study – A Progress Report. WP-80-74. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Andersson, A.E. and D. Philipov (1979) Proceedings of Task Force Meeting I on Regional Development Planning for the Silistra Region (Bulgaria). CP-79-07. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Bírowo, A.T. and U. Renborg (1965) Interregional Planning for Agricultural Production in Sweden. In: Interregional Competition in Agriculture, Problems of Methodology. Paris: OECD.

Egbert, A.C. and F. Estacio (1975) Regional Agricultural Planning. In: Study of Agricultural Systems, ed. E.G. Dalton. London: Applied Science Publishers.

Gouevsky, I. and D. Maidment (1977) Agricultural Water Demands: Preliminary Results of the Silistra Case Study. RM-77-44. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Gutenbaum, J., M. Makowski, and J.W. Owsinski (1980) The System of Models for the Upper Notec Region. Paper presented at the Regional Conference on Theoretical and Practical Aspects of Regional Development Modeling, March 18–21, 1980. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Heady, E.O. and U.K. Srivastava (1975) Spatial Sector Programming Models in Agriculture. Ames, Iowa: Iowa State University Press.

Hexem, R.W. and E.O. Heady (1978) Water Production Functions for Irrigated Agriculture. Ames, Iowa: Iowa State University Press.

Ikeda, S., J.W. Owsinski, and D. von Winterfeld (1979) Regional Planning, Environmental Management and Modeling in the Kinki Region of Japan: A Case Study. CP-79-03. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Kallio, M., A. Lewandowski, and W. Orchard-Hays (1980) An Implementation of the Reference Point Approach for Multi-Objective Optimization. WP-80-35. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Klatzmann, J. (1965) Interregional Competition in Agricultural Research in France. In: Interregional Competition in Agriculture: Problems of Methodology. Paris: OECD.

Knop, H., ed. (1976) The Tennessee Valley Authority Experience. CP-76-02. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Knop, H. and A. Straszak, eds. (1978) The Bratsk–Ilimsk Territorial Production Complex: A Field Study Report. RR-78-02. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Kostrowicki, J. (1978) Introduction to Agriculture of the Upper Notec River Basin. In: M.M. Albegov and R. Kulikowski. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Kulikowski, R. (1978) Agriculture Model for Evaluation of Policy Impact on Production, Structural and Technological Change. In: M.M. Albegov and R. Kulikowski. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Kulikowski, R. and L. Kruś (1980) Notec Project: Model of Regional Development and Policymaking. Paper presented at the Regional Development Conference on Theoretical and Practical Aspects

of Regional Development Modeling, March 18–21, 1980. Laxenburg, Austria: International Institute for Applied Systems Analysis.
Langvath, T.L. (1962) Allocation of Production in Norwegian Agriculture: An Attempt at Industrial Economic Programming. Oslo: Norwegian Institute of Agricultural Economics. RB 27.
Nicol, K.J. and E.O. Heady (1975) A Model for Regional Agricultural Analysis of Land and Water Use, Agricultural Structure and the Environment: A Documentation. Ames, Iowa: Center for Agricultural and Rural Development, Iowa State University.
Orchard-Hays, W. (1977) SESAME Mathematical Programming System. DATAMAT Reference Manual D 0087. Computer Research Center for Economics and Management Science, National Bureau of Economic Research, Inc. (Revised edn.) Laxenburg, Austria: International Institute for Applied Systems Analysis.
Orchard-Hays, W. (1979) GRAM Generator Reference Manual. Internal Report. Laxenburg, Austria: International Institute for Applied Systems Analysis.
von Sauer, D. (1970) Regionales Modell der Landwirtschaftlichen Produktion in Niedersachsen. Hanover: Alfred Strothe.
Semionova, V.S. (1976) A Model of Production and Spatial Structure of a Regional Agro-Industrial Complex. In: Optimization Models for Forming Territorial Production Complexes, ed. M.K. Bandman. Novosibirsk: USSR Academy of Sciences, Siberian Branch, Institute of Economics and Organization of Industrial Production.
Seo, F. and M. Sakawa (1979) An Evaluation Method for Environmental Systems Planning: An Alternative Utility Approach. Environment and Planning A:11.
Somorowski, Cz. (1978) Problems of Water Resources in the Upper Notec Agricultural Region. In: M.M. Albegov and R. Kulikowski. Laxenburg, Austria: International Institute for Applied Systems Analysis.
Straszak, A., ed. (1980) The Shinkansen Program: Transportation, Railway, Environmental, Regional, and National Development Issues. CP-81-82. Laxenburg, Austria: International Institute for Applied Systems Analysis.
Straszak, A. and J.W. Owsinski (1980) Imbedding Perceptions of Regional Problems in the Integrated Modeling Framework. Paper presented at the IFAC/IFORS Conference on Modeling and Control of National Economies, Warsaw (June 1980).
Wierzbicki, A.P. (1979) The Use of Reference Objectives in Multiobjective Optimization – Theoretical Implications and Practical Experience. WP-79-66. Laxenburg, Austria: International Institute for Applied Systems Analysis.

