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ON DINKA, CATTLE AND GRAIN
an interdisciplinary simulation study of a rural area in Southern Sudan

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Summary

Planning of rural development in developing countries requires participation and integration of various disciplines, such as economics, sociology, agriculture and health. Very often not all relevant disciplines participate and if they do, they tend to analyze, plan and implement their programmes separately.

This paper presents an example of the use of simulation for interdisciplinary analysis of rural areas in the Third World. The analysis of the Bor District in Southern Sudan serves as an example.

First a general verbal and graphical overview of the situation in the rural area of the Bor District is provided. This is followed by a more detailed analysis regarding population, foodconsumption, agricultural production and livestock production in the area.

Due to lack of data, a common problem in remote areas of the Third World, many parameters had to be derived from studies of other, but to some extent similar, areas. Validation was therefore carried out by means of a sensitivity analysis and by comparing the model results with developments in other areas.

Experiments have been carried out by simulating the effects of one or more interventions, such as the improvement of health services, veterinary services, watersupply, education, employment opportunities and the possibilities to import food, and the introduction of improved agricultural practices.

The results indicate, that several interventions, that initially seem to benefit the development of the area, prove to be disastrous after a number of years. In addition to that, some processes, that are un-important in periods of stability, appear to become important when the system becomes unstable.

1. Introduction

Considering the results of the efforts in rural development in the Third World over the past 25 years, we may conclude that considerable progress has been achieved in certain respects, e.g. the tremendous increase of the total food production. Nevertheless we must also conclude that poverty is still on the increase: apparently not everybody has been able to benefit from this progress.

A major cause of this phenomenon is the fact, that policy measures and technological development were usually not geared towards solving the problems of the poor. This has increased the gaps between developed and less developed areas and between rich and poor people within such areas.

One of the causes of these failures is that rural development programmes are often based on the contribution of a limited number of specialists, who each view the problems from their own disciplinary angle. As these specialists are not able to grasp the problem to its full extent, they tend to reduce the total problem to a problem which they are able to deal with. However, such a reduction may leave out aspects that are crucial for a proper understanding of the problem.

This difficulty has been recognized since many years and efforts have been undertaken at all levels to develop approaches, that are more appropriate.

In the sixties and seventies the Integrated Rural Development approach was developed to meet this challenge.

An important characteristic of Integrated Rural Development is that it attempts to cover all aspects that affect rural development by employing multi-sectoral activities, that are directed towards a target group in a limited area. In the eighties however the interest gradually faded away, mainly because of problems regarding management and organization such as the cooperation between different government sectors. As a solution to overcome these problems of management and coordination, Birgegard (1987) suggests an integrated planning followed by a non-integrated implementation. According to this approach the nature, the causes and the relationships of development problems are identified and analyzed with a broad multi-sectoral approach at area and household level. In this framework planning should be seen as a continuous process and not as a so-called blue-print planning.

Another attempt to better address the problems of the poor, was the development of the Farming Systems Research approach. Farming Systems Research was introduced in the seventies and eighties to offer an alternative for the existing top-down approach in agricultural research. In this top-down approach, technological innovations were developed and tested at the research stations and subsequently introduced by the extension services. It appeared however, that the circumstances of most of the farmers, and in particular the poor, were so different from those at the research stations (e.g. differences regarding soils, availability of labour or access to the inputs required), that these farmers were not able to adopt these innovations. Farming System Research (FSR) attempts to adapt agricultural research to the situation of a particular group of farmers, by first analyzing their farming system and subsequently conducting research on the farmers field in close cooperation with the farmer.

Although the concept of Farming Systems Research has been widely accepted, the way it has been applied has also met with some criticism:

- Most FSR-activities are directed towards the development of interventions that are appropriate within the existing constraints. It seems that such an approach does not do justice to the possibility to remove these constraints through the manipulation of socio-economic or infrastructural factors (Norman and Gilbert, 1982).
- An other critique that is leveled against the practice of FSR, is that it does not sufficiently take into account, that a farming system is embedded in a dynamic environment, so that the notion of what is appropriate changes all the time (Little, 1985; Maxwell 1986; Dorward, 1986). Fresco (1986) suggests therefore that more attention should be paid to the wider environment of the farming system.
- Farming systems research is mostly carried out with the objective to increase production (sometimes limited to one particular crop) on a certain category of farms, thereby assuming that when production increases, the well-being of the farmers household will improve as well. This, however, may not always be the case as the well-being of the household does not only depend on the production of one or more crops. This means that an increased crop production may be a weak indicator. Indicators such as the nutritional status or income of the household may convey more information about the well-being of the farmers households. FSR and other interventions should therefore explicitly be directed towards such goals.

This means that before embarking on a Farming Systems Research programme, one should have a broad understanding of the problem situation as a whole. For the analysis of such a situation, one should start from the higher level goals (e.g. nutritional status, income), try to understand the causes of the problems on that level and define constraints for the solutions of these problems. Based on this analysis precisely defined questions can be submitted to specialists, an approach that is in line with the suggestions of Birgegard (1987).

An important prerequisite for an integrated approach requires the participation of specialists who are ready to let their contribution be defined by the problem rather than to define the problem by their discipline.

The system approach is considered to be a useful tool for an integrated analysis. In this approach the problem situation is considered as a whole of interrelated elements: a system. When the behaviour of one element changes, the behaviour of the other elements, and thus of the whole system, changes as well. Examples of a system are a plant, a person, a household, a village, a region etc. This approach allows the analyst to relate the behaviour of parts of the system to the overall behaviour of the system.

The general objective of this study is to show how a method of system analysis (System Dynamics) can contribute to a better understanding of the dynamics of rural development and so to a better integrated planning. This technique will be applied for an analysis of a region in Southern Sudan: the Bor District.

This study is built up in the following way:

- chapter 2 describes the methodology of System Dynamics;
- chapter 3 provides a description of the Bor District and a statement of development objectives and constraints for this particular area;
- chapter 4 gives the general framework of the study;
- in chapter 5 a detailed and quantified description is given of the model;
- in chapter 6 the validity of the model is discussed;
- in chapter 7 the results of the model experiments are presented;
- in chapter 8 the applicability of the approach is discussed in view of the results of the case study.

2. Methodology

The application of system analysis requires a definition of the system, i.e. one has to define the elements that are relevant for the system.

The answer to the question which elements are relevant depends on the objectives and constraints, one has in mind: maximizing agricultural output of an area within the budgetary constraints of the government requires a different set of elements than improving the nutritional status of the poorest without disturbing ecological sustainability.

Elements that belong to the system are called endogenous elements and those elements that are not part of the system, but which do influence the system without significantly being influenced by the system, are considered to belong to the environment of the system: exogenous elements. Examples of exogenous elements for a farmer may be rainfall and prices.

As it is quite impossible to objectively describe a system in the real world, it is necessary to give a simplified representation of the system: a model. Such a model consists of variables and constants, representing the selected elements and relationships between them. As a matter of fact, everybody is using these simplified representations in order to cope with the complex realities of daily life: mental models. The problems of mental models however are that they are not very accessible for other persons, that they may change unnoticed and that they may be too complex to allow consistent reasoning. This constitutes an important disadvantage, especially when persons with different backgrounds have to work together in multidisciplinary teams.

Mathematical models may offer a solution for this problem. Mathematical models have become important tools in research and various types of mathematical models have been developed over the last few decades. Some types are used to determine the optimal state of a system, based on certain criteria, while others are used to better understand a system. Among the latter, simulation models, which allow the analyst to obtain insight into the behaviour of the system under various circumstances, play an important role (Crawford, 1982).

Mathematical models consist of two types of equations (Sidhamed and Koon, 1984):

- empirical equations, which are based on relevant data of the past, rather than on the underlying reasons for the relationship;
- theoretical equations, which are based on theoretical or hypothetical considerations regarding the relationship.

Models in which empirical equations play an important role require an extensive and reliable data-base. In cases where such a database is lacking, models will be developed which make to a larger extent use of theoretical equations.

In order to be able to decide which type of modelling technique is to be used for a better understanding of rural development in the Third World, some considerations should be taken into account.

Especially in rural areas of developing countries it is often difficult, time-consuming and costly to acquire an extensive data-base and there is an increasing reluctancy to spend much time and money to acquire the data required. Moreover the situation may change so fast, that historical data may bear little relevance to the new problem situation.

Under such conditions, a method is required, that allows the planners to obtain a general understanding of the system and to integrate the various aspects of the system in order to have a basis for planning of development activities or for the planning of more detailed studies of certain aspects. Even in situations where time and money are available to build an extensive and reliable database, it could be desirable to first have an overall picture of the problem situation, before embarking on a data-collection project, with the view to increase the chance that only relevant data will be collected (Anderson e.a., 1987).

A simulation technique that is considered to be appropriate under these conditions is System Dynamics.

System Dynamics is used to simulate the dynamic behaviour of a system over a period of time. To this end all relevant elements, that influence the behaviour of the system, and the relationships between them are identified. Once the model has been constructed it is possible to carry out experiments by changing certain policy variables (i.e. exogenous variables, that can be influenced by the project or the government) to obtain insight into the behaviour of the system under various circumstances.

The System Dynamics methodology can be divided into seven phases:

1. Choice of objectives, identification of constraints and possibilities to influence the behaviour of the system.
   In some cases the objectives, the constraints and the possibilities for intervention are narrowly defined by the clients, but in other cases there is more room left for interpretation to the analyst. While top-down approaches were commonly followed in the past, it is nowadays more and more attempted to involve the target population in defining the objectives and the constraints, and methodologies have been developed to identify them, e.g. Rapid Rural Appraisal (Hildebrand, 1981) and Forum method (IMSA, 1985).

2. Identification of important variables, time horizon, system boundary and level of aggregation.
   The identification of these aspects depends on the objectives, constraints and possibilities for intervention.
   Variables can be divided in criterium variables, exogenous variables (policy-variables and variables that can not be influenced by the system), indicator variables and intermediate variables.
   Criterium variables represent the criteria that should be satisfied by the solu-

tion of the problem. Policy variables represent the means, that are available to the client, to influence the system. Non-manipulable exogenous variables are variables, that do influence the system but cannot be significantly influenced by the client (e.g. the weather). Indicator variables are variables that provide information regarding the state of the system though they do not belong to the criterium variables. Intermediate variables are all other variables, required to link the above mentioned variables.

The time horizon is the length of the period over which the behaviour of the system is considered and is largely determined by the objectives of the system.

An extension of the time horizon usually leads to the inclusion of other variables because variables that hardly change over a short period may significantly change over a longer period. This will also result in a shift of the boundary of the system. The level of aggregation is determined by the objectives as well as by the information that is available regarding the system: the scope in time and space determines the level of aggregation to a large extent and a lack of detailed information forces the analyst to increase the level of aggregation.

3. Graphical representation of the system by means of a causal diagram.
   A causal diagram is a graphical representation of the structure of the model, in which important variables are indicated by arrows as shown in figure 1 and 2. A causal diagram can serve as a means to facilitate a first discussion on the model as long as it is not too complex. On the other hand it can also be used to provide a summary of the system after the analysis has been carried out. A causal diagram can especially be helpful in the location of sources of stability and instability of the system.
   Whether a system is stable or not depends on the feedback relations in a model (Richardson, 1986).
   Feed back relations play an important role in System Dynamics, as it is assumed that the behaviour of the system can, to a large extent, be explained by the internal structure (Meadows and Robinson, 1984; Forrester, 1987).
   In fig. 1 the number of births increases if the population increases and the population increases if the number of births increases. This is called a positive feedback loop indicated by (+) and usually has a destabilizing effect on the behaviour of the system.
   Fig. 2 represents a system in which the supply of food is constant. When

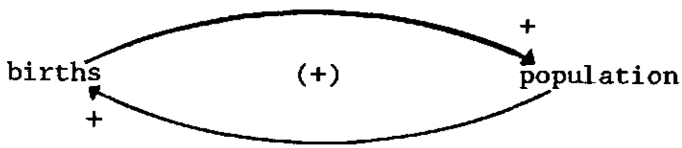

Fig. 1. A positive feedback loop

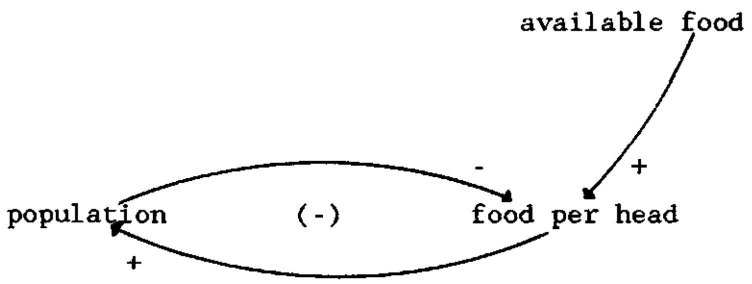

Fig. 2. A negative feedback loop

the population increases, the amount of food per head will decline resulting in a higher deathrate and a decreasing population. This will raise the available food per head and so causing the population to increase again. This is called a negative feedback, indicated by (−). Negative feedbacks have a stabilizing effect on a system.

4. The representation of the system by a mathematical System Dynamics model. The mathematical model consists of a number of mathematical equations, written in the DYNAMO language.
There are three types of equations in DYNAMO: levels, rates and auxiliaries in which respectively level-, rate- and auxiliary-variables are calculated. Each type of variable corresponds to certain properties, that elements within a dynamic system possess. Level variables represent accumulations of material over time and are fundamental to all dynamic systems. Level variables cannot change instantly and hence their value at any time is essential for the overall behaviour of the system. The means by which level variables change is referred to as integration, a process that converts a rate of change over time into an actual change.
Rate equations determine how level variables change over time and auxiliary variables are used to facilitate connections between level- and rate-variables.
An advantage of System Dynamics is that it allows the modeler to use any relationship between two variables; these relationships do not need to be linear and can even be given in a tabular form.
The possibility to include the effects of delays on the behaviour of the system constitutes an important aspect of System Dynamics as well. This provides the modeler with the opportunity to keep into account that effects of a change in one variable may gradually appear after some time.

5. Choice of parameter values and initial values of level variables.
Parameters determine the relationship between two or more variables. They can be statistically derived from longitudinal data concerning these variables. When the database is limited, these parameters must be obtained in another

way. In such a case one can make use of parameters that are based on data from another but in many respects similar situation or, if no such data are available, one has to accept guesses, based on personal observations. The importance of giving accurate parameter values depends on the feedback structure of the model: if the behaviour of the model does not change significantly when a parameter value is changed within its realistic range (sensitivity analysis), further efforts to obtain more reliable information need not to be undertaken. On the other hand if changes of the parameter values do considerably alter the behaviour of the model, more information is required or one should be very cautious in drawing conclusions from the results of the model runs.
The choice of initial values of the level variables presents usually less difficulties as data of just one year regarding these variables are required.

6. Validation of the model.
   By the validity of a model is meant the extent to which the model gives an adequate description of the system (Becker, 1976). Meadows and Robinson (1984) mention a number of conditions that have to be met by a model:
   – when the model is used to simulate historical periods, every variable exhibits the qualitative and roughly the quantitative behaviour, that was observed in the real system; in particular the model should clearly generate the problem it was meant to investigate;
   – when the model is simulated under extreme conditions, the results should remain plausible: i.e. physical quantities should not become negative or exceed feasible bounds and impossible behaviour should not appear;
   – parameters that are sensitive to numerical changes in the model should also be sensitive to similar changes in the real system.

7. Carrying out experiments with the model.
   For a better understanding of the system under varying conditions, model experiments are carried out by changing one or more exogenous variables; policy options can be compared by changing one or more policy variables. This is especially useful in situations where 'live'-experiments cannot be carried out.

The methodological objective of this study is to show that System Dynamic modeling can be a useful tool for the analysis of problem situations in a rural area in the Third World and for defining possible ways to find solutions for these problems. This means, that it should be suitable for integrating the relevant aspects of the system and that it can be applied in the absence of an extensive database.

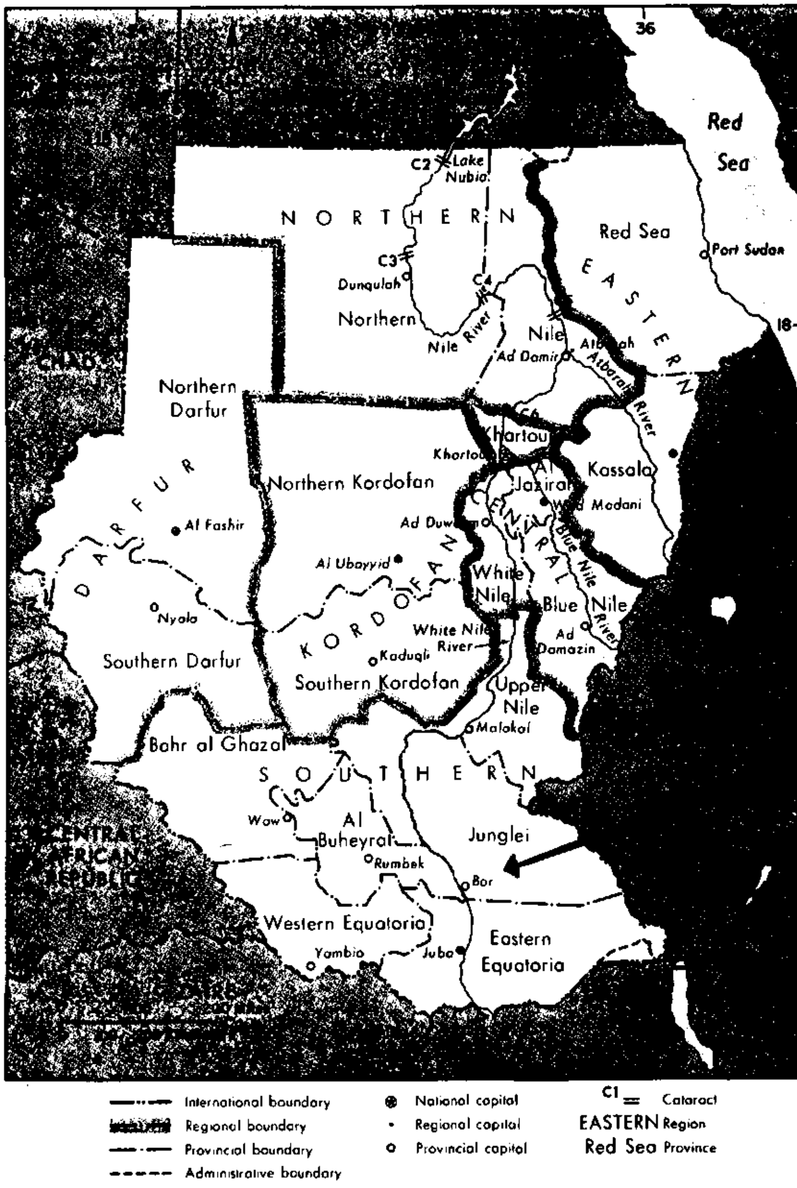

Fig. 3. Democratic Republic of Sudan, 1982

3. Description of the Bor district

3.1. Introduction

The area that has been selected for the case study is the Bor District in Southern Sudan (fig.3), where the author has been working as an agronomist from 1979 to 1983 in an agricultural and rural development project.

The two main objectives of the project were:

- to test the possibility to produce sorghum (and later also rice) for export in a large-scale mechanized production system;
- to start small development projects in the rural areas of the Bor District in the field of agriculture, animal husbandry, health, education and water supply.

Besides this project there have been various other projects in connection with the construction of the Jonglei Canal in the area (Howell e.a.,1988).

Although these projects have carried out research in various fields, a consistent longitudinal database is lacking, which precludes the construction of a model, that is largely based on statistically derived parameters.

A remark should be made here regarding the relevance of the results of this study for the area itself. In 1983 problems started to emerge in this area, which developed into a devastating civil war that has totally upset large parts of Southern Sudan including the Bor District, killing thousands of people. This study is based on the situation as it was before the civil war, so that the results of this study should not be considered as directly applicable to the present situation.

3.2. Physical environment

The Bor District is situated on the East bank of the Nile at approximately 6° NL between Malek in the south and Jalle in the north (100 km) and between the Nile in the west and the Pengko Plains in the east (100 km).

The climate is characterized by one rainy season, that lasts from the end of April till the beginning of November (table 1).

The average precipitation over this period was 899 mm with a standard deviation of 158 mm. The distribution of the rainfall over the rainy season can be very irregular and dry periods of more than one week frequently occur. The average annual temperature is 27.7 °C; the highest monthly maximum temperatures are recorded in February and March (37 °C) and the lowest monthly maximum temperatures in January (20.1 °C) (ILACO, 1981b).

The area can be characterized as flat: the slope from south to north over a distance of hundreds of kilometers averages 10 cm per km (ILACO, 1980; Howell e.a., 1988). Nevertheless micro-topographical differences can be considerable, giving rise to differences of more than 50 cm over a distance of just a few meters.

Table 1. Average monthly rainfall (mm) at Bor over the period 1931-1970 (ILACO, 1981b)

January	5	July	145
February	7	August	130
March	35	September	125
April	77	October	114
May	113	November	30
June	112	December	6

The Bor District can be divided into four zones from west to east (ILACO, 1983):

- the Sudd zone: the part of the Nile swamp that is permanently flooded;
- the Toic zone: the part of the Nile swamp that is flooded between June and December;
- the Savanna zone: a zone of open woodland, that stretches from the Nile 50 km eastward;
- the grassland zone (the Pengko Plains): a zone without trees that can be heavily flooded during the rainy season.

Except for a very narrow strip along the Nile, most soils consist of clay and loam, which increase eastward in clay content. Due to the high bulk density of the soil (1.6 – 1.8 $g.cm^{-3}$), the internal drainage and the available moisture holding capacity (52 mm across a soil depth of 40 cm) are very low (ILACO, 1980). This results in floods during the rainy season on the lower places, while during the dry season the soils become very hard and virtually impossible to cultivate.

3.3. Population

The Bor District can be divided in Bor, a small town of about 15,000 inhabitants, and in a rural area, where approximately 45,000 people live in villages. The villages consist of a number of kinship groups, that belong to the Dinka (ILACO, 1982a). Kinship ties play an important role in the life of the Dinka, as relatives do not only help one another in the daily tasks but can also appeal for help to their relatives in times of distress, such as during famines (Howell e.a., 1988). A web of kinship is created through marriage, whereby a bridewealth of cattle from the kin of the bridegroom is transferred to the kin of the bride.

The smallest socio-economic unit is the household, consisting of a wife and her children with a husband, dividing his attention and labour between the households of his different wives. The average size of a household is 7.

The age structure of the population (table 2) shows the shape of a broad-based pyramid due to a high mortality, especially among young children (45% of the children die before their third year). The most important diseases are intestinal infections, whooping cough, measles and tuberculosis.

Table 2. The estimated age structure of the population in 1979 (ILACO, 1982a)

age group		number
children	(0 – 6 yr)	10485
youth	(7 – 13 yr)	8820
adolescents	(14 – 19 yr)	6300
young adults	(20 – 29 yr)	6885
adults	(30 – 39 yr)	5535
middle aged	(40 – 49 yr)	4095
elder	(50 – 75 yr)	1845

The Dinka are semi-nomads and their life is primarily based on self-subsistence: virtually all products of agriculture and livestock are consumed by the local population and there is little trade. The most important sources of food are sorghum, milk, meat, other cultivated products, fish, bush meat and wild fruits and vegetables. Sorghum is, in terms of energy, the most important food. It is produced by the population itself, though also some sorghum (approx. 3 kg per head per year) is received as a gift from relatives in Bor town.

Any seasonal abundance of sorghum tends to be used for beer brewing, marriages or is given to poor relatives or neighbours (Howell e.a., 1988).

In years of a low sorghum production the rural population may purchase sorghum at the market in Bor, that is imported from Northern Sudan by steamer. This sorghum is in the first place meant to supply Bor town, but may also be purchased by the rural population in times of scarcity. Due to the weak infrastructure of the area the quantity of imported sorghum may not always be sufficient to cover the requirements of the total population.

Normally cattle are not killed for consumption, though almost every animal that dies is consumed. Cattle may be killed for ceremonial purposes and in times of famine. The Dinka are also reluctant to sell their cattle and will only do so when they require money to pay for the necessities of life and when their sorghum production is not sufficient. When they are forced to sell cattle, they will first sell male animals, then dry cows and finally calves and heifers.

The number of heads of cattle sold and the average prices per head are given in table 3.

The infrastructure of the area is very poor. There are no all-weather roads, that connect Bor with other areas of Sudan. The Nile steamer calls in at Bor at irregular times.

The villages consist of houses that are scattered over a large area as the inhabitants have to construct their dwellings on relatively high places, that will not be flooded during the rainy season. There is a general lack of facilities in the villages: there are very few water supply points and the health services are at a very low level. There are no shops and markets, while the condition of the roads is such that most of the villages are virtually cut off from Bor town during the rainy season. Although during the seventies some schools have been established in the villages, school attendance is still low. In 1979 33% of the boys

Table 3. Number of cattle sold in Bor during the period 1974-1979 and the average prices (ILACO, 1981a)

year	number	price (Sud. Pounds)
1974	2651	S£ 26.85
1975	3780	S£ 27.17
1976	4680	S£ 30.58
1977	4752	S£ 33.95
1978	4212	S£ 41.16
1979	5927	S£ 68.97

and 2.9% of the girls, who were between 7 and 13 years old, went to school (ILACO, 1982a). One of the reasons for this is the lack of general facilities in the villages: teachers are difficult to motivate to teach in such villages.

The attraction of the facilities in Bor-town and other places, such as Juba, and the increasing number of educated people has caused a considerable outmigration of people in the agegroup of 20 – 39 yrs. This has resulted in a negative population growth of the rural areas of – 0.73% per year.

Bor town on the other hand is rapidly growing at a rate of 8% per year. Unfortunately there are insufficient jobs in the towns, so that the number of unemployed is steadily growing.

3.4. Livestock

As already indicated above, cattle play an important role in the culture and the economy of the Dinka:

- cattle are instrumental in maintaining the system of reciprocal obligations;
- cattle provide the population with milk and meat;
- cattle is sold (although reluctantly) to obtain money for general expenses (cloths, vegetable oil, taxes, medicines) or to purchase food during periods of food shortage.

The cattle can be divided into two groups: a group that remains close to the house of the owner, to provide the household with milk and a group that is herded together with other groups in large herds by the young unmarried people outside the villages. The total herdsize in the Bor District was in 1979 estimated at 80,000 heads (ILACO, 1981a).

The estimated composition of the herd is given in table 4.

Songbulls are castrated male animals, which have a special relationship with a particular person, mainly male adolescents and young adults (ILACO, 1982a).

Besides cattle, goats, sheep and poultry are kept as well, but constitute only 3.4% of the domestic animals, when expressed in animal units (ILACO, 1981a).

Table 4. The estimated composition of the cattle herd in the Bor District (%) (ILACO, 1981a)

female animals		male animals	
calves	17%	calves	3%
heifers	19%	adult males	2%
cows in milk	18%	ox calves	11%
dry cows	18%	adult oxen	7%
		songbulls	4%

The average liveweight of male cattle is 237.7 kg and of female cattle 225.2 kg of which 57% is edible (ILACO, 1982c).

During the rainy season, the cattle graze in the savanna zone. At the beginning of the rainy season the quantity and the quality of the grass are sufficient. Towards the end of the rainy season the quality decreases, so that the growth of the animals slows down. In November the large herd is brought to the grassland zone, but this cannot prevent the growth of the animals to further slow down and even become negative. In January most of the cattle move to the toic zone; although the quality of the grass meets the minimum standard, the quantity is not sufficient for the animals to maintain their weight (table 5).

Lack of feed of sufficient quality is therefore one of the main reasons for the high mortality among the cattle: 25% calf mortality and 5% cow mortality (Howell e.a., 1988). Another reason of the high mortality among the cattle is the incidence of diseases such as rinderpest, contagious bovine pleuro-pneumonia and brucellosis (ILACO, 1981a; Howell e.a., 1988). Due to these adverse conditions maturity is delayed till the age of 4, calving rate is 56% and milk production is low: the average yield of milk taken for human consumption per lactating cow varies from 0.1 to 0.5 kg per day (ILACO, 1981a).

The total milk production per lactation is estimated to be approx. 750 kg of which approx. 525 kg is taken by the calf. It should be noted that female calves receive more milk than male calves, which causes a higher mortality among the latter.

Table 5. The growth of adult cattle during the year in kg per head as estimated by ILACO (1983)

period	growth
May – July	+ 35 kg
August – October	0 kg
November – January	– 5 kg
February – April	– 10 kg

3.5. Crop production

Crops are produced in a system of shifting cultivation. The crops are grown on a plot surrounding the homestead of a household for about 10 to 15 years. After that period the soil fertility has declined to such an extent, that the household has to move to another place. As long as the population density remains low, the area can sustain this practice of shifting cultivation. In 1979 the cultivated area was estimated at 6400 ha. However, with an increasing population density, the cultivated area might rise above a critical level which causes a decline of the average soil fertility in the area.

While cattle herding is the task of the young people, cultivation is the work of the married people, men as well as women.

Table 6 gives an estimation of the manpower-equivalent per person of a certain age class for men as well as women. One manpower-equivalent is represented by a rural active man between 20 and 39 years of age, who is able to cultivate 0.55 ha per year. The table shows that women spend more time on cropping activities than men. The low involvement of male youth and adolescents is caused by the relatively high percentage of school-going boys.

The productivity is negatively influenced by the lack of facilities: much time is required for the collection of water and for traveling to Bor to purchase oil, clothes etc. or for medical treatment. Because of shortage of drinking water, the population leaves the villages during the dry season and joins the cattle herd in the toic. As they return only to their homes after the onset of the rains, the preparation of the fields and the sowing of the sorghum is delayed.

Although various crops are cultivated, sorghum is by far the most important crop. Its tolerance to flooding and drought makes it very suitable for this area. Two crops of sorghum are grown per year: the main crop is grown during the rainy season and a minor one at the end of the rainy season, which is harvested in the dry season. Other crops are maize, cowpea, pumpkin, okra and tobacco, which are cultivated during the rainy season.

Cultivation practices are still primitive: except for some simple hand tools

Table 6. The distribution of male and female labour per age class over cropping and animal husbandry activities (ILACO, 1982a)

age	male			female		
	pot.lab.	perc. of time spent on		pot.lab.	perc. of time spent on	
	(man eq.)	cropping	livestock	(man eq.)	cropping	livestock
7-13	0.6	0%	56%	0.4	0%	95%
14-19	0.8	0%	56%	0.7	25%	70%
20-39	1.0	50%	30%	0.8	80%	20%
40-49	0.8	90%	0%	0.7	100%	0%
50-59	0.6	84%	0%	0.4	100%	0%

Table 7. Summary of annual reports concerning grain supplies in 2 areas of the Bor District over a period of 15 years (J.I.T., 1954)

	surplus	sufficient	shortage	cause of shortage	
				flood	drought
Bor Athoic	–	4	11	8	3
Bor Gok	1	3	11	8	3

no modern techniques are used. Production therefore depends very much on the vagaries of the climate and the labour capacity of the population.

The most important problem is flooding: although sorghum is to some extent resistant to flooding, it does not survive prolonged flooding. Pests and diseases are present but, except birds, these pose no serious threat to production.

The average production of the main sorghum crop is estimated at 1000 kg/ha. The production of the second crop is much lower due to lack of rainfall and is estimated to vary between 50 and 250 kg per ha (ILACO, 1980).

Table 7 shows that in most years the rural areas of the Bor District fail to meet self-sufficiency in sorghum production, mainly due to flooding.

3.6. Definition of the problem

This study is undertaken with the objective to identify interventions, that

- improve the health of the rural population, in terms of the level of morbidity and incidence of hunger;
- stabilize the population of the rural area, in order to avoid an urbanization rate, that exceeds the absorption capacity of the towns.

The first of the main objectives of the project (see section 3.1), large-scale mechanized production of sorghum and rice, is not taken into consideration here.

The objectives should be achieved under the following conditions:

- the herd size should remain stable to avoid both overgrazing due to an overpopulation of cattle and a disintegration of the socio-economic structure, caused by a failure to maintain the system of bridewealth due to a shortage of cattle.
- the cultivated area should not exceed the critical size, beyond which the average level of soil fertility declines;
- although initially funds for development may be raised from external sources (development cooperation), on the long run the Government of Southern Sudan should be able to bear the expenditures.

The following assumptions have been made:

- the conditions of the main roads will remain poor. (Experience has learned,

that roads on this soil type are very difficult to maintain). Secondary roads between villages however may slightly improve the accessibility if maintained by the villagers themselves.
- the attitude of the Dinka concerning the trade of livestock and agricultural products does not change during the period under consideration (1979-2000);
- the availability of and the demand for external inputs such as fertilizer, pesticides and modern agricultural tools will remain very low.

The following possibilities for interventions are considered:
- Improvement of general facilities: year round supply of potable water, improved local roads, good quality school buildings.
- Improvement of medical facilities: better trained staff in the rural health centers, mass immunization campaigns (DTP and Tuberculosis), mother and child care. It is expected that such measures will only have a significant effect on the morbidity and the mortality of children if accompanied by a proper supply of potable water.
- Improvement of veterinary facilities, such as vaccination campaigns against rinderpest and Contagious Bovine Pleuro-Pneumonia (CBPP) and control of parasitic worms. As one vaccination against rinderpest provides a lifelong protection, the elimination of rinderpest seems feasible but the control of CBPP and worms requires repeated treatment (Howell, e.a., 1988).
- Introduction of a sorghum-rice intercropping system to prevent the grain production from declining because of flooding. In this system rice is sown between the sorghum on spots that are prone to flooding in wet years: in dry years only sorghum will grow, in moderately wet years some sorghum and some rice will be produced, while in very wet years only rice will grow on the heavily flooded spots. This may maintain the total grain production at approximately the same level (Struif Bontkes, 1986).
- Improvement of the supply of sorghum on the market of Bor town by increasing river transport facilities.
- Improvement of employment opportunities in Bor town.

The time horizon of this simulation study covers the period from 1979 to 2000.

4. The general structure of the problem situation: causal diagram

Based on the general knowledge of the problem situation, the objectives, the constraints and the possibilities to improve the situation, at first a rough structure has been designed, which is represented by the causal diagram in Fig. 4. The relationships between the variables are discussed in detail in chapter 5.