APPENDIX A SEQUENCE OF SESAME/DATAMAT COMMANDS THAT ACTIVATE GRAM-Gen AND LEAD TO GENERATION OF THE MODEL MATRIX ON THE BASIS OF DATA ALREADY FILED

To run the GRAM Notec model (as set up by William Orchard-Hays), several steps are necessary:

(1) Assuming the Pisa line is up, log-in as follows:

- (a) Type *P* and carriage return. On response, type *v*.
- (b) After VM/370 response, hit carriage return. A dot should appear.
- (c) Type *l gram gen*.
- (d) After log-in messages, etc., type *def stor 1m*.
- (e) After message about disabled state, type *i cms*.

(2) After next stop, type *sesame*.
This will activate the SESAME/DATAMAT system. However, if message reading UNABLE TO ALLOCATE D-DISK appears, answer *no* and try later.

(3) After prompt SESAME COMMAND: type *short* for short prompts. Then, if off-line output is required, type

TITLE 'some text' (quotes are mandatory)

and follow instructions appearing on the screen.

(4) The next step depends on what one wants to do.

(a) To change the availability/demand tables, type

run change rhs

and follow instructions appearing on the screen.

(b) To modify the model with changed availability/demand tables, type

run change model

(c) To run LP, type

run auto solve

and then issue normal SESAME commands, e.g.:

call restore name=xxx (*xxx*= name of last basis saved)
$flog=20, $fbreakl=200
call iterate nowt

In case of check errors, first try

call invert 0 — 1 (changes inversion algorithm)

Use step after AT LEVEL 1 message (i.e., not continue)
If error persists, but magnitude not too large, type

$checksw=0
continue

This will only work after ERROR AFTER INVERT. To change error tolerance, type

$tolerr=no. (e.g., *no.* = 1*e — 4*)

At BREAK1 (caused by $fbreak1 above), type

continue

but every few hundred iterations, save the basis with

call save name=xxx (e.g., *xxx=ito00*)

Use step after LEVEL 1 message.
At optimal or no feasible solution, also save basis for restarting next time. To get full solution, type

call solution active

(Omitting active gives listing of ALL variables, which is very long and the only information is dual values of main variables.)

To see only infeasibilities, use following sequence:

call mapgen map=inf, infeas
msgclass report=both
call solution inmap=inf
msgclass report=off

(Do not forget the last line after solution print or ALL off-line output will continue to come up on screen as well.)
To terminate SESAME, just type

quit

If print output does not start, have someone check the TPA.
If right line on modem is off, type

m rscs1 please start remlax

After several LP runs, MAPSFILE will have a lot of dead space. At start of LP run (after run auto-solve), use the following sequence to clean up the file:

call restore name=xxx (basis wanted)
cms erase mapsfile mpfile
call save name=xxx