The two major objectives are to increase health (**health**), to reduce the incidence of famine (**relative consumption**) and to stabilize the rural population (**rural population**). Relative consumption represents the extent to which the actual con-

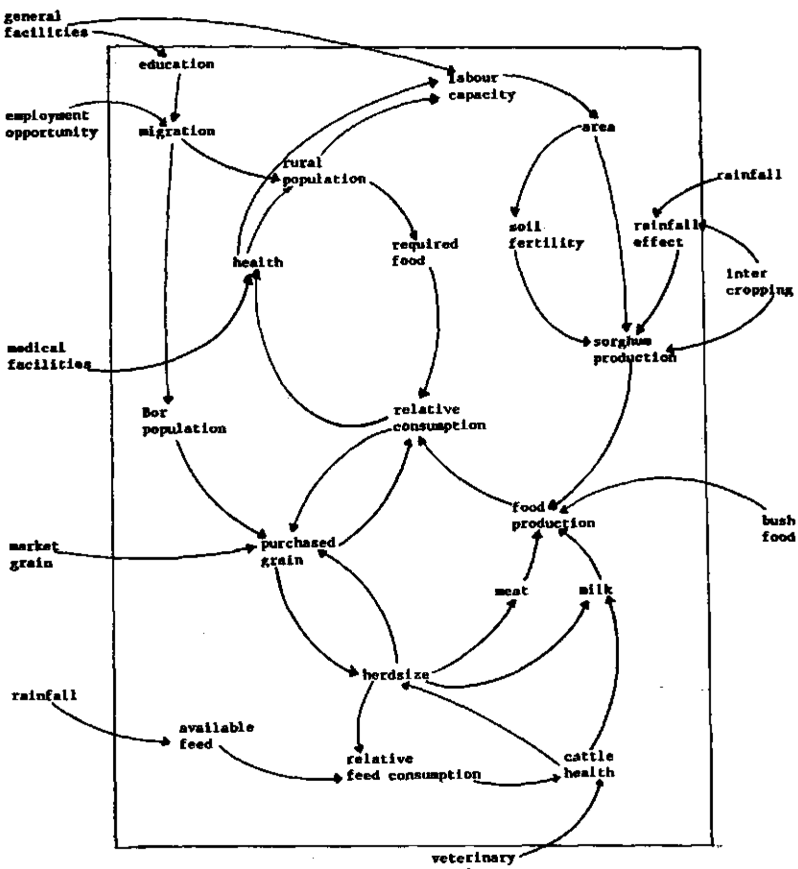

Fig. 4. Causal diagram, representing the general structure of the system

sumption meets the food requirement of the population.

As already indicated it is deemed important, that **herdsize** and **soil fertility** do not decline. These 5 variables can be considered as criterium variables.

The following variables can be directly influenced by the project (policy variables): **medical facilities, general facilities** (water supply, roads and schools), **veterinary services**, the effect of rainfall on grain production (**rain effect**), the supply of sorghum on the market (**market grain**) and the opportunities for employment outside the rural area (**employment opportunity**).

It is assumed, that the availability of water for plantgrowth (**rainfall**) is an exogenous variable, that cannot be influenced.

It is assumed, that the **health** of the population is influenced by the **relative consumption** and the **medical facilities**.

The **relative consumption** depends primarily on the total quantity of food produced (**food production**) and the quantity of food that is required by the rural population (**required food**). The size of the rural population (**rural population**) depends on their mortality and birth rate (**health**), but also on the outmigration (**migration**) of the area. The migration rate depends thereby on the level of education (**education**) and on the possibilities to find a job outside the area (**employment opportunity**). The level of education is largely determined by the **general facilities** as these are considered to increase the number of schools and the readiness of teachers to work in the villages.

The availability of food depends mainly on the local food production (**food production**), which is determined by the production of sorghum (**sorghum production**), the milk produced by the herd (**milk**), the cattle that die and subsequently consumed (**meat**) and by other sources of food, such as minor food crops, bushmeat, wild fruits and vegetables and fish (**bushfood**).

The production of sorghum depends on the soil fertility (**soil fertility**), the area cultivated (**area**), the rainfall (**rainfall**) and the effect of the rainfall on the grain production (**rainfall effect**). The effect of the rainfall is negative when low, as there will be drought problems, but also negative when rainfall is high, due to the effect of flooding. However the rainfall effect can be changed by introducing sorghum-rice intercropping (**intercropping**).As long as the size of the cultivated area (**area**) is below a certain maximum, the average **soil fertility** can be maintained but when the size exceeds that maximum, soil fertility will decline.

The area cultivated is determined by the available labour force (**labour capacity**), which depends on the size and the health of the population.

The milk production depends on the herd size (**herd size**) and on the health of the cattle (**cattle health**), which influences calving rate and the milk production per lactation. The health of the cattle depends on the quantity and quality of the available feed per head of cattle (**relative feed consumption**) and on the level of veterinary services (**veterinary services**). The available feed per head depends on the total quantity of **available feed** and on the herdsize. The total quantity of feed is determined by the rainfall.

The herdsize depends on the cattle health but also on distress sales and on distress slaughter. If there is not sufficient food for human consumption available, grain will have to be purchased on the market (**purchased grain**) or if the quantity of grain that is available in the market (**market grain**) is not sufficient, the population will kill part of their cattle in order to survive. The quantity of grain, that is available for the rural Dinka depends on the quantity that is imported in Bor and on the requirements of the population of Bor town (**Bor population**). It is assumed, that if the demand for grain exceeds the supply in the market, the price of grain will increase so that more cattle will have to be sold to be able to purchase the grain. This causes an increase in the supply of cattle which will lower the price of cattle.

An important assumption in this model is that food shortages are equally distributed over the total population, due to the high social cohesion which is still prevalent among the Dinka.

5. Detailed description of the model

In chapter 4 a general structure of the problem has been described and represented by a causal diagram to provide an overview of the problem situation. The next step is to construct a mathematical model. The model itself, written in the DYNAMO-language, is not included in this report, but can, at request, be made available by the author (adress: T.E. Struif Bontkes, Department of General and Regional Agriculture, Agricultural University Wageningen, Hollandseweg 1, 6706 KN Wageningen). In this chapter a detailed description of the model is given.

The time horizon of the model covers the period from 1979, when most of the data were collected, to 2000.

The calculations are made in time steps of one year, which reflects the length of the agricultural production cycle.

The model is divided into four submodels: the population submodel, the food consumption submodel, the sorghum production submodel and the animal production submodel.

For each submodel a simplified causal diagram is presented, relations between the variables described and initial values and parameter values given. These values are, as far as possible, derived from the data that are available from the area. However, as there is a dearth of data, many parameters have been derived from other studies from similar areas, such as Northern Sudan and the Sahel.

5.1. The population submodel (fig.5)

Age and sex composition of the population play an important role in this system as they determine to a large extent a number of important characteristics of a person such as mortality, education, occupation (herding or cultivating), migration, fertility and labour capacity.

The specification of the population, according to age and sex for the year 1979, that is used for the model, is presented in table 8.

The population per age class has been derived from table 2, as more precise figures are not available. The division of the population per age class in male and female population is based on the assumption, that both have the same chances to survive, but men are more likely to migrate than women. As it is assumed that migration is mainly a phenomenon of recent years, the difference between male and female population in the ages beyond 40 is smaller.

The population per age class is determined by:

– the number of births (in the age class 0) or by the number of people that

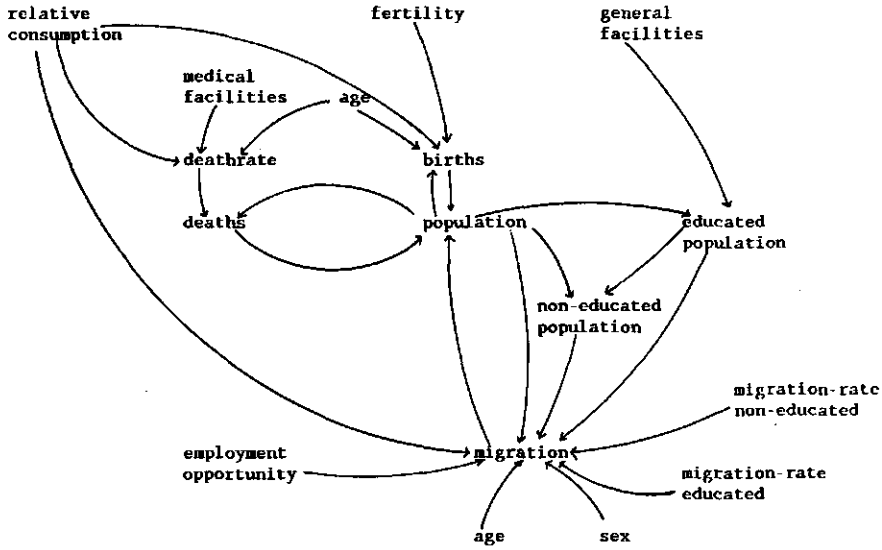

Fig. 5. A simplified causal diagram of the population submodel

moves from one age class to the next;
- the number of deaths;
- the number of persons that migrate.

The number of births depends on the fertile female population and on their food supply (relative consumption).

The number of people that die, is determined by the relative consumption and (for the children) by the level of medical facilities.

Migration will increase with the level of education and the employment facilities in Bor-town, but when the food supply over the past three years is low there may be distress-migration.

For the sake of readability age classes and sexes have not explicitly been included in fig. 5.

5.1.1. Births

The number of births is calculated as:

births = female population per age class * age specific fertility * fertility coefficient

As there are no data concerning the fertility per age class available, use has been made of data from a survey in Mali among Bambara (agriculturalists), Tamaseq (pastoralists) and Fulani (agro-pastoralists) (Hill, 1984) and of a fertili-

Table 8. The age structure of the population in 1979 as used in the model

age class	number male	female	age class	number male	female	age class	number male	female
0	1050	1050	26	260	410	51	110	110
1	800	800	27	245	390	52	100	100
2	725	725	28	245	380	53	90	90
3	680	680	29	240	370	54	80	80
4	670	670	30	255	360	55	70	70
5	665	655	31	255	350	56	60	60
6	655	655	32	255	340	57	55	55
7	656	656	33	245	330	58	45	45
8	649	649	34	250	310	59	40	40
9	640	639	35	245	300	60	35	35
10	630	630	36	250	280	61	30	30
11	621	621	37	250	270	62	25	25
12	611	611	38	240	260	63	20	20
13	602	602	39	235	250	64	15	15
14	580	580	40	235	240	65	10	10
15	570	570	41	230	230	66	5	5
16	560	560	42	230	230	67	2	3
17	520	550	43	235	235	68	2	1
18	460	520	44	215	220	69	1	0
19	340	490	45	215	220	70	1	0
20	310	470	46	190	190	71	1	0
21	290	460	47	175	180	72	1	0
22	280	450	48	170	165	73	1	0
23	275	440	49	145	145	74	1	0
24	265	430	50	125	125	75	1	0
25	260	420						

ty survey in (Northern) Sudan (Rizgalla, 1985). The age-specific fertility rates are presented in table 9.

Shortage of food reduces fertility. In Darfur (Western Sudan) and in south-central Niger fertility declines of 40-50% were found after some sequential years of famine (Faulkingham, 1977; De Waal, 1989).

It is therefore assumed that the average relative consumption over the previous three years will influence the fertility in the next year (table 10).

5.1.2. *Ageing*

The number of people, that moves per year from one age class to the next is determined by the number that moved last year into that age class minus the number of people that died in that age class and minus the number of people in that age class that migrated out of the area.

ageing per age class per year = population per age class – deaths per age class per year – migration per age class per year

Table 9. Age-specific fertility rates of the Bor District expressed in number of births per year per woman per age class

age class	fertility rate	age class	fertility rate	age class	fertility rate
15	0.025	25	0.310	35	0.200
16	0.075	26	0.305	36	0.180
17	0.150	27	0.300	37	0.160
18	0.200	28	0.295	38	0.140
19	0.250	29	0.290	39	0.120
20	0.270	30	0.285	40	0.100
21	0.285	31	0.275	41	0.080
22	0.300	32	0.260	42	0.060
23	0.310	33	0.240	43	0.040
24	0.315	34	0.220	44	0.020

Table 10. Effect of the average relative consumption over the previous three years on fertility, expressed as fertility coefficient

average relative consumption	fertility coefficient
0.6	0.1
0.7	0.3
0.8	0.6
0.9	0.9
1.0	1.0

5.1.3. Deaths

The number of people that die at a certain age is determined by a specific death rate per age:

deaths per age class = population per age class * age-specific death rate

This specific death rate depends on an age specific basic death rate and the effect of hunger (hunger factor) and the effect of medical facilities (morbidity factor). It is thereby assumed that an improvement of medical facilities will only gradually – with a delay of 3 years – decrease morbidity.

age-specific death rate = basic death rate per age * hunger factor * morbidity factor

The basic death rate is the death rate that prevails in the area, when there is no lack of food and without medical facilities. The basic death rates (table 11) have been based on reports on mortality figures from other areas in Africa (WFS Comparative Studies (1984); United Nations (1986); FAO (1986); MacCormack (1984)).

Table 11. Basic death rates per age class per year, expressed in the chance that a person of a certain age class dies in a certain year

age	basic dthrate	age	basic dthrate	age	basic dthrate	age	basic dthrate	age	basic dthrate
0	0.30	15	0.015	30	0.025	45	0.036	60	0.22
1	0.18	16	0.015	31	0.025	46	0.037	61	0.25
2	0.075	17	0.015	32	0.025	47	0.038	62	0.28
3	0.025	18	0.015	33	0.025	48	0.039	63	0.32
4	0.015	19	0.015	34	0.025	49	0.04	64	0.36
5	0.015	20	0.015	35	0.030	50	0.045	65	0.40
6	0.015	21	0.015	36	0.030	51	0.055	66	0.45
7	0.015	22	0.015	37	0.030	52	0.065	67	0.50
8	0.015	23	0.015	38	0.030	53	0.075	68	0.55
9	0.015	24	0.015	39	0.030	54	0.085	69	0.60
10	0.015	25	0.02	40	0.031	55	0.10	70	0.65
11	0.015	26	0.02	41	0.032	56	0.12	71	0.70
12	0.015	27	0.02	42	0.033	57	0.14	72	0.80
13	0.015	28	0.02	43	0.034	58	0.165	73	0.90
14	0.015	29	0.02	44	0.035	59	0.19	74	0.95
								75	1.0

The influence of hunger on the death rate (hunger factor) depends on the extent to which the energy requirements of the total population are met, the so-called relative consumption:

relative consumption = available energy / energy requirement of the total population

Based on information on social response during food shortages (Dirks, 1980) it is assumed that the effect of hunger on death rates is more severe for children and for people that are over 60 years.

To estimate the effect of food shortages on mortality, use is made of the Manual for the application of the FAO/WHO/ONU energy requirement recommendations (1987). According to this manual the total energy requirement is calculated as follows:

total energy required = BMR * BMR-factor

The BMR (basic metabolic rate) of a person can be derived from his/her age and body weight. The BMR-factor depends on the level of activity (table 12).

Assuming that the average body weight of adult men is 57 kg and of adult women is 53 kg, their BMR's will respectively be 6.5 and 5.3 MJ/day (average 5.9 MJ/day). The average total energy requirement for an adult is 10.45 MJ/day, which gives a BMR-factor of 1.77.

According to table 12 a BMR of 1.2 means that a person is almost dying. The energy intake of such a person is in that case 7 MJ/day or a relative consumption of 0.67. It is generally assumed, that under famine conditions, people will first decrease their activities to try to balance intake and expenditure of energy,

Table 12. BMR-factors for men and women for different levels of activity (FAO /WHO/ONU, 1987)

activity	BMR-factor	
	men	women
just surviving, no activity	1.2	1.2
resting	1.27	1.27
maintenance, some activity (e.g.walking)	1.4	1.4
light work	1.65	1.56
medium work	1.78	1.64
heavy work	2.10	1.82

Table 13. The relationship between relative consumption and the hunger factor

relative consumption	hunger factor	
	children/persons over 60	others
0.6	6	6
0.7	3	2
0.8	1.5	1.2
0.9	1.2	1.0
1.0	1.0	1.0

so that their health will not be seriously affected (Corbett, 1988; Spurr, 1984; Dirks, 1980).

Based on this theory it is assumed that mortality will slowly increase when relative consumption decreases from 1 to 0.8. A further deterioration of the food supply will give a rapid increase of the hunger factor. Table 13 presents the assumed effects of relative consumption on the hunger factor.

The actual impact of medical care is difficult to assess as health care is only one of the many interrelated factors that affect levels of morbidity and mortality. Some suggest that the quality of medical care is less important than lifestyle and environmental factors. Immunization programmes to protect infants from diseases like measles and whooping cough, however, can significantly reduce infant mortality, e.g. the infant mortality rate in a Southern Nigerian locality was reduced from 295 to 72 per 1000 live births and child mortality from 69 to 28 with the provision of physician-staffed primary care and some nutritional assistance (Stock, 1985). Walsh and Warren (1980) believe that a categorical disease control programme with vaccinations against measles, diphtheria, poliomyelites and tetanus, encouragement of long term breast fee- ding, chloroquine for children under 3 years and oral rehydration packets with instructions would decrease mortality from measles, whooping cough, neonatal tetanus, malaria and diarrhoea by 25 to 50%.

Grosse (1980) compared for Ghana the effects of different health care projects on crude mortality rates (table 14). He also states that in Bangladesh 24% of

Table 14. Effects of level of health care on crude mortality in Ghana (Grosse, 1980)

health care	crude death rate
no health care	3.2%
hospital/health center	2.5%
hospital/health center/immunization	1.7%
hospital/health center/immunization/ sanitation/nutrition	0.8%

Table 15. Medical facilities coefficients representing the effect of available medical facilities on child morbidity

availability of medical facilities	medical facilities coefficient
no facilities available	1
hospital/health centers	0.8
hospital/health centers/immunization	0.6
hospital/health centers/immunization/ sanitation/nutrition	0.3

all child mortality can be avoided by vaccination, and that the use of oral rehydration will decrease child mortality by 14%.

For the situation in the Bor District it is assumed that an improvement of medical facilities will only affect the death rates of children.

In table 15 the levels of medical facilities and the related coefficients for medical facilities are presented.

An improvement of medical facilities will not immediately have the effect mentioned. It is therefore assumed that it requires some time before the effects are fully realized.

5.1.4. Migration

Migration constitutes an important drain on the population, especially in the age class between 16 and 40.

Todaro (1977) considers education and expected increase in income as important determinants of outmigration. In areas where school enrollment is high, the propensity of school leavers to migrate to the towns is very high (Godfrey, 1973). In this model it is therefore assumed, that migration will be very high among school leavers and increase with an increasing employment opportunity outside the area. It is also assumed, that migration rates among men will be higher than among women. Moreover lack of food during a number of years will increase the propensity to migrate, irrespective of education, sex or age.

The number of educated people per sex and age class that migrate per year is calculated as follows:

educated people that migrate = sex/age specific migration rate for educated people * educated people per sex/age class * employment opportunity coefficient

The number of non-educated people per sex and age class that migrate per year is calculated as follows:

non-educated people that migrate = sex/age specific migration rate for non-educated people * non-educated people per sex/age class * employment opportunity coefficient

Table 16. Parameter values per age class indicating the specific migration rates for educated and for non-educated, male and female persons

age class	specific migration rate			
	educated		non-educated	
	male	female	male	female
16	0.2	0.2	0	0
17	0.4	0.4	0.02	0.01
18	0.8	0.8	0.05	0.02
19	0.5	0.9	0.15	0.03
20	0.5	0.9	0.2	0.04
21	0.4	0.9	0.2	0.04
22	0.3	0.9	0.2	0.05
23	0.3	0.9	0.175	0.04
24	0.3	0.3	0.15	0.03
25	0.25	0.25	0.125	0.025
26	0.25	0.25	0.1	0.02
27	0.25	0.25	0.09	0.015
28	0.2	0.2	0.08	0.01
29	0.2	0.2	0.07	0.01
30	0.2	0.2	0.06	0.01
31	0.15	0.15	0.05	0.01
32	0.15	0.15	0.04	0.01
33	0.15	0.15	0.03	0.01
34	0.1	0.1	0.02	0.01
35	0.1	0.1	0.01	0.01
36	0.1	0.1	0	0
37	0.05	0.05	0	0
38	0.05	0.05	0	0
39	0.05	0.05	0	0

The sex and age specific migration rates are presented in table 16. The determination of these rates is based on the assumption, that educated people will almost all try to find a job outside the area – as there are virtually no jobs available within the area – and that a smaller part of the non-educated population will try to get employment as un-skilled labourer. The specific migration rates for the non-educated population have been estimated based on the available immigration data of Bor town.

The number of educated persons per age class depends on the number that has received primary education.

The number of boys and girls, that go to school is determined by the facilities in the rural areas: number of schools, the availability of teachers and the possibility for the children to get food at school. It has already been explained that the availability of teachers also depends on the presence of facilities, such as medical facilities, shops, clean drinking water and roads.

It is assumed that an improvement of the facilities in the area will have a delayed effect on the number of children that start education: this delay is estimated at 3 years. This effect is higher for boys than for girls.

The delayed effect of the facilities in the area on the portion of boys and girls that start school is represented by the following equations:

$$\textbf{part of boys starting education} = \frac{\mathbf{1}}{\mathbf{1 + exp[-2 * (facility\ factor - 1.7)]}}$$

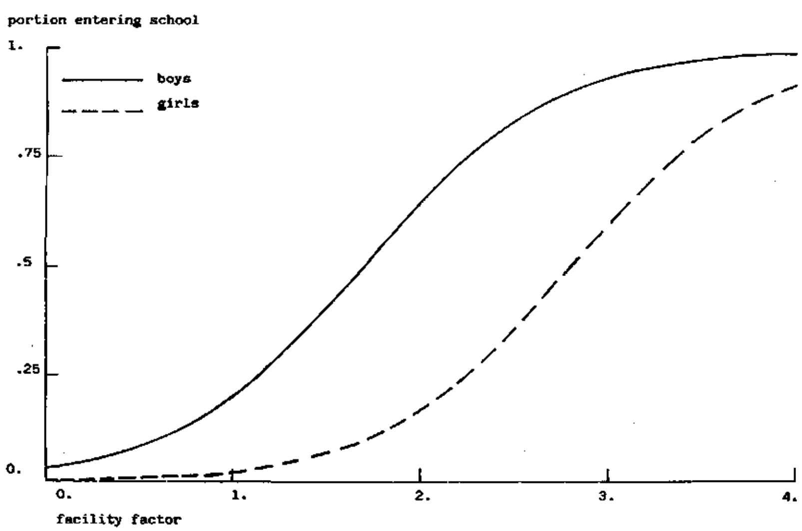

Fig. 6. The relationship between the facility factor and the portion of boys and girls who start education

$$\textbf{part of girls starting education} = \frac{1}{1 + \exp[-2 * (\text{facility factor} - 2.8)]}$$

The shape of the relationships between the facility factor and the fraction of boys and girls that go for the first time to school is given in figure 6.

It is hereby assumed, that without any facility, hardly any child would go to school, while under very favourable conditions approx. 90 % of the children go to school.

At the time of the survey in 1979 approximately 33% of the boys and 3% of the girls were going to school (ILACO, 1982a). It is assumed that the portion of boys and girls that were going to school has gradually increased in the course of the years (table 17).

The children that start primary school will be, after eight years, educated persons in the age class of 15 years, who will start migrating from the age of 16 years onwards.

The values of the facility factor, representing various levels of facilities are given in table 18.

The employment opportunity coefficient represents the effect of the level of employment opportunity outside the rural area on the propensity to migrate. These coefficients are given in table 19.

The employment opportunity coefficient is assumed to be 0 if there are no employment opportunities at all, 1 if there is some opportunity for employment and 2 if this opportunity is high. The situation in 1979 is characterized by an employment opportunity coefficient of 1.

Table 17. Percentages of school-going boys and girls in seven age classes

age class	boys	girls
8	41	6
9	40	5
10	38	4
11	35	3
12	31	2
13	26	1.5
14	20	1

Table 18. Values of the facility factor, representing the level of facilities available

level of facilities	facility factor
no facilities	0
facilities in 1979	1.5
medical facilities and water	2
good overall facilities	3

Table 19. Employment opportunity coefficients representing the effect of various levels of employment outside the area on the propensity to migrate.

employment outside the area	employment opportunity coefficient
none	0
low	1
high	2

Table 20. The relationship between the average relative consumption over the past three years and the part of the population that migrates

average relative consumption	migration rate
0.75	0.8
0.8	0.4
0.85	0.2
0.9	0.1
0.95	0
1	0

The migration because of famine is independent from age and education, and depends solely on the average relative consumption over the past three years (see table 20).

5.2. The food consumption submodel

In this submodel food requirement and consumption are calculated. These calculations are entirely based on energy contents of the food expressed in megajoule (MJ). The reasons for this approach are

- that the intake of dietary energy is considered as the most likely limiting factor for physical performance and health (Pacey and Payne, 1985);
- that animal products form an important part of the local diet, so that it can be assumed that the quality does not really constitute an important problem (Hjort, 1980).

As there is known very little about the age-specific energy requirements of the Dinka, information has been drawn from relevant literature (FAO/ WHO/ ONU, 1987; WHO, 1985; Brun, 1984); the results are given in table 21.

The required food per age class per day is calculated by:

required food per age = population per age * requirement per age

These figures represent average daily requirements over a year, but it should be noted that the daily energy requirement may fluctuate during a year, due to fluctuations in workload (Haswell, 1981; Longhurst and Payne, 1981). It is,

Table 21. The energy requirements per age class in megajoule (MJ) per person per day

age	energy needs	age	energy needs	age	energy needs	age	energy needs	age	energy needs
0	3.35	15	10.45	30	10.45	45	10.05	60	9.20
1	4.80	16	10.45	31	10.45	46	10.05	61	9.20
2	5.65	17	10.45	32	10.45	47	10.05	62	9.20
3	6.50	18	10.45	33	10.45	48	10.05	63	9.20
4	6.50	19	10.45	34	10.45	49	10.05	64	9.20
5	7.55	20	10.45	35	10.45	50	9.60	65	8.80
6	7.55	21	10.45	36	10.45	51	9.60	66	8.80
7	8.15	22	10.45	37	10.45	52	9.60	67	8.80
8	8.15	23	10.45	38	10.45	53	9.60	68	8.80
9	8.15	24	10.45	39	10.45	54	9.60	69	8.80
10	8.80	25	10.45	40	10.05	55	9.60	70	8.35
11	9.20	26	10.45	41	10.05	56	9.60	71	8.35
12	9.60	27	10.45	42	10.05	57	9.60	72	8.35
13	10.05	28	10.45	43	10.05	58	9.60	73	8.35
14	10.45	29	10.45	44	10.05	59	9.60	74	8.35

however, assumed that people can build up energy in the slack season, when there is little work to be done and expend it during the cultivation period (Longhurst, 1984; Dugdale and Payne, 1987).

Fig. 7 gives a simplified causal diagram of the food consumption submodel.

Based on the study of the Jonglei Investigation Team in the fifties (J.I.T., 1954), it is assumed that 840 KJ per person per day is obtained from (bush)-meat, fish, maize, wild fruits and vegetables (bushfood) and the remainder from the locally produced sorghum, milk, meat (from small ruminants and poultry and from cattle that died) and a quantity of sorghum, that the rural population receives from relatives in town.

When food supply is not sufficient to cover the requirement, the population will follow certain strategies to escape starvation. Corbett (1988) has developed a model of a three-stage famine-coping strategy under drought conditions, that is based on information from several cases, a.o. areas in Northern Sudan. Based on the cases presented by her, the following assumptions have been made concerning the coping strategy under conditions of food shortage by the Dinka in the Bor District.

At first the population will try to obtain food from relatives and economize on meals. When the average relative consumption drops below 100% they will sell part of the cattle in order to be able to purchase grain on the market, that is imported from Northern Sudan. They first sell unproductive animals such as oxen (except the songbulls) and old female animals. If there is not sufficient grain on the market to satisfy the needs, the population will be forced to kill the less productive animals of the herd (Evans-Pritchard, 1940; Krummel e.a., 1986).

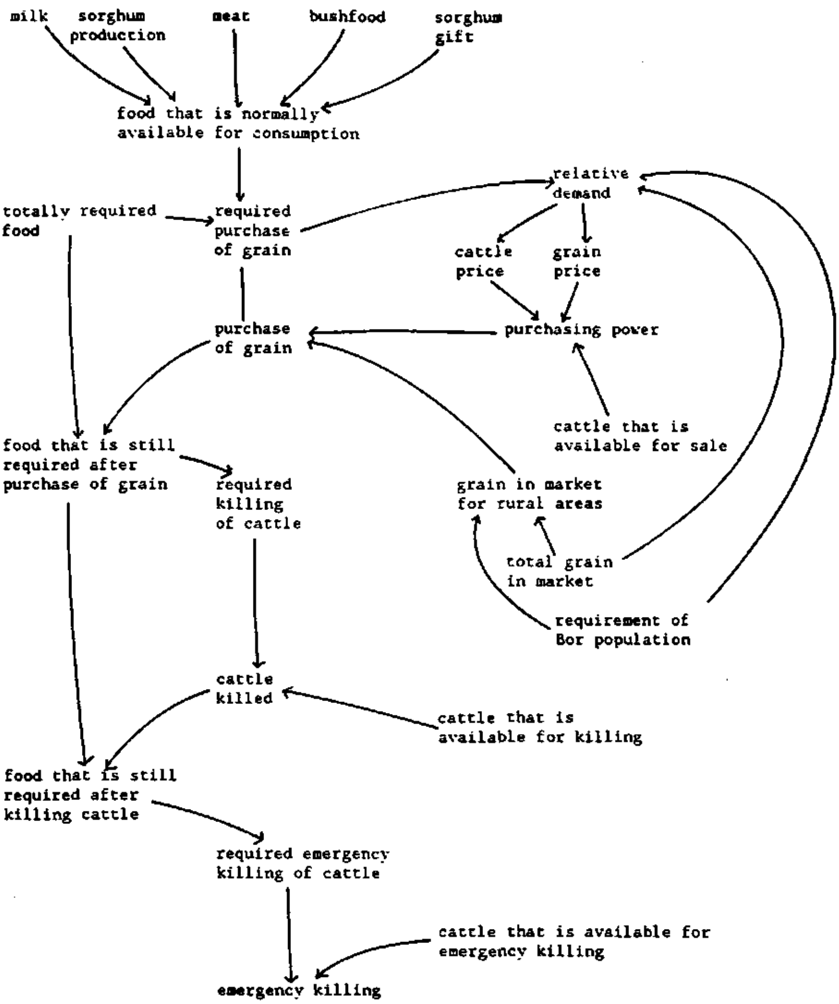

Fig. 7. Causal diagram of the food consumption model

It is assumed that they will continue to kill these animals until 95 % of their food requirement is satisfied.

When the famine gets more severe, the population will also start killing their productive animals to avoid a relative consumption, that is below 90 % (emergency slaughter). When things get still worse, people will migrate to other areas (distress migration).

The total consumption per year can now be calculated as follows:

total consumption = **bushfood + sorghum produced + milk + dead cattle + sorghum gift + sorghum purchased + cattle killed + emergency killing**

It should be noted here that the population consumes the sorghum that was produced during the previous year, but that the milk is consumed at the time it is produced. The population does not sell the sorghum it has produced. If the production exceeds the requirement, sorghum will still be consumed, especially as local beer (merissa) or stronger drinks.

The calculation of the quantity of sorghum, that is produced will be discussed in the sorghum production submodel (section 5.3) and the milk production in the animal husbandry submodel (section 5.4). The energy that is provided by the dead cattle depends on the number of cattle per age class that die and their liveweights. The average liveweights for male and female animals per age class are derived from results of a survey of the slaughter slab at Bor (ILACO, 1982c) and from a study in West-Africa (Brandl, 1988). The average weight of female animals in the Bor survey was 225.2 kg, which agrees rather well with the figures of Brandl. The average weight of the male animals in the Bor survey (238.7 kg) were well below the estimates of Brandl.

The weights of the male animals per age class have therefore been estimated by multiplying the weight of the female animals by a factor 1.06. The weights per age class of both female and male animals are presented in table 22.

Based on the research of Cossins and Upton (1987 and 1988b) the energy value per kg liveweight is estimated at 5.43 MJ.

The sorghum received from relatives in town amounts to 10 kg per head of the town population (ILACO, 1981a).

The quantity of sorghum, that is purchased on the market depends on several factors:

a. The shortage of food (required purchase), which is equal to the total food requirement minus the food acquired from the bush, secondary crops and

Table 22. Average live weights in kg of male and female animals per age class

	average live weight			average live weight	
age	female	male	age	female	male
0	85	90	8	230	244
1	145	154	9	230	244
2	170	180	10	220	233
3	195	207	11	210	223
4	210	223	12	200	212
5	220	233	13	190	201
6	230	244	14	180	191
7	230	244			

fish (bushfood), minus their own sorghum production, minus the quantity of milk and meat that is available for human consumption and minus the sorghum they receive from relatives in Bor-town.

required purchase = food requirement – bushfood – sorghum production – milk – dead cattle – sorghum gift

b. The extent to which the population is ready to sell cattle in order to purchase food. As already indicated before, it is assumed that they start selling their cattle – in excess of what they sell in normal years – if their energy needs are satisfied for less than 100%.
c. Their purchasing power. The purchasing power depends on the number of cattle that they can sell, the price they obtain and the sorghum price. This means that it is more useful to express their purchasing power in terms of sorghum than of money.
d. The quantity of sorghum in the market, that is available for sale to the rural areas.

It is assumed, that as long as there is sufficient grain in the market to satisfy the energy needs of the rural population, the price of sorghum will remain constant: it is put at 15 S£ (Sudanese Pounds) per 100 kg (being the price in 1979). As 1 kg of sorghum represents an energy value of 15 MJ/kg, the price per 1,000,000 MJ sorghum under these conditions is S£ 10,000 (norm sorghum price). Under those conditions the price per head of cattle is also constant: S£ 70. According to various authors (Sen, 1981; Dahl and Hjort, 1979; Cutler, 1984 and 1986) the ratio between the price of cattle and the price of grain will drop if there is a shortage of grain: the price of sorghum will increase because demand exceeds supply so that more cattle have to be sold to obtain the same quantity of grain and an increase in the supply of cattle will cause a drop in the price of cattle.

No data are available regarding the relationship between the price ratio of cattle and sorghum on the one hand and the shortage of food in the Bor District on the other hand. Sen found during the 1972-1973 famine in Ethiopia, that the index of the price ratio between cattle and sorghum dropped from 100 in 1971 (normal year) to 42 in 1972 and 28 in 1973 in the pastoralist area of Southern Ogaden and from 100 to 75 in 1972 and to 70 in 1973 in Harerghe, an area of agriculturalists. Cutler (1984) found in Northern Ethiopia that the barter terms of trade for oxen and sorghum fell from 4.3 in October 1982 to 1.3 in July 1983.

As the price ratio between grain and cattle is more interesting than their absolute prices the development of the grain price is simulated, whereby the cattle price is held constant. When there is a small shortage of grain in the market it is assumed that the price will rise slowly; if the shortage increases however, the price will increase faster until a certain point (when demand exceeds the market supply by 20%). The price will then increase again slowly before reaching a maximum of 4 times the normal price of grain. The reason for this is that at this price the population has not enough purchasing power and may as well eat their own animals because the price per unit energy derived from sorghum is as high as the price of a unit of energy derived from meat.

$$\textbf{sorghum price} = \textbf{norm sorghum price} * \left(1 + \frac{3}{1 + \exp[-20 * (\textbf{rel.demand} - 1.2)]}\right)$$

The relative demand is calculated as

rel.demand = (required purchase + requirements of Bor town)/market grain

The relationship between the sorghum price and the relative demand is graphically presented in fig. 8.