This starts a new MAPSFILE with only the single basis on it.
Then proceed with call iterate, etc.
To see how many maps and basis saves are on MAPSFILE, type

call listmaps

APPENDIX B EXEMPLARY SHORT-LIST PRINT-OUT OF GRAM OPTIMAL SOLUTION RESULTS, FOR AN EARLY VERSION OF THE MODEL

AT 16:24:36 ON 11/22/79

SOLUTION

PAGE 26

COLUMNS SECTION

NUMBER	.COLUMN	AT	...ACTIVITY...	..INPUT COST..	..LOWER LIMIT.	..UPPER LIMIT.	.REDUCED COST.
302	XR.1HRG	LL	.	.	.	NONE	119.01943
303	XO.1HPW	HS	49.679799	.	.	NONE	.
304	XO.1HPM	LL	.	.	.	NONE	1.6527842
305	XO.1HPP	LL	.	.	.	NONE	160.30463
306	XO.1HPG	LL	.	.	.	NONE	61.078955
307	XO.1HFW	HS	91.424849	.	.	NONE	.
308	XO.1HFM	HS	54.742567	.	.	NONE	.
309	XO.1HFP	LL	.	.	.	NONE	29.717105
310	XO.1HFG	LL	.	.	.	NONE	49.137794
311	XO.1HRW	LL	.	.	.	NONE	178.89115
312	XO.1HRM	LL	.	.	.	NONE	169.07020
313	XO.1HRP	LL	.	.	.	NONE	177.05921
314	XO.1HRG	LL	.	.	.	NONE	185.65630
315	XL.1HPW	LL	.	.	.	NONE	2019.7228
316	XL.1HPM	LL	.	.	.	NONE	1564.4950
317	XL.1HPP	LL	.	.	.	NONE	1982.7735
318	XL.1HPG	LL	.	.	.	NONE	1033.8365
319	XL.1HFW	LL	.	.	.	NONE	1337.5339
320	XL.1HFM	LL	.	.	.	NONE	727.77726
321	XL.1HFP	LL	.	.	.	NONE	722.19385
322	XL.1HFG	LL	.	.	.	NONE	338.92087
323	XL.1HRW	LL	.	.	.	NONE	770.84982
324	XL.1HRM	LL	.	.	.	NONE	304.45175
325	XL.1HRP	LL	.	.	.	NONE	300.46357

326	XL.1BHG	BS	119.00000	.	.	NONE	.
327	XP.1HPW	LL	.	.	.	NONE	180.33365
328	XP.1HPM	LL	.	.	.	NONE	107.25621
329	XP.1HPP	LL	.	.	.	NONE	326.92841
330	XP.1HPG	LL	.	.	.	NONE	124.28443
331	XP.1HFW	LL	.	.	.	NONE	96.573935
332	XP.1HFM	LL	.	.	.	NONE	5.3203708
333	XP.1HFP	LL	.	.	.	NONE	105.42492
334	XP.1HFG	LL	.	.	.	NONE	14.115747
335	XP.1HRW	LL	.	.	.	NONE	84.769980
336	XP.1HRM	BS	574.70245	.	.	NONE	.
337	XP.1HRP	LL	.	.	.	NONE	105.63684
338	XP.1HRG	LL	.	.	.	NONE	15.731611
339	XM.1HPW	LL	.	.	.	NONE	157.50129
340	XM.1HPM	LL	.	.	.	NONE	127.78004
341	XM.1HPP	LL	.	.	.	NONE	231.07126
342	XM.1HPG	LL	.	.	.	NONE	77.747088
343	XM.1HFW	LL	.	.	.	NONE	69.003513
344	XM.1HFM	LL	.	.	.	NONE	19.412206
345	XM.1HFP	LL	.	.	.	NONE	9.6758941
346	XM.1HFG	BS	104.00000	.	.	NONE	.
347	XM.1HRW	LL	.	.	.	NONE	158.71394
348	XM.1HRM	LL	.	.	.	NONE	101.04476
349	XM.1HRP	LL	.	.	.	NONE	81.353430
350	XM.1HRG	LL	.	.	.	NONE	58.717890
351	XS.1HPW	LL	.	.	.	NONE	428.11504
352	XS.1HPM	LL	.	.	.	NONE	278.24695
353	XS.1HPP	LL	.	.	.	NONE	362.83082