It should be noted here that the purchasing power is not determined by the total number of cattle, that is in the area, but by the total number of cattle that the population is willing to sell. This will be worked out in the animal production submodel (section 5.4).

The total quantity that is available is limited due to transport problems and the quantity that is available for the rural population is the quantity remaining after the requirements of the town population have been met. The population

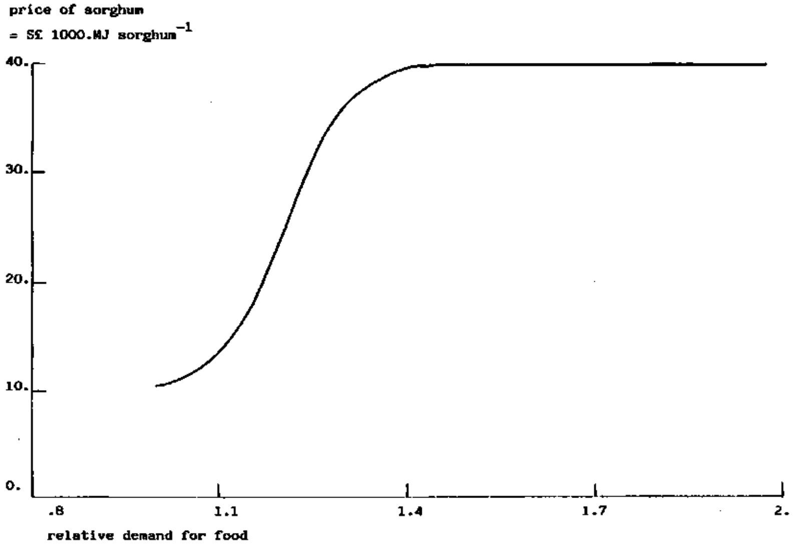

Fig. 8. The relationship between the relative demand for grain and the price of sorghum (in Sudanes pounds per 1000 MJ of sorghum)

of Bor town requires 7.55 MJ of sorghum per day per person (including the quantity they give to their rural relatives). In 1979 there was 4,275,000 kg of sorghum on the market and in 1980 5,220,000 kg. It is assumed in the model that the quantity of grain that is available in the market will increase by 3% per year. The quantity of grain available for the population of the rural areas can be calculated as follows:

grain for rural area = total grain in the market – grain required for Bor town

The grain that is required by the population of Bor town is:

grain required for Bor town = population Bor town * 7.55 MJ * 365 days

The population of Bor town has a yearly natural increase of 2.5% and an increase through migration from the rural area that is equal to the outmigration from the rural area of the Bor District:

increase population Bor town = population Bor town * natural rate of increase + migration Bor district

The energy that the population tries to obtain by killing cattle (req. energy from killing) is determined by the food requirement, the bushfood, the produced sorghum, the milk consumption, the cattle that die, the sorghum gift and the purchased sorghum. As indicated above the population is assumed to start killing their cattle when less than 95 % of their energy needs are met:

req.energy from killing = 0.95 * energy required – bushfood – sorghum produced – milk – dead cattle – sorghum gift – sorghum purchase

The energy from cattle that have to be killed when less than 90% of the energy requirements are satisfied (required emergency killing) is calculated as follows:

req.energy from emerg.killing = 0.9 * energy required – bushfood – sorghum produced – milk – dead cattle – sorghum gift – sorghum purchased – cattle killed

5.3. The sorghum production submodel

The total sorghum production in the area depends on the area cultivated, the soil fertility, the rainfall and the energy value of sorghum.

sorghum production = area * soil fertility * rainfall effect * energy value

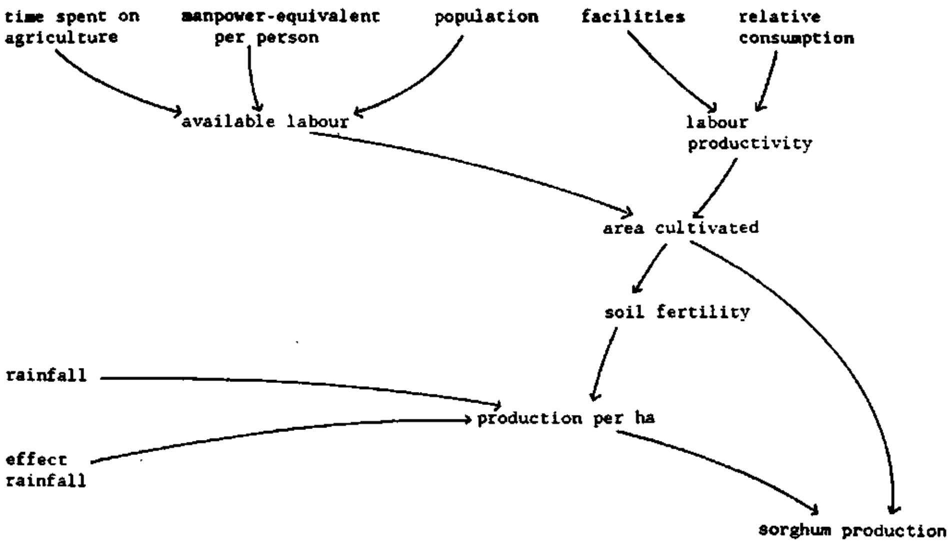

Fig. 9. A Causal diagram showing the most important relationships within the sorghum production model

A simplified causal diagram of the sorghum production submodel is presented in fig.9.

The area cultivated, depends on the availability of male and female labour and on the labour productivity:

area = labour * labour productivity

As already discussed in chapter 3, the labour that is available for sorghum production is determined by the manpower-equivalents per sex and per age class and by the time each sex and age class spends in agriculture.

The labour productivity is the number of hectares one manpower-equivalent is able to cultivate. Under the conditions of 1979 this is 0.55 ha (ILACO, 1981a) but this can increase or decrease, depending on the extent to which the energy requirements of the population are satisfied and on the facilities in the rural areas: when more facilities, such as easy access to drinking water, are available, then less time needs to be spent on collecting drinking water.

Lack of food can influence the labour productivity in two ways: people will require more rest to recover from the efforts and their performance per unit of time will decrease (Immink et al, 1984; Spurr, 1984; Longhurst, 1984; Payne, 1985).

Just as for the determination of the effect of food shortage on mortality, the

Table 23. The influence of the relative consumption on the consumption coefficient

relative consumption	consumption coefficient
0.6	0
0.7	0
0.8	0
0.9	0.65
1	1

estimation of the effect of food shortages on labour productivity is based on the Manual for the application of the FAO/WHO/ONU energy requirement recommendations (1987).

According to table 12 a BMR of 1.4. means that no work is carried out, which is equal to an energy intake of 8.3 MJ/day or a relative consumption of 0.8. It is therefore assumed, that no work will be carried out below a relative consumption of 0.8.

Table 23 presents the assumed relationship between relative consumption and the labour productivity coefficient, represented by the consumption coefficient.

There are no data available on the effect of general facilities on productivity. According to ILACO (1981a) the cultivation of one hectare requires 1300 hours. Assuming that the average working day is 5 hours per day, 260 days are (partly) used to cultivate one hectare, which is equivalent to 1.8 manpowerequivalent (m.p.e.); so one manpower-equivalent is equal to 144 working days. Assuming, that a substantial improvement of general facilities in the rural area will increase the number of working days by 15, a manpower-equivalent would increase from 144 to 159 days or from 0.55 ha to approx. 0.60 ha.

It is assumed that a complete absence of general facilities will decrease the labour productivity to 0.50 ha per manpower-equivalent.

Based on these assumptions, the effects of the level of general (including medical) facilities (represented by the facility coefficient) and the relative consumption (represented by the consumption coefficient) on the labour productivity is as follows.

$$\textbf{labour productivity} = \textbf{(0.50 + facility coefficient)} * \textbf{consumption-coefficient}$$

whereby the facility coefficient is calculated as follows:

$$\textbf{facility coefficient} = \frac{\textbf{0.10}}{\textbf{1 + exp [-2 * (facility factor - 1.5)]}}$$

(see table 18 for the facility factor)

This relationship is presented in figure 10.

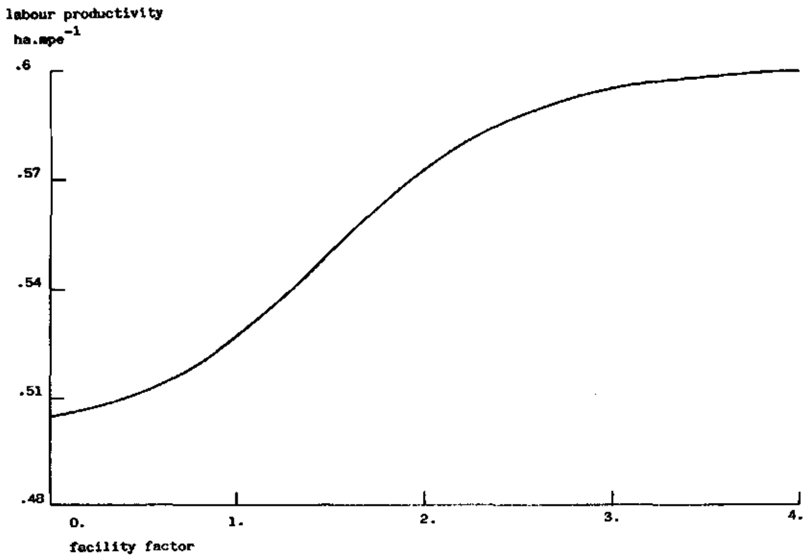

Fig. 10. The relationship between general (including medical) facilities and labour productivity (ha per man power equivalent), when the consumption coefficient is 1

Soil fertility is expressed in the yield of sorghum per hectare, that can be obtained under conditions of a favourable rainfall and depends on the maximum yield and a soil fertility factor:

soil fertility = maximum yield * soil fertility factor

whereby the maximum average yield, that is obtained under local conditions, is put at 1250 kg of sorghum per ha.

The soil fertility factor is usually 1, but will be less if the cultivated area will become so large, that it is not anymore possible to practice shifting cultivation without a decline of the average soil fertility. It is assumed that, when the cultivated area exceeds 9000 ha, the fallow period will be too short to restore the soil fertility level to 1250 kg per ha. The soil fertility factor is for a cultivated area larger than 9000 ha calculated as:

soil fertility factor = 9000 / cultivated area

Rainfall has an important influence on the production of sorghum: when rainfall is far below normal, the crop will suffer from drought, while the crop will suffer from flooding in years of an average or higher rainfall (table 7). Although it should be realized that flooding and drought are related to the distribution of the rainfall rather than to the total rainfall, in the model a direct link has been

Table 24. The rainfall and its effects on the sorghum production per hectare

rainfall	rainfall effect
600	0.7
700	0.9
800	1.0
900	0.9
1000	0.7
1100	0.5
1200	0.3

Table 25. Annual rainfall figures from 1979 to 2000

year	rainfall	year	rainfall	year	rainfall
1979	916	1987	875	1994	1032
1980	1008	1988	1029	1995	743
1981	735	1989	821	1996	876
1982	914	1990	805	1997	876
1983	1044	1991	966	1998	1092
1984	659	1992	748	1999	1135
1985	809	1993	1023	2000	962
1986	815				

established between rainfall and the occurrence of effects of flooding and drought in which the effect is expressed by the rainfall factor (table 24).

Rainfall data over the period 1979-2000 have been generated by a random function based on the average rainfall of 899 mm and a standard deviation of 158 mm (table 25).

5.4. The animal production submodel

The size of the herd is determined by the number of calves that are born, the cattle that die, the cattle that are sold and the cattle that are killed.

A simplified causal diagram of the animal production model is presented in fig. 11.

As the behaviour of the population towards their cattle depends on the sex and the age of the animals, the cattle have been divided according to age and sex: 15 age classes of female and male animals have been distinguished (see table 26).

The number of calves is determined by the number of adult females and the calving rate, whereby the calving rate is related to the weight increase of young animals. The increase of weight is again determined by the feed supply, which depends on the rainfall and the herdsize.

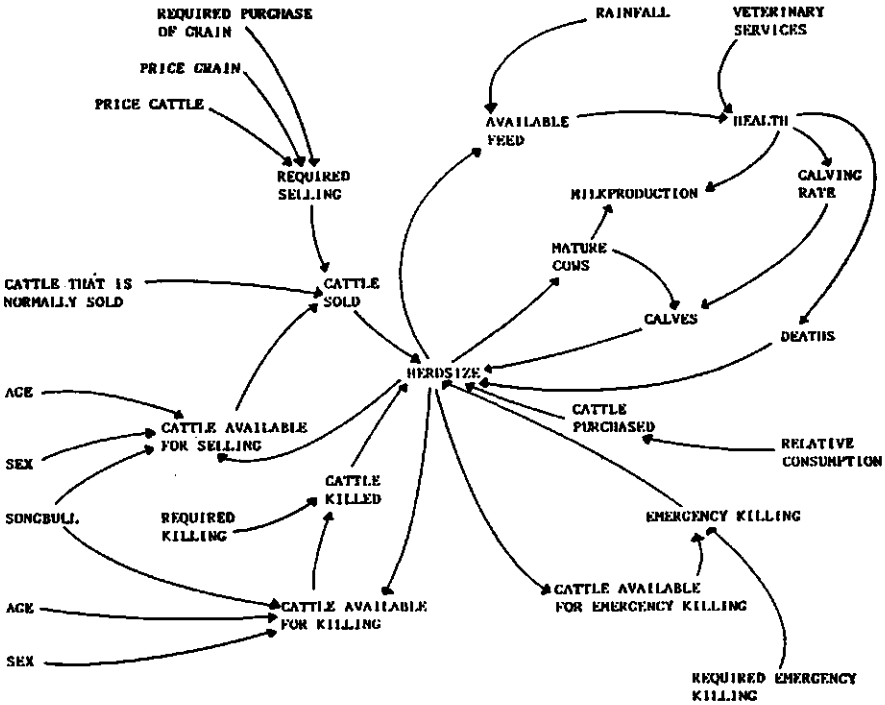

Fig. 11. A simplified causal diagram of the animal production submodel

Table 26. The numbers of animals according to age and sex as estimated for 1979 (ILACO, 1981a)

age	female animals	male animals	age	female animals	male animals
0	8500	8500	8	3000	50
1	7900	5000	9	2000	25
2	7000	4000	10	1000	15
3	6300	3000	11	500	7
4	5800	2000	12	250	2
5	5000	1000	13	100	1
6	4500	400	14	50	0
7	4000	100			

The number of animals that die is influenced by the feed supply, the incidence of epizootic diseases, such as rinderpest, and the level of veterinary facilities. The deathrate of male calves is also influenced by the quantity of milk they are allowed to drink: when the population is short of food they will increase the off-take of milk from cows with male calves.

As already discussed, cattle may be sold or killed in periods of famine. The selection of animals that will be sold and killed depends on the intensity of the famine, sex and age of the animals and, for the male animals, whether they belong to the songbulls or not. Milk production depends on the number of calves that are born and the feed supply.

5.4.1. The female cattle

The female herdsize per age class is determined by the number of female calves that are born or the number of animals that move from one age class to the next, and by the number of female animals that die, are sold or are killed in periods of food shortage.

The number of female calves, that are born is half the total number of calves that are born.

The total number of calves that are born is determined by the number of adult female cows and the calving rate:

calves = mature cows * calving rate

A female animal calves, under the conditions that prevail in the Bor District, for the first time at the age of 4 (ILACO, 1981a). Breman and De Ridder assume a relationship between the weight of a cow and the chance that the cow will become in heat. When a cow, that is in bad condition, is forced to use her reserves, her weight will drop and the chance to conceive will decrease.

Breman and De Ridder use the annual weight increase of heifers in their second year as an indicator of the condition of the cows of the same herd. The increase in weight of these heifers is a result of the feed supply. The weight increase depends on the quantity as well as on the quality of the feed that is available. When there is enough feed but the quality of the feed is low, the animals will not be able to digest the feed. The quality of the feed is determined by its N-content.

In the beginning of the rainy season, there is enough grass of good quality. In the course of the rainy season, the amount of dry matter increases, but the N-content decreases. However, as the biomass is more than enough, the animals select the most palatable parts of the plants. When the dry season starts, the quality of the feed intake may drop below 8 g N/kg dry matter, resulting in loss of weight. During this season the herders try to find fodder of good quality, which they may find in the lower areas of the Pengko Plain or in areas that contain enough soil moisture to permit regrowth of young grass after burning. The availability of feed of good quality depends on the rainfall just before and during this period.

During the second half of the dry season the herds move to the riverine areas of the Nile (toic), where they spend app. 100 days. The quality of the feed in the toic is mediocre (only 25% of the biomass reaches a nitrogen content of

8 g N/kg dry matter) and the quantity is limited as well.

When quantity is not the limiting factor, Breman and De Ridder calculate the increase of weight as follows:

1. based on the N-content, the digestibility of the feed is determined;
2. based on the N-content and the digestibility, the intake of digestible dry matter (D), expressed in $g.kg^{-0.75}.day^{-1}$, is estimated;
3. the weight increase of heifers in kg per day is then calculated with the following equations:
   - if $D > 36$: $0.49*(D-36)*W^{0.75}*0.001$
   - if $D < 36$: $0.58*(36-D)*W^{0.75}*0.001$

   whereby W represents the weight of the animal at the beginning of their second year, which is estimated at 100 kg.

The following data concerning the N-content (g N/kg dry matter) of the biomass are available (ILACO, 1983): in May 17 g N/kg, in June 18.5 g N/kg, in August 7.5 g N/kg and in October 5.1 g N/kg was found. Based on the assumption, that there is enough biomass between July and November to permit a selective grazing, the following estimates of the monthly weight increase are made (table 27).

This amounts to an increase of 55 kg during the rainy season. For the growth between November and mid-January rainfall is taken into account. It is thereby assumed, that in a year with an annual rainfall of 1200 mm the average N-content over this period will be 7 g N/kg dry matter and in a year with 600 mm rainfall the average N-content will be 5 g N/kg dry matter. This amounts to a weight loss in a very wet year of app. 5 kg and in a very dry year of app. 14 kg.

For the estimation of the loss of weight during the period in the toic, it is assumed that the total quantity and the quality of the feed remains constant. When there would be very few animals in the toic, they would have enough feed of 8 g N/kg dry matter at their disposal to avoid a loss of weight. When the herd increases, the animals are forced to eat more grass of a lower quality and therefore suffer a loss of weight. This means that the loss of weight in the toic depends on the herdsize. ILACO (1983) estimates the carrying capacity of the toic at 7 animals per ha and the weight loss at 10 kg per animal, which amounts to a N-content of 6.5 g N/kg dry matter. This was the case at the time

Table 27. The calculated estimates of the weight increase of heifers in their second year from May till October

month	N-content g N/kg d.m.	percentage digestibility	intake(D) ($g.kg^{-0.75}.d^{-1}$)	increase of weight (kg) per day	per month
May	17	67	69	0.511	15.8
June	18.5	68	73	0.573	17.2
July	13	60	53	0.263	8.2
August	12	59	51	0.232	7.2
September	11	56	46	0.155	4.7
October	9	52	40	0.062	1.9

of the survey, when the herd consisted of 80,000 animals.

According to Breman and De Ridder, a quantity of biomass that contains 6.5 g N/kg dry matter can be compared with 70% of that quantity with a N-content of 8 g N/kg dry matter. In other words if there would be only 70% of the 80,000 animals in the toic, there would be no loss of weight. This theory permits to establish a relationship between herdsize and loss of weight during the grazing period in the toic (table 28).

The above assumptions result in the following relationship between herdsize, annual rainfall and annual increase of weight (table 29).

The relationship between the yearly increase of weight of young heifers and the calving rate of the adult cows in the same herd is given in table 30.

The number of female cattle per age class, that die, depends on the number in that age class and the specific deathrate for that age class:

dead female cattle = number of female cattle * specific deathrate

The deathrates of the female animals are determined by their health and a basic deathrate.

Table 28. Estimated relationship between the herdsize and the weight loss in the toic

herdsize	percentage of the feed with > 8 g N/ kg d.m.	N-content of of the feed	intake (D)	weight loss
50,000	100%	8 %	36	0 kg
60,000	93%	7.7%	34	3.5 kg
70,000	80%	7 %	32	7.5 kg
80,000	70%	6.5%	30	11 kg
90,000	62%	6.1%	29	13 kg
100,000	56%	5.8%	28	15 kg
110,000	51%	5.5%	27	17 kg

Table 29. The annual increase of weight (kg/year) of young heifers for different combinations of herdsize and annual rainfall

herdsize	rainfall		
	600 mm	900 mm	1200 mm
50,000	41	45.5	50
60,000	37.5	42	46.5
70,000	33.5	38	42.5
80,000	30	34.5	39
90,000	28	32.5	37
100,000	26	30.5	35
110,000	24	28.5	33

Table 30. The relationship between the yearly increase of weight of young heifers and the calving rate (Breman et De Ridder)

yearly increase of weight of young heifers	calving rate
20 kg	0.4
30 kg	0.5
40 kg	0.6
50 kg	0.7
60 kg	0.8

specific deathrate = specific basic deathrate / cattle health factor

For each age class an age specific basic deathrate is determined. These age specific basic deathrates are the deathrates, that prevail under conditions of an optimum supply of feed and without epizootic diseases. No specific basic deathrates for cattle are available from the area, but based on various sources (ILACO, 1981a; Upton, 1986; Wilson et al., 1984; Ariza-Nino and Shapiro, 1984 and Brandl, 1988) basic deathrates have been chosen (see table 31).

The health of the cattle is influenced by the availability of feed, the incidence of epizootic diseases (such as Rinderpest and Contagious Bovine Pleuropneumonia) and the availability of veterinary facilities for enzootic diseases (represented by the veterinary facility factor).

The influence of the availability of feed on the deathrate is derived from the weight increase of young heifers and represented by the growth factor.

cattle health factor = (basic cattle health factor + coefficient for veterinary facilities) * growth factor / coefficient for epizootic diseases

It is assumed that without preventive measures against epizootic diseases, there will be an outbreak every 10 years. Although little can be said regarding the effect of epizootic diseases on the mortality figures in the Bor District, it has

Table 31. Basic death rates per age class for male and female cattle

age	basic death rate	age	basic death rate
0	0.1	7	0.04
1	0.04	8	0.04
2	0.02	9	0.04
3	0.02	10	0.04
4	0.04	11	0.07
5	0.04	12	0.1
6	0.04	13	0.5
		14	1.0

Table 32. The veterinary facility factors

nature of the veterinary facilities	veterinary facility factor
no facilities	0
veterinary care for enzootic diseases	0.1

been assumed, that an outbreak of an epizootic disease will raise mortality by a factor 3 (McCabe, 1987).

The veterinary facility coefficient represents the effect of the introduction of veterinary facilities on enzootic diseases. It is thereby assumed, that it will take 3 years before the veterinary facilities are fully effective.

The values that have been assigned to the veterinary facility factor are presented in table 32.

The relationship between the weight increase and the growth factor is given in table 33. It is hereby assumed, that starting from conditions of a low feed supply, an improvement of the feed supply will have an effect on survival, that is initially very strong, but becomes weaker as the supply improves.

The number of female animals that move from one age class to the next is determined by the number that moved last year into that age class minus the number of females that died, were sold or were killed during that year.

Cattle are sold for two reasons: to obtain money for regular expenses (clothes, oil, taxes, school-fees) and to purchase food in times of scarcity.

It is assumed that a certain number of cattle per person per year is sold to meet the regular expenses. This number depends on:

- the average number of animals per person. It is assumed that the population will sell 0.1 head of cattle per person if the herdsize is twice the size of the population. When the number of animals per person drops below 2, the population will become more reluctant to sell cattle, but when the number of animals increases beyond 2 they are willing to sell more animals (up to 0.2 head per person).

Table 33. The relationship between the annual weight increase of young heifers and its effect on survival (represented by the growth factor)

yearly increase of weight of young heifers	growth factor
25	0.15
30	0.33
35	0.45
40	0.52
45	0.56
50	0.58

– the number of animals that has to be sold to be able to purchase sorghum in times of food scarcity. In that case the number of animals the farmer should sell for purchasing food, is deducted from the animals that he sells for his regular expenses.

The number of animals that is sold to finance regular expenses (regular sold) is determined as follows:

regular sold = regular selling rate * total population – req.cattle sold for sorghum

The regular selling rate is determined as follows:

$$\textbf{regular selling rate} = \textbf{0.1} * \left(\textbf{1} - \frac{\textbf{(2 * total population - herdsize)}}{\textbf{2 * total population}}\right)$$

It is supposed that the owners of the cattle will make a selection of animals that is to be sold first. They will first sell part of their male animals and then part of their female cattle. The farmer will not sell all his female animals: he does not want to sell his young female animals, but is ready to sell the older, less productive ones (Hjort, 1980; Ariza-Nino and Shapiro, 1985). This means that the selling rates per sex and age class differ.

female animals sold = (female herdsize – dead female cattle) * selling rate per female age class

The selling rate per female age class (female selling rate) is determined by:
– the maximum share per female age class, that the farmer is prepared to sell (max. female selling rate), see table 34. As there are no relevant data available, guesses are made based on the reasoning expounded above.
– the total number of female cattle, that the farmer is prepared to sell (max.sell female cattle);
– the number of female cattle, that the farmer should sell to purchase sufficient food (req.sell female cattle).

$$\textbf{female selling rate} = \textbf{max. female selling rate} * \frac{\textbf{req.sell female cattle}}{\textbf{max.sell female cattle}}$$

The total number of female cattle, that should be sold is determined by the total number of cattle, that should be sold (req.sell total cattle) minus the number of male cattle that has been sold (male cattle sold). It should be noted, that the total number of female cattle, that should be sold can never exceed the number, that is available for sale.

req.sell female cattle = req.sell total cattle – male cattle sold

The total number of female cattle that is available for sale depends on the number

Table 34. The maximum selling rates per age class of female animals, that the farmer is prepared to sell

age	max. female selling rate	age	max. female selling rate
0	0	8	0.2
1	0	9	0.5
2	0	10	1.0
3	0	11	1.0
4	0	12	1.0
5	0	13	1.0
6	0.1	14	1.0
7	0.1		

of female cattle per age class, the female cattle that died (dead female cattle) and the maximum female selling rates per age class.

max.sell female cattle = (female cattle – dead female cattle) * max.fem.selling rate

The number of heads of cattle that should be sold in order to purchase sorghum (req. cattle sold for sorghum) is determined by the quantity of sorghum, that should be purchased (req. sorghum), the sorghum price (sorghum price) and the price of cattle (cattle price).

req. cattle sold for sorghum = req. sorghum * sorghum price / cattle price

When there is not enough sorghum in the market to satisfy 95% of the energy requirement, the population will kill their animals starting with the males and then the older females (Hjort, 1980).
Similar to the selling of cattle, the killing rates differ per age class (female killing rate).

female animals killed = (female herdsize – dead female cattle – female sold) * female killing rate

The female killing rate per age class is determined by the maximum share per age class, the farmer is prepared to kill (max.female killing rate) (table 35), the total number of female cattle the farmer is prepared to kill (max. kill female cattle) and the number of female cattle the farmer should kill in order to fulfill 95% of the energy requirements of the population (req.kill female cattle):

$$\textbf{female killing rate} = \textbf{max.female killing rate} * \frac{\textbf{req.kill female cattle}}{\textbf{max.kill female cattle}}$$

Table 35. Maximum shares per female age class of cattle that the farmer is prepared to kill

age	max.female killing rate	age	max.female killing rate
0	0	8	0.4
1	0	9	0.8
2	0	10	1.0
3	0	11	1.0
4	0	12	1.0
5	0.1	13	1.0
6	0.1	14	1.0
7	0.2		

As there is also a lack of data on the max. female killing rates, the rates that are used are highly speculative and only supported by general statements, such as that of Hjort (1980).

The number of female animals that should be killed (req.kill female cattle) depends on the number of animals to be killed and the male cattle that have been killed for the same purpose.

req.kill female cattle = number of animals to be killed – male cattle killed

The total number of female cattle that the farmer would ultimately be prepared to kill depends on the number of female cattle per age class, the female cattle that died (dead female cattle) or has been sold (female cattle sold) and the maximum female killing rates per age class.

max.kill female cattle = (female cattle – dead female cattle – female cattle sold) * max.female killing rate

The total number of animals to be killed is determined by the quantity of joules that is required to satisfy the energy requirements up to 95%. The cattle that are killed are mostly male adults. Their average energy value is put at 1286 MJ.

number of animals to be killed = req.energy from killing/ MJ per head of cattle

As already mentioned before, when food supply drops below 90% of the quantity that is required, the population will also start killing animals they were hitherto not prepared to kill: emergency killing.
The number of female cattle, that are killed in this emergency situation is determined by the number that is available, multiplied by the emergency killing rate:

emerg.killing of female cattle = (female herd – dead fem.cattle – fem.cattle sold – cattle killed) * em.killing rate

The emergency killing rate is determined in the equation:

em.killing rate = req.emergency killing/(herdsize – dead cattle – cattle sold – cattle killed)

5.4.2. The male cattle

The male herdsize per age class is determined by the number of male calves, that are born or the number of male animals, that move from one age class to the next, and by the number of male animals, that die, are sold or are killed in periods of serious food shortage.

The number of male calves, that are born, is equal to the number of female calves. The number of male animals, that move from one age class to the next, is determined by the number that moved last year into that age class minus the number that died, was sold or killed during that year.

The number of male animals that die, depends on the number in that age class and the specific deathrate for that age class:

dead male cattle = number of male cattle * specific male deathrate

The specific deathrate is determined by the basic deathrate per age class and by the factors that determine the health of the male cattle. The basic deathrate figures are the same as for the female cattle (table 31), while the health factor is also calculated in the same way, except for the male calves.

The reason for this is that it is assumed, that there exists a competition between man and male calve for milk in periods of food scarcity. Female calves are not affected by this competition as they are considered more valuable than male calves. The quantity of milk, received by the male calves, depends on the extent to which the food production meets human requirement (the relative food production), whereby the relative food production is defined as follows:

relative food production = (sorghum production + bushfood + sorgh gift + dead cattle + milk productioncalves * req.milk per calf) / total food requirement

It should be noted that the male calves, that die because of lack of milk, are not included in the dead cattle. So, if the relative food production declines, the quantity of milk per male calf will decrease as well. The relationship between the relative food production and the share of milk, the male calves receive (male share milk), is given in table 36.

The influence of the share of milk, received by the male calves, on their health is represented by the milk effect factor (table 37).

male calves health factor = cattle health factor * milk effect factor

Although male cattle will be sold before female cattle, the farmers tend to keep part of the males as bulls or as songbulls. In the equation below, the bulls are

Table 36. The relationship between the relative food production and the share of milk the male calves receive

relative food-production	male share milk
0.6	0.6
0.7	0.6
0.8	0.6
0.9	0.7
1.0	0.9

Table 37. The relationship between the share of milk the male calves receive and the effect on their health

male share milk	milk effect factor
0.6	0.4
0.7	0.5
0.8	0.6
0.9	0.8
1.0	1.0

included in the number of songbulls.

male animals sold = (male herdsize – dead male cattle – songbulls) * selling rate per male age class

It is assumed that every male adolescent and young adult has a songbull. The maximum proportion of male cattle per age class, that is songbull, is given in table 38.

The actual proportion of male cattle that is songbull (songbull rate) is determined by the number of songbulls required (req.songbulls) and the number that

Table 38. The maximum proportion of male cattle per age class that is songbull

age class	max.songbull rate	age class	max.songbull rate
0	0	8	1
1	0.5	9	1
2	0.5	10	1
3	1	11	1
4	1	12	1
5	1	13	1
6	1	14	1
7	1		

is available for this purpose (available songbulls).

$$\textbf{songbull rate} = \frac{\textbf{req.songbulls}}{\textbf{available songbulls}}$$

available songbulls = max.songbull rate * male cattle per age

The number of songbulls per age class is therefore defined as:

songbulls per age class = (male animals per age class – dead male cattle) * songbull rate

The selling rate per male age class (male selling rate) is determined by the maximum share of male animals per age class, that the farmers are prepared to sell (max.sell male cattle), and the number of cattle that the farmers should sell in order to purchase sufficient food to cover their food requirement (req.sell male cattle):

male selling rate = max. male selling rate * req.sell male cattle / max.sell male cattle

The maximum selling rates per age class are presented in table 39. Similar to the killing rates, the estimation of the selling rates are the result of some guess work.

Similar to the female animals, male animals may be killed as well in times of severe food shortage.

male animals killed = (male herdsize – dead male cattle – males sold – songbulls) * male killing rate

The male killing rate is determined by the maximum share per age class the farmer is prepared to kill (max.male killing rate, see table 40), the total number

Table 39. The maximum selling rates of male animals the farmer is prepared to sell

age class	max.sell male cattle	age class	max.sell male cattle
0	0	8	1
1	0.1	9	1
2	0.1	10	1
3	0.2	11	1
4	1	12	1
5	1	13	1
6	1	14	1
7	1		

Table 40. Maximum shares per male age class of cattle that the farmer is prepared to kill

age class	max.male killing rate	age class	max.male killing rate
0	0	8	1
1	0.1	9	1
2	0.3	10	1
3	1	11	1
4	1	12	1
5	1	13	1
6	1	14	1
7	1		

of male animals the farmer is prepared to kill (max.kill male cattle) and the number of cattle the farmer should kill in order to fullfil 95% of the energy requirements of the population (req.kill cattle):

$$\textbf{male killing rate} = \textbf{max.male killing rate} * \frac{\textbf{req.kill cattle}}{\textbf{max.kill male cattle}}$$

The total number of male cattle that the farmers would ultimately be prepared to kill depends on the number of male cattle per age class, the male cattle that died or has been sold, the number of songbulls and the maximum killing rates per male age class:

max.kill male cattle = (male cattle – dead male cattle – male cattle sold – songbulls) * max.male killing rate

The number of male cattle that is killed in an emergency situation is determined by the following equation:

emergency killing of male cattle = (male herdsize – dead male cattle – male cattle sold – male cattle killed) * em.killing rate

5.4.3. Milk production

The milk production depends on the number of calves and the milk production per lactation. It is assumed that the cows do not produce milk when their calves die. It is therefore useful to define in this case the number of calves as the average of the number of calves, that was born in one year and the number that has moved to the next age class in that year:

milk production = 0.5 * number of animals in the first two age classes * milk production per lactation

Table 41. The relationship between the annual weight increase of young heifers and the milk production per lactation in the same herd (Breman and De Ridder)

yearly increase of weight of young heifers	milk production per lactation (kg/cow)
20	450
30	575
40	700
50	825
60	950

Breman and De Ridder have established a relationship between the weight increase of young heifers and the milk production per lactation in the same herd (table 41).

It is assumed that female calves consume 525 kg milk per year (milkcalves) and male calves a smaller quantity, depending on the relative food production (see table 36).

The total milk consumption by the female calves is:

milk female calves = milkcalves * 0.5 * the number of female animals in the first two age classes

The total milk consumption by the male calves is:

milk male calves = milkcalves * male share milk * 0.5 * the number of male animals in the first two age classes

The quantity of milk that is available for human consumption is:

milk for human consumption = milk production – milk female calves – milk male calves

6. VALIDATION OF THE BEHAVIOUR OF THE MODEL

In the previous chapter the elements and the relationships between them have been discussed. In this chapter the behaviour of the model is validated. The behaviour of a model can be validated by comparing the results of the model with historical data. However there are only few historical data available. These have been used to construct the model and can therefore not be used for validation.