AT 16:24:36 ON 11/22/79

SOLUTION

PAGE 24

ROWS SECTION

NUMBER	...ROW..	AT	...ACTIVITY...	SLACK ACTIVITY	..LOWER LIMIT.	..UPPER LIMIT.	.DUAL ACTIVITY
209	KSG..P	UL	45.000000	.	NONE	45.000000	741.06270
210	KSG..F	UL	12.000000	.	NONE	12.000000	786.06270
211	KSS..S	BS	1023.4428	176.55718	NONE	1200.0000	.
212	KSS..P	BS	.	60.000000	NONE	60.000000	.
213	KSS..E	UL	240.00000	.	NONE	240.00000	50.000000
214	KSP..S	BS	.	1600.0000	NONE	1600.0000	.
215	KSP..P	UL	120.00000	.	NONE	120.00000	51.056398
216	KSP..E	UL	240.00000	.	NONE	240.00000	71.056398
217	KSM..S	UL	40.000000	.	NONE	40.000000	364.71027
218	KSM..P	UL	30.000000	.	NONE	30.000000	309.71027
219	KSM..F	UL	24.000000	.	NONE	24.000000	547.71027
220	KSF..S	UL	400.00000	.	NONE	400.00000	137.46943
221	KSF..P	UL	90.000000	.	NONE	90.000000	137.46943
222	KSF..E	UL	48.000000	.	NONE	48.000000	207.46943
223	KSV..S	BS	.	40.000000	NONE	40.000000	.
224	KSV..P	BS	.	15.000000	NONE	15.000000	.
225	KSV..E	UL	12.000000	.	NONE	12.000000	143.89007
226	KSK..S	UL	400.00000	.	NONE	400.00000	237.38114
227	KSK..P	UL	150.00000	.	NONE	150.00000	250.38114
228	KSK..E	UL	.	.	NONE	.	300.38114
229	KSL..S	UL	60.000000	.	NONE	60.000000	2964.6154
230	KSL..P	UL	15.000000	.	NONE	15.000000	822.61538
231	KSL..E	UL	24.000000	.	NONE	24.000000	5235.6154
232	KSZ..S	BS	.	.	NONE	.	.
233	KSZ..P	BS	.	.	NONE	.	.
234	KSZ..F	BS	.	.	NONE	.	.
235	KTM..S	UL	140.00000	.	NONE	140.00000	3146.7753
236	KTM..P	UL	50.400000	.	NONE	50.400000	5246.7753
237	KTM..E	UL	18.200000	.	NONE	18.200000	6346.7753
238	KTL..S	UL	1050.0000	.	NONE	1050.0000	6.5000000
239	KTL..P	UL	126.00000	.	NONE	126.00000	6.5000000
240	KTL..E	UL	364.00000	.	NONE	364.00000	15.000000
241	KTD..S	UL	280.00000	.	NONE	280.00000	402.74584
242	KTD..P	UL	75.600000	.	NONE	75.600000	404.74584
243	KTD..F	UL	72.800000	.	NONE	72.800000	424.74584
244	KTF..S	BS	.	21.000000	NONE	21.000000	.
245	KTF..P	BS	.	10.080000	NONE	10.080000	.
246	KTE..F	UL	3.6400000	.	NONE	3.6400000	538.87437
247	KTW..S	BS	.	10.500000	NONE	10.500000	.
248	KTW..P	BS	.	5.0400000	NONE	5.0400000	.
249	KTW..E	BS	.	1.8200000	NONE	1.8200000	.

AT 16:24:36 ON 11/22/79

SOLUTION

PAGE 19

OPTIMAL SOLUTION AT ITERATION NUMBER 454

...NAME...	...ACTIVITY...	DEFINED AS
FUNCTIONAL	2045426.0	F$.....1
RESTRAINTS		RHS
BOUNDS....		40G
RANGES....		RNG

ABSTRACTS OF OTHER IIASA PUBLICATIONS

Leonardi, G., Editor, Public Facility Location: Issues and Approaches. IIASA Research Report RR-82-23, June 1982.
Reprinted from *Sisemi Urbani*, Vol. 3, 1981, pp. 293–470.

The papers collected in this issue were presented at the Task Force Meeting on Public Facility Location, held at IIASA in June 1980. The meeting was an important occasion for scientists with different backgrounds and nationalities to compare and discuss differences and similarities among their approaches to location problems. Unification and reconciliation of existing theories and methods was one of the leading themes of the meeting, and the papers collected here are part of the raw material to be used as a starting point towards this aim. The papers themselves provide a wide spectrum of approaches to both technical and substantive problems, for example, the way space is treated (continuously in Beckmann, in Mayhew, and in Thisse *et al.*, discretely in all the others), the way customers are assigned to facilities (by behavioral models in Ermoliev and Leonardi, in Sheppard, and in Wilson, by normative rules in many others), the way the objective function is defined (ranging from total cost, to total profit, total expected utility for customers, accessibility, minimax distance, maximum covering, to a multi-objective treatment of all of them as in ReVelle *et al.*). There is indeed room for discussion, in order to find both similarities and weaknesses in different approaches.

A general weakness of the current state of the art of location modeling may also be recognized: its general lack of realism relative to the political and institutional issues implied by locational decisions. This criticism, developed by Lea, might be used both as a concluding remark and as a proposal for new challenging research themes to scholars working in the field of location theory.

Rogers, A., and J.G. Williamson, Editors, Urbanization and Development in the Third World. IIASA Research Report RR-82-24, June 1982.
Reprinted from *Economic Development and Cultural Change*, Vol. 30, 1982, pp. 463–538, 595–623, 649–670.

Scholars and policy makers are divided on the issue of rapid urbanization and urban growth in the Third World. Some see these trends as effectively speeding up national processes of socioeconomic development; others believe their impacts to be largely undesirable and argue that they should be slowed down. Yet many of the determinants and consequences of urban and rural demoeconomic patterns of change are poorly understood, and there is an urgent need for improved methods for analyzing the fundamental issues and options that they bring about.

During the past several years, the Human Settlements and Services Area of the International Institute for Applied Systems Analysis has focused much of its research on population growth, structural change, and settlement dynamics. The five papers in this collection, written by current or past scholars in the Area, are a representative sample of this research. Together with three papers by other authors (not included here), they form the proceedings of a symposium on urbanization in the Third World published by the journal *Economic Development and Cultural Change*.

Sebestyen, I., The Videodisc Revolution. IIASA Research Report RR-82-27, July 1982. Reprinted from *Electronic Publishing Review*, Vol. 2(1), 1982, pp. 41–89.

This paper attempts to make a comprehensive analysis of present and future videodisc technologies and a thorough examination of the impacts of this technology on different information application classes and on other media. First the basic principles of this new technology are described. This is followed by a summary of some major hardware and software functions of such systems. In the subsequent chapter, the extremely broad range of videodisc applications is dealt with. In the final summarizing chapter some conclusions are drawn pointing to the vast potential of this new technology, which according to the author, could lead to a new revolution in the information and entertainment industry.

Ledent, J., Migration and Settlement: 15. France. IIASA Research Report RR-82-28, August 1982.

The comparative analysis of national patterns of interregional migration and spatial population growth is being carried out by an international network of scholars who are using methodology and computer programs developed at IIASA.

In this report the authors discuss the historical trends of population redistribution in France and go on to analyze current migration patterns. Much of the data used were unpublished and presented problems for which the authors created innovative solutions. The empirical results of the study are insightfully analyzed and contribute to the literature on internal migration in France.

Espenshade, T.J., L.F. Bouvier, and W.B. Arthur, Immigration and the Stable Population Model. IIASA Research Report RR-82-29, August 1982.
Reprinted from *Demography*, Vol. 19(1), 1982, pp. 125–133.

This paper reports on work aimed at extending stable population theory to include immigration. Its central finding is that, as long as fertility is below replacement, a constant number and age distribution of immigrants (with fixed fertility and mortality schedules) lead to a stationary population. Neither the level of the net reproduction rate nor the size of the annual immigration affects this conclusion; a stationary population eventually emerges. How this stationary population is created is studied, as is the generational distribution of the constant annual stream of births and of the total population. It is also shown that immigrants and their early descendants may have fertility well above replacement (as long as later generations adopt and maintain fertility below replacement), and the outcome will still be a long-run stationary population.