Another way to validate the behaviour of the model is to see whether the behaviour of the model is plausible under standard and under extreme conditions. This is discussed in 6.1 and 6.2.

A third possibility to validate the model is by carrying out a sensitivity analysis. In 6.3 a summary of the results of a number of sensitivity analyses is presented, followed by a number of typical examples.

6.1. The standard run

To judge the plausibility of the model, the behaviour of a number of key variables in the standard run are examined:

a. the population (total, female and male) of the area;
b. variables that pertain to the health of the population: average death rate and relative consumption;
c. the migration (total, female and male);
d. the herdsize;
e. variables that pertain to the grain production: area cultivated and soil fertility.

In this standard run no special interventions are considered, although some exogenous variables vary:

- the annual rainfall varies and therefore the yields as well (section 5.3);
- there are two outbreaks of epizootic diseases (in 1983 and in 1993), see section 5.4;
- the quantity of imported grain increases at a rate of 3% per year (section 5.2).

According to the standard run, the population will decrease from 44,000 in 1979 to 34,600 in 2000 (fig. 12). This is caused by the high level of migration and the high death rate.

There are two major causes for the high level of migration. One cause is the fact that the possibilities for employment in Bor town are increasing due to

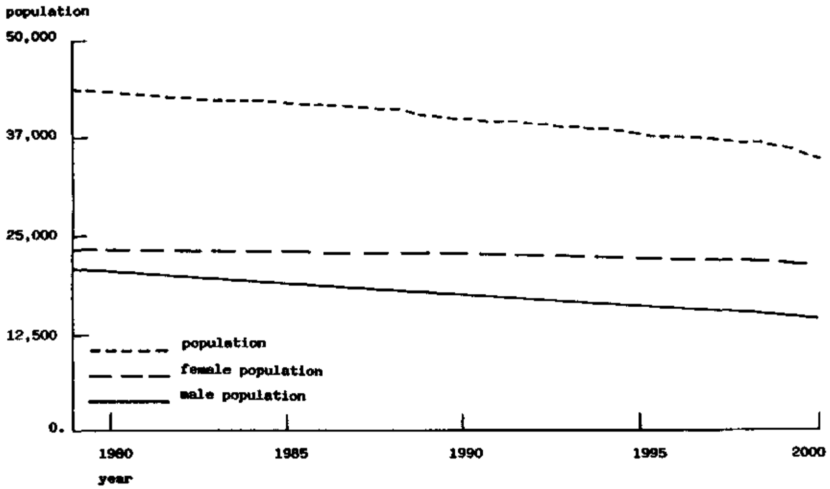

Fig. 12. The development of the size of the male, the female and the total population in the standard run

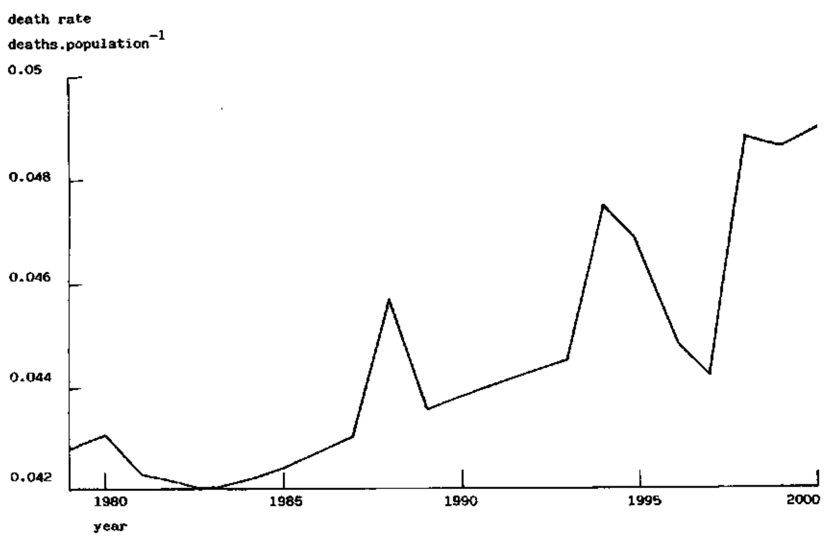

Fig. 13. The development of the average death rates of the rural population

the presence of the project and to the construction of roads, that link the Bor area with Juba. The second cause is the increasing number of school leavers due to the increased number of schools and teachers in the rural areas. Almost all school leavers attempt to find a job outside the rural area, although non-educated young people are attracted by the towns as well. As the propensity to migrate is higher among men than among women, the male population is declining faster than the female population.

The death rate, that is already high, steadily increases towards the end of the century with several peaks (fig.13). The overall increase can be attributed to a change in the distribution over the various ages (table 42).

Table 42 shows that the share of age groups with high deathrates, such as children and elder, increases, while the share of the adults, who have a relatively low death rate, decreases. The peaks in the death rates are caused by scarcity of food (resulting in a decline of the relative consumption (fig.14)). This affects the death rates of children and elder people, but it does not raise the death rates of the other age groups.

The scarcity of food is caused by several factors:

- due to the migration of the age groups, that significantly contribute to crop production, the available food decreases faster than the food requirement of the total population;
- the increasing population of Bor-town requires every year a larger share of the grain, that is imported. This reduces the availability of imported grain for the rural population;
- the above mentioned structural problems are aggravated by the high rainfalls in 1998 and 1999 (see table 25), resulting in low yields. These low yields reduce the relative consumption and so diminish the labour productivity. That results on its turn in a lower production; the system gets then into a downward spiral of decreasing yields and labour productivity, that reinforce each other.

Initially the herdsize tends to increase as long as no epizootics occur. In times of epizootics however (in 1983 and 1993), the herdsize is seriously affected (fig. 15). After each epizootic the herd recovers quickly as the quantity of feed that is available per animal increases and the readiness of the population to

Table 42. The distribution of the population over the various age groups, expressed in percentages of the total population

age group	1979	1985	1990	1995	2000
child	23.8	25.1	25.6	25.9	25.4
youth	20.1	20.4	21.2	22.0	22.4
adolescents	14.3	15.5	15.6	16.1	17.1
young adults	15.7	13	13.1	13.1	13.4
adults	12.6	11.1	9.1	8.2	8.5
middle aged	9.3	9.7	9.5	8.6	7.2
elder	4.2	5.1	5.9	6.2	6.1

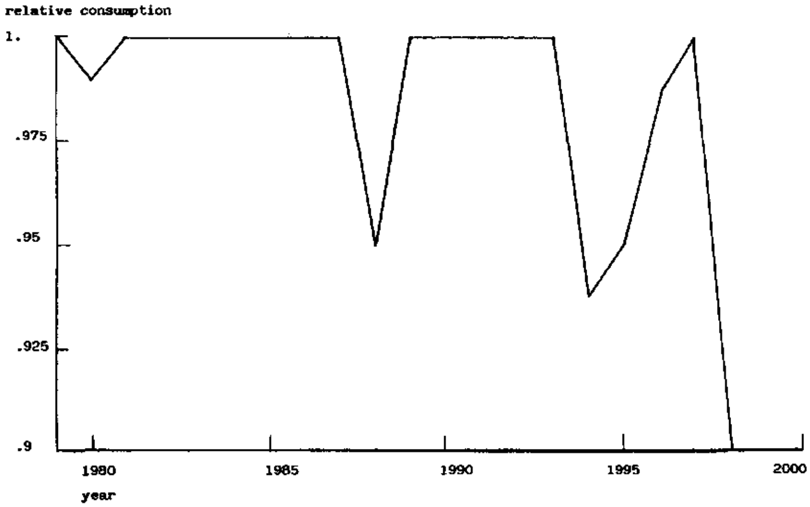

Fig. 14. The relative consumption (energy consumed energy required)

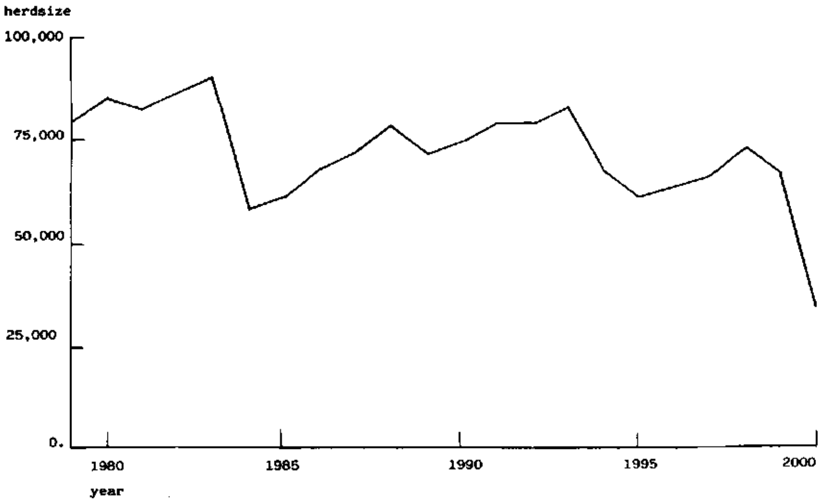

Fig. 15. The development of the herdsize

sell their animals decreases. At the end of the century, the population is forced to sell and kill large number of animals to avoid famine, resulting in a quick decline of the herdsize.

Table 43. The values of the policy variables that have been used to test the model

	unfavourable	conditions standard	favourable
medical facilities	1	0.8	0.3
facilities	0	1.5	3
employment opportunity	0	1	2
veterinary facilities	0	0	0.1
epizootics (number of occurrences)	4	2	0
food in the market	35	78	100
annual increase of market supply	0	3%	6%

The ecological stability expressed by the soil fertility is not endangered as the population does not increase, so that the land use is not intensified.

6.2. Model behaviour under extreme conditions

To test the model under extreme conditions two experiments have been carried out. In these experiments the policy variables have been put at their extreme values (table 43).

Under unfavourable conditions the food supply in the market remains very low, so that all imported grain is used by the population of Bor town and nothing is left for the rural population. When their own food production is not sufficient, the population is forced to kill their cattle in order to survive. Moreover shortage

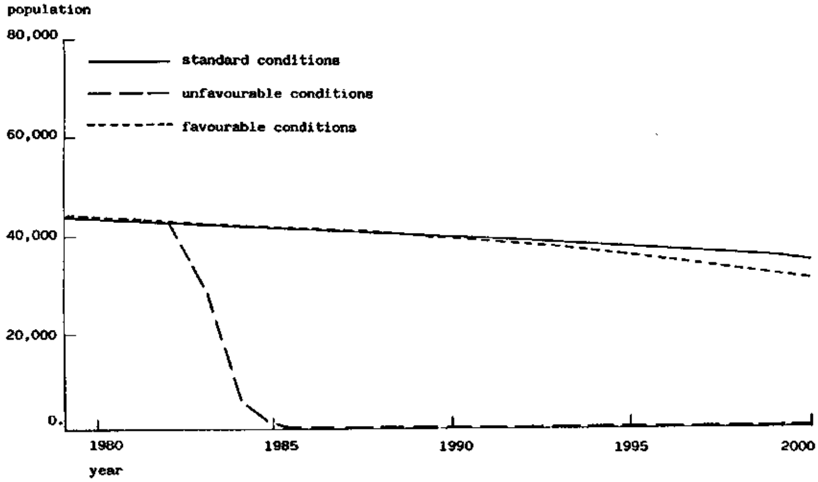

Fig. 16. The effects of extreme conditions on the size of the population

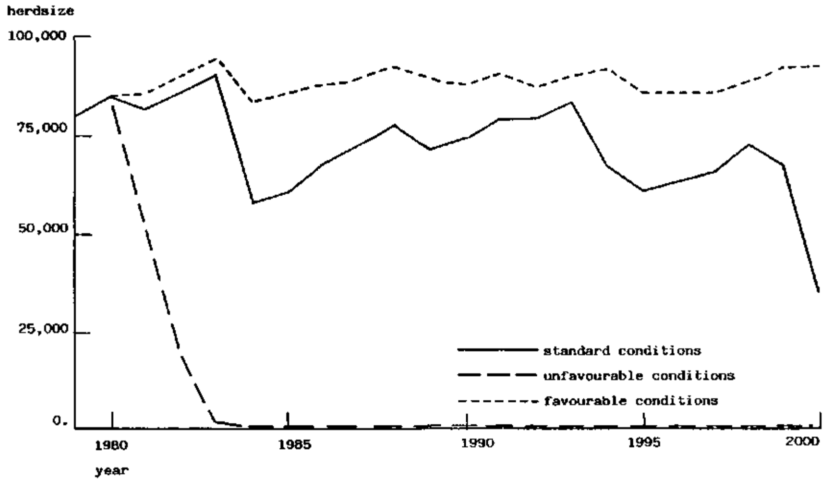

Fig. 17. The effect of extreme conditions on the herdsize

of food reduces the labour capacity as well and therefore the sorghum production. By 1985 all animals have been killed (fig. 17) and by 1986 the population has either left the area or has died because of starvation (fig. 16).

Under favourable conditions, there is enough food for everybody throughout the period under consideration. Due to the high level of medical and other facilities, mortality figures decline and labour productivity is high. On the other hand the high level of facilities and employment opportunity in Bor town cause a considerable increase of the migration, so that the decline of the rural population proceeds at a faster rate than under normal conditions. The herdsize is larger under favourable conditions for various reasons:

- due to the availability of veterinary services the mortality of the cattle is lower;
- due to the availability of sufficient grain in the market, the population does not kill its animals to avoid starvation.

From the above it is concluded that the model shows a plausible behaviour under extreme conditions.

6.3. Sensitivity analysis

As already mentioned, a number of parameters is not derived from empirical data of the area concerned or other similar areas. Therefore the author had to rely on his own judgement or that of others to estimate these values. In order to determine to what extent errors of judgement invalidate the model, a sensitivity analysis is carried out. In a sensitivity analysis the parameter values are varied within reasonable bounds; if the behaviour of the key variables does not significantly change, then one does not need to worry about the question whether the value of this particular parameter was correctly chosen. If, however, the behaviour of these variables changes significantly, either further justification of the choice of the value of the parameter or further research regarding the relationship concerned is required.

The following sensitivity analyses have been carried out:

fertility parameters

1. specific fertility:
   * low: the specific fertility is multiplied by a factor 0.8
   * high: the specific fertility is multiplied by a factor 1.2
2. the effect of the average relative consumption over the previous three years on fertility (fertility coefficient):

average relative consumption	fertility coefficient		
	weak	standard	strong
0.6	0.3	0.1	0
0.7	0.6	0.3	0.1
0.8	0.8	0.6	0.4
0.9	0.95	0.9	0.8
1	1	1	1

health parameters

1. basic death rate:
   * low: the basic death rate is multiplied by a factor 0.8
   * high: the basic death rate is multiplied by a factor 1.2
2. the effect of the relative consumption on the hunger factor:

relative consumption	hunger factor					
	children/elder			all others		
	weak	standard	strong	weak	standard	strong
0.6	3	6	12	3	6	12
0.7	1.5	3	6	1	2	4
0.8	1	1.5	4	1	1.2	3
0.9	1	1.2	2	1	1	1.5
1	1	1	1	1	1	1

3. the effect of the medical facilities on the morbidity of children and elderly people:
   strong : medical facilities coefficient = 0.6
   standard : medical facilities coefficient = 0.8
   weak : medical facilities coefficient = 0.95

migration parameters

1. the effect of employment facilities on migration:
   low : employment opportunity coefficient = 0.5
   standard : employment opportunity coefficient = 1
   high : employment opportunity coefficient = 2
2. the effect of (school-)facilities on migration:
   low : facility factor = 0.5
   standard : facility factor = 1.5
   high : facility factor = 3
3. the effect of the migration rates on migration:
   low : the migration rates of the uneducated people are multiplied by a factor 0.3 and of the educated people by a factor 0.8
   high : the migration rates of the educated and the uneducated people are multiplied by a factor 2

parameters concerning the purchase of grain

1. the annual percentage increase of the grain that is imported
   low: 1 standard: 3 high: 10
2. the parameters that determine the price of grain:

   weak relationship:

$$\text{price grain} = 10000 * \left(1 + \frac{3}{1 + \exp(-10 *(\text{rel.demand} - 1.4)}\right)$$

   standard:

$$\text{price grain} = 10000 * \left(1 + \frac{3}{1 + \exp(-20 *(\text{rel.demand} - 1.2)}\right)$$

   strong relationship:

$$\text{price grain} = 10000 * \left(1 + \frac{3}{1 + \exp(-40 *(\text{rel.demand} - 1.1)}\right)$$

3. the level of the relative consumption at which the population will respectively purchase grain, kill their less productive animals and kill their more productive animals

	low	standard	high
purchase	0.95	1	1
kill less prod. animals	0.9	0.95	1
kill more prod. animals	0.85	0.9	0.95

sorghum production parameters

1. basic labour productivity: 0.45, 0.50 and 0.55
2. the effect of the available facilities on the labour productivity:
   low:

$$\text{labourproductivity} = \frac{0.05}{(1 + \exp(-2 *(\text{facilityfactor} - 1)}$$

   standard:

$$\text{labourproductivity} = \frac{0.10}{(1 + \exp(-2 *(\text{facilityfactor} - 1)}$$

   high:

$$\text{labourproductivity} = \frac{0.15}{(1 + \exp(-2 *(\text{facilityfactor} - 1)}$$

3. the effect of relative consumption on labour productivity:

relative consumption	consumption coefficient		
	low	standard	strong
0.6	0	0	0
0.7	0	0	0
0.8	0.4	0	0
0.9	0.8	0.65	0.5
1	1	1	1

4. the maximum grain yields: 1100, 1250 and 1400 kg per ha.
5. the critical area under cultivation above which the soil fertility will decline: 6000 ha, 9000 ha and 12000 ha.
6. the effect of rainfall on the production per ha:

rainfall	effect on production		
	weak	standard	strong
600	0.8	0.7	0.6
700	0.9	0.9	0.8
800	1	1	1
900	0.9	0.9	0.8
1000	0.8	0.7	0.6
1100	0.7	0.5	0.3
1200	0.5	0.3	0.1

cattle parameters

1. the effect of annual weight increases on calving rate:

annual weight increase	effect on calving rate		
	weak	standard	strong
20 kg	0.50	0.4	0.25
30 kg	0.55	0.5	0.45
40 kg	0.60	0.6	0.60
50 kg	0.65	0.7	0.75
60 kg	0.70	0.8	0.90

2. the effect of the herdsize on the basic annual increase of weight:

herdsize	effect on annual increase of weight		
	low	standard	high
50,000	37	41	45
60,000	34	37.5	41
70,000	31	33.5	37
80,000	28	30	34
90,000	26	28	32
100,000	24	26	30
110,000	23	24	28

3. the effect of an increase in rainfall of 100 mm on the annual increase of weight:
   low : 1 kg/100 mm
   standard : 1.5 kg/100 mm
   high : 2 kg/100 mm

4. the basic deathrates of cattle:
   low : the basic death rates of cattle are multiplied by a factor 0.5
   high : the basic death rates of cattle are multiplied by a factor 1.2
5. the effect of epizootics on the death rate of the cattle: 2, 3 en 4
6. the effect of the annual increase in weight of young heifers on survival (growth factor):

annual increase of weight	growth factor		
	low	standard	high
25	.10	.15	.25
30	.25	.33	.43
35	.35	.45	.55
40	.42	.52	.62
45	.46	.56	.66
50	.48	.58	.68

7. the effects of changes in the maximum selling and killing rates of cattle and the maximum percentages of male cattle that become songbull.
   low : these rates are multiplied by a factor 0.5
   high : these rates are multiplied by a factor 1.5

Based on the results of the sensitivity analyses, three categories of parameters can be distinguished:

a. parameters, that do not significantly alter the behaviour of the important variables, when their values are changed;
b. parameters, that only significantly alter the behaviour of the important variables, when their values are changed, in case there is no annual increase of imported grain;
c. parameters, that also significantly alter the behaviour of the important variables, when their values are changed, in case of an annual increase of imported grain.