Robinson, J.M., Technological Learning, Technological Substitution, and Technological Change. IIASA Research Report RR-82-31, August 1982.
Reprinted from *Technological Forecasting and Social Change*, Vol. 18, 1980, pp. 39–49.

From a simple dynamic model of competition between product lines it is shown that the shape of learning curves has a powerful influence on the dynamics of technological substitution. Learning of both production efficiency and marketing efficiency is considered. It is asserted that both types of learning are important and that the two are complementary. It is further speculated that production learning is probably more important for commodities and in situations of low per capita income, whereas market learning gains ascendancy in cases of high income and specialized and diversified product lines. In closing, it is noted that simple competitive models are misleading, first because complementarities and coevolutionary processes are probably as important in the overall development of technology as are competitive processes, and second because optimization of the technological system's parts does not guarantee improvement of the performance of the system as a whole.

Keyfitz, N., and A. Rogers, Simplified Multiple Contingency Calculations. IIASA Research Report RR-82-30, August 1982.
Reprinted from *The Journal of Risk and Insurance*, Vol. 49, 1982, pp. 59–72.

Standard life contingency formulas are shown to have matrix analogues. The derivation of these multidimensional forms permits simple solutions to multiple contingency problems, including moves in and out of employment, insurance, marriage, sickness, and retirement. Awkward and inaccurate approximations now commonly used can thus be replaced by matrix formulas readily manipulated by computer.

BIOGRAPHIES

Murat M. Albegov, USSR

Murat Albegov came to IIASA in November 1976 to work on problems of integrated regional development. He is from the GOSPLAN Council for the Location of Productive Forces. Professor Albegov graduated from the Moscow Institute of Economics and Engineering in 1955. He received his Candidate's degree in 1962 and his doctorate from the Central Institute of Economics and Mathematics in 1972. From 1955 to 1960 he worked for the Krizhizhanovsky Energy Institute of the U.S.S.R. Academy of Sciences on problems of fuel and energy balance. He worked as a Senior Scholar for the Council for Location of Productive Forces since 1962, and in 1974 he became Chief of the Economics and Mathematics Department of the Council. Professor Albegov took part in constucting models for the development and allocation of a number of branches of the national economy, and in modeling the regional allocation of production. He is Professor at the All-Union Polytechnic Extra-Mural Institute.

Csaba Csáki, Hungary

Csaba Csáki joined IIASA in September 1976. His work at IIASA focuses on the modeling of the world's food and agriculture problems, and the development of national food and agriculture policy models of European CMEA and other countries. Dr. Csáki received his university degree (1963) and doctorate (1964) in Agricultural Economics from the Karl Marx University of Economics in Budapest. He became a Candidate of Economic Sciences of the Hungarian Academy of Sciences in 1971. Since 1963 he has been with the Department of Agricultural Economics at the Karl Marx University, where he leads a group dealing with the teaching of quantitative methods in agriculture and farm management economics. Dr. Csáki's scientific interests include: agricultural economics; farm management economics; modeling of agriculture; and planning, analysis, and simulation in agriculture. He is a member of the Hungarian Economic Society, the European Association of Agricultural Economists, and the Committee for Agricultural Planning and Management of the Hungarian Academy of Sciences.

Muhammad Jameel, Pakistan

Muhammad Jameel joined IIASA's Energy Systems Program in mid-June 1980 to work on the studies of energy demand in rural areas of developing countries and the prospects of renewable resources. He is from the Pakistan Atomic Energy Commission and is Chief Scientific Officer at PINSTECH, a physical sciences research center in Islamabad. Dr. Jameel studied at Karachi University and received his M.Sc. in Physics from there in 1958. He received his Ph.D. in Mathematical Physics from Edinburgh University, Scotland, in 1962. In 1963 he joined the Lahore Laboratories of the Pakistan Atomic Energy Commission. He also held the posts of Director of Scientific Information (1967–1969), Director of the Physics Division (1970–1972), and Head of Programme Coordination (1976–1980), all at the Pakistan Atomic Energy Commission. He has lectured at the Universities of Karachi, Panjab, and Baluchistan in Pakistan; at Sydney University in Australia; and at the University of Malaya in Kuala Lumpur. He has also been Visiting Scientist at the International Centre for Theoretical Physics, Trieste, Italy. Dr. Jameel has published on physics and on science policy matters. He has served on various national committees dealing with science education, science information, and the role of science and technology in development. Dr. Jameel is a Fellow of the Institute of Physics, London.

Janusz Kacprzyk, Poland

Janusz Kacprzyk visited IIASA in 1979 to help in the construction of the GRAM model with the Regional Development Task Group. He is a research scholar at the Systems Research Institute of the Polish Academy of Sciences in Warsaw, Poland.

William Orchard-Hays, USA

William Orchard-Hays came to IIASA in May 1975 to work on the modeling of energy systems. He is a research associate with the National Bureau of Economic Research (NBER) Computing Research Center for Economics and Management Science, Cambridge, Massachusetts. Mr. Orchard-Hays received his B.A. (1951) and M.A. (1954) degrees in Mathematics from the University of California at Los Angeles. He has been associated, in both technical and executive positions, with the Rand Corporation (1951–1956); CEIR Inc. (1956–1963); his own company, Orchard-Hays & Company (1963–1968); and Management Science Systems Inc. (1968–1971). Mr. Orchard-Hays' scientific interests include: the development and automation of algorithms and computational methods for mathematical programming; the organization, implementation and use of specialized application software systems; and the organization and management of projects using computerized methods, including networks. A former Associate Editor of *Management Science*, Mr. Orchard-Hays has established courses in computer programming, and has taught seminars at the American Management Association.

Jan W. Owsinski, Poland

Jan Owsinski came to IIASA from the Institute for Organization, Management and Control Sciences of the Polish Academy of Sciences. While at IIASA, he was concerned with the use of mathematical models and computer applications in planning and decision making in large organizations and undertakings (elaboration of analytic methodology and assessment of universalities). Mr. Owsinski received his M.S. in Control Science from the Technical University of Warsaw in 1970. Since 1970 he has been associated with the Institute of Automatics, the Institute of Applied Cybernetics, and the Institute for Organization, Management and Control Sciences, all of the Polish Academy of Sciences. From 1972 to 1973 he participated in an international postgraduate program for computer science and applications organized by the Commissariat à l'Energie Atomique at Saclay. His scientific interests include: modeling organizations; hierarchicity/stability/evolution; organizational phenomena; and the impact of modeling and computer applications on organizations. He is a member of the editorial board of *Control and Cybernetics*.

Andrej Straszak, Poland

Andrej Straszak joined IIASA in March 1976 to lead IIASA's research on planning, management, and organization of large-scale complex development programs. He was formerly Director of the Institute for Organization, Management, and Control Sciences of the Polish Academy of Sciences. Professor Straszak received his M.E. in Control Engineering (1955) from Warsaw Technical University, his Ph.D. in Technical Cybernetics (1959) from the Moscow Power Institute, and his Dr.sc. in System Science (1967) from the Polish Academy of Sciences. He was Head of the Control Theory Department of the Institute for Automatic Control from 1959 to 1972, and Director of the Institute for Applied Cybernetics from 1972 to 1973. Professor Straszak's scientific interest is cybernetic and mathematical modeling of large-scale organizations (at national, regional, corporation and enterprise levels). He is Vice Chairman of the Economic and Management Systems Committee of IFAC, Vice Chairman of the Technical Cybernetic Committee of the Polish Academy of Sciences, a member of the "Poland 2000" Committee, and editor and co-editor of two journals.

IIASA
REPORTS

Volume 6 Number 1 July–September 1982

Published quarterly

CONTENTS

IN FORTHCOMING ISSUES:

V.G. CHANT Two Global Scenarios: The Evolution of Energy Use and the Economy to 2030

J.C. STONE, M. GADKOWSKI, A. SALEWICZ, W. SIKORSKI, AND F.D. SINGLETON, JR. Water Demand for Generating Electricity in Poland: A Programming Approach

Z. KOS Stochastic Supplementary Irrigation Water Requirements in Water Resources Systems

Printed by NOVOGRAPHIC, Vienna, Austria.