As can be seen from table 44 there are many parameters for which the behaviour of the key variables is only sensitive when the quantity of imported grain falls short of the requirement of the inhabitants of Bor town and the rural areas. Under 'normal' conditions, changes of these parameter values do not significantly influence the overall behaviour of the model. This means that it is necessary to obtain more information regarding these parameters if a shortage of imported grain is expected.

Below the results of the sensitivity analyses of three parameters, each belonging to a different category of sensitivity, are further discussed.

Table 44. A classification of the parameters, according to their sensitivity

parameter	sensitivity		
	no	only, if the quantity of imported grain falls short of the requirement is in short supply	yes
Fertility			
spec.fertility		+	
fertility coefficient	+		
Health			
basic death rate		+	
hunger factor	+		
med.facilities coef.		+	
Migration			
employment opportunity			+
facility factor			+
spec.migration rates		+	
Purchase of grain			
increase imported grain			+
price parameters		+	
relationship between relative cons. and the purchase of grain or the killing of cattle			+
Sorghum production			
basic labour productivity		+	
facilities effect		+	
consumption coefficient		+	
maximum yield			+
critical area	+		
rainfall effect			+
Cattle			
effect weight increase on calving rate	+		
effect herdsize on weight		+	
effect rainfall on weight	+		
basic death rate	+		
epizootics	+		
growth factor		+	
max.rates of selling, killing and songbulls		+	

Effect annual weight increase on calvingrate

The sensitivity of the model to the changes in the effect of annual weight increase on calving rate has been tested calculating the effects of these changes on herdsize as it can be safely assumed, that herdsize is the first important variable, that will be affected. From figure 18 it appears that the herdsize does not react to these changes in this parameter. This means that it is not necessary

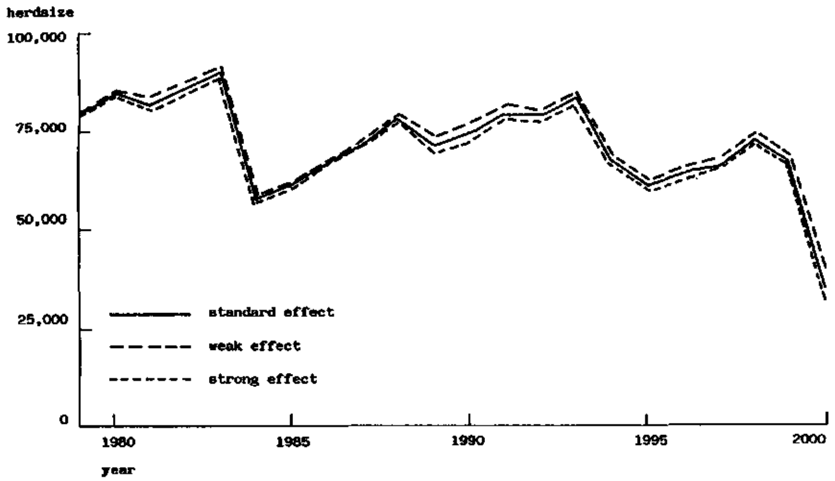

Fig. 18. The effect of various strengths of relationship between the annual weight increase and calving rate on herdsize

to put efforts in research that aims at obtaining a better estimation of the effect of annual weight increase on calving rate.

Consumption coefficient

The consumption coefficient represents the effect of the relative consumption on the labour productivity. It exerts its effects via the sorghum production on relative consumption and population. The results of changes in the values of this parameter on the population are presented in fig. 19.

This figure shows, that as long as no serious disturbances occur, changes of the consumption coefficient do not influence the size of the population. However when there is a shortage of food in the market, the relationship between relative consumption and labour productivity becomes an important determinant of the population size in case of a strong consumption effect. This shows that relationships, that appear not to be important for the functioning of a system, may become important when the system is destabilized.

The consequence is that further research into this relationship is required if a destabilization of the system is expected.

Employment opportunity coefficient

The employment opportunity coefficient relates the level of employment facilities to the propensity to migrate. Figure 20 shows, that variation in the value of this parameter changes the population size in a significant way in comparison to 'normal' circumstances. This means that it is very important, that a reliable estimation of this parameter is available.

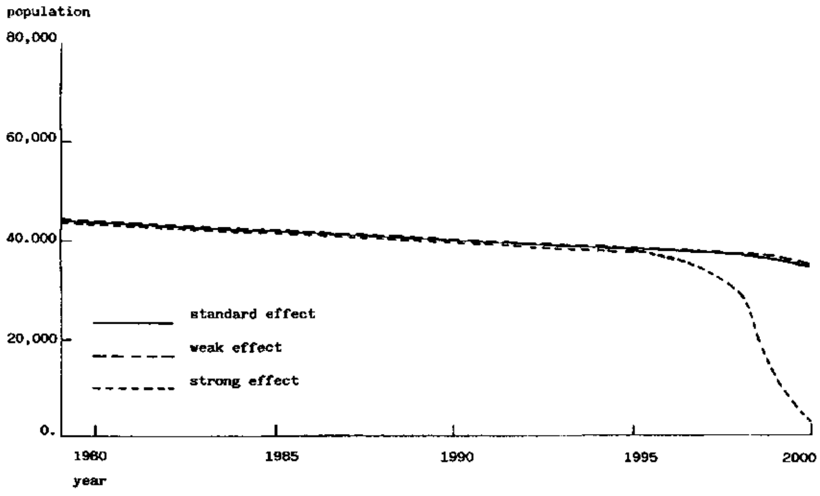

Fig. 19. The effect of variations of the consumption coefficient on population size

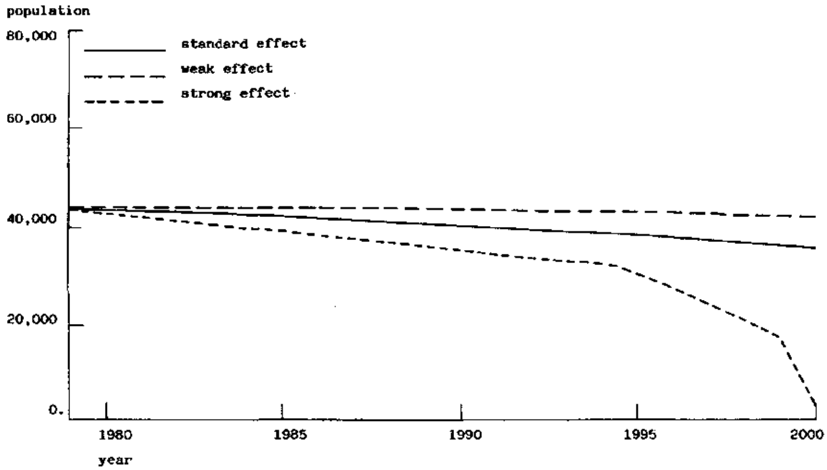

Fig. 20. The effects of various levels of the employment opportunity coefficient on population size

7. MODEL EXPERIMENTS

In order to obtain insight in effects of possible interventions on a number of key variables, model experiments have been carried out.
In these experiments one or more parameter values have been changed, representing an intervention.

The effect of changes in medical and other facilities
In this experiment four options are compared:

1. no improvement of the existing facilities:
   medical facilities coefficient = 0.8 (hospital and health posts)
   general facilities coefficient = 1.5 (the above mentioned medical facilities and a few schools and water points)
2. the existing medical facilities including the supply of clean water are improved:
   medical facilities coefficient = 0.6 (hospital, health posts and immunization)
   general facilities coefficient = 2 (the above mentioned medical facilities, roads, schools and a good water supply)
3. the existing medical and other facilities, such as roads and schools, are strongly improved:
   medical facilities coefficient = 0.3 (hospital, health posts, immunization, sanitation and nutrition)
   general facilities coefficient = 3 (the above mentioned medical facilities, roads, transport, schools, shops and a good water supply)
4. the existing facilities are removed:
   medical facilities coefficient = 1
   general facilities coefficient = 0

It is assumed, that an improvement of medical facilities is accompanied by an improvement of the level of general facilities.

The level of medical facilities influences the death rate of young children and the level of general facilities influences labour productivity and the percentage of the school-going children and therefore the migration rate as well.

An improvement of these facilities increases the health of young children and the labour productivity. This results in a lower death rate and a higher food production, thus in a population increase (fig. 23). Due to the improved facilities, more children go to school and when these children leave school, the number of migrants increases (fig. 21). This stops the population increase. As these migrants consist of persons that significantly contribute to the sorghum produc-

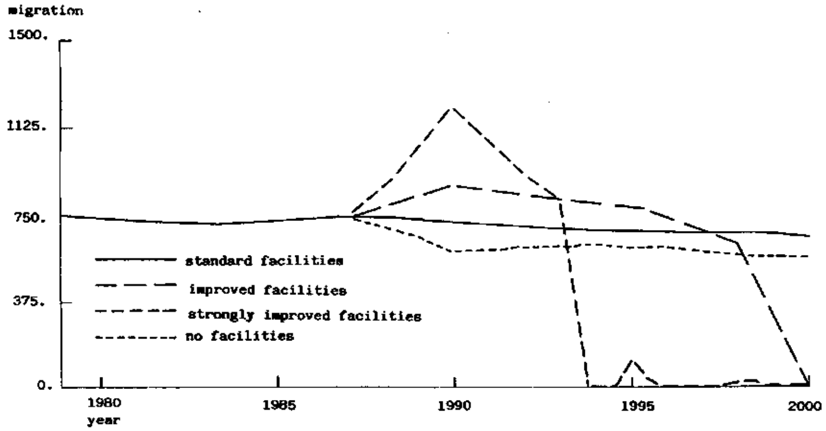

Fig. 21. The effects of various levels of medical and general facilities on migration

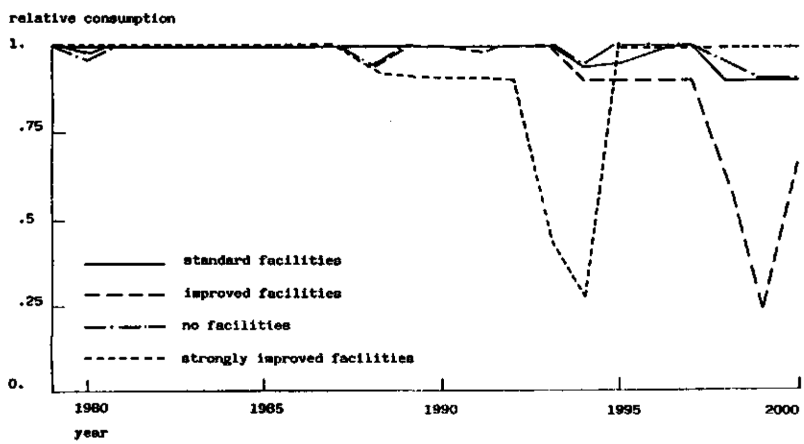

Fig. 22. The effects of various levels of medical and general facilities on relative consumption (energy required energy consumed)

tion, the proportion of the productive versus the unproductive population declines, resulting in a rapid drop of the relative consumption (fig. 22) and thus of the labour productivity and the sorghum production, which again causes a further reduction of the population.

In order to survive, cattle will first be bartered for sorghum and later be killed: before the end of the century no cattle will be left.

If the existing medical and other facilities are removed, the deathrate of young children increases and the labour productivity drops. This results in a slightly lower population size. Due to the lower level of facilities however, the number

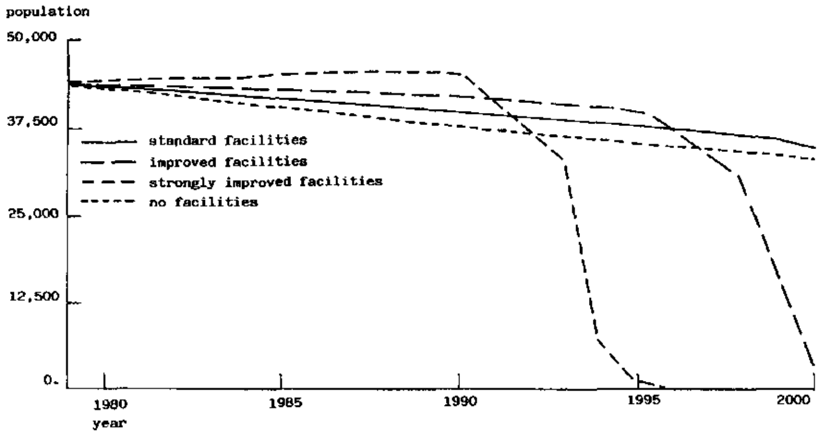

Fig. 23. The effect of various levels of medical and general facilities on population

of school-going children decreases and after some time the number of migrants decreases as well, so that the proportion of the population that is productive is relatively high. Under these conditions a famine is avoided at the end of the century.

It is therefore concluded that better medical and other facilities at first improve life of the population, but will at the end force the population to sell and kill more cattle. This is caused by the fact that on the one hand the total population remains at a higher level and that on the other hand the part of the population, that contributes most to the food production, migrates because of the increase of the number of educated people.

It should be noted, however, that if the quantity of imported grain remains sufficient up to 2000, the population development is different: similar to the other situation, the population growth is the highest under conditions of the best medical and other facilities and also under these conditions the population starts to decrease when migration increases due to the higher percentage of educated persons (fig. 24). This, however, does not cause a famine situation as there is sufficient food available in the market, so that labour productivity remains high and no cattle needs to be killed for food.

Effects of changes in employment opportunity

In this experiment the effects of changes in the employment opportunity outside the area are compared:

1. the standard employment opportunity (employment opportunity factor = 1)
2. a high employment opportunity (employment opportunity factor = 2)
3. no employment opportunity (employment opportunity factor = 0)

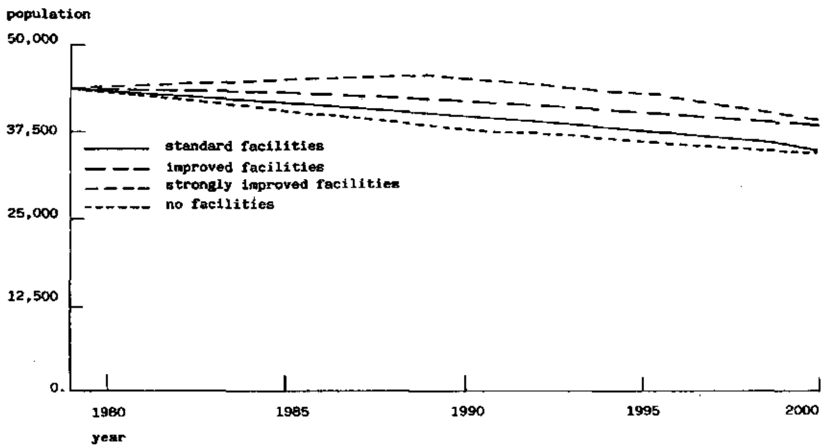

Fig. 24. The effects of various levels of medical and general facilities on population when the import of grain is sufficient to satisfy the requirement of the population

An increase of the employment opportunity will initially increase migration (fig. 25) and so reduce the part of the population with the highest contribution to the production of sorghum, resulting in a rapidly declining relative consumption (fig. 26), a lower labour productivity, a higher death rate and a very small population (fig. 27).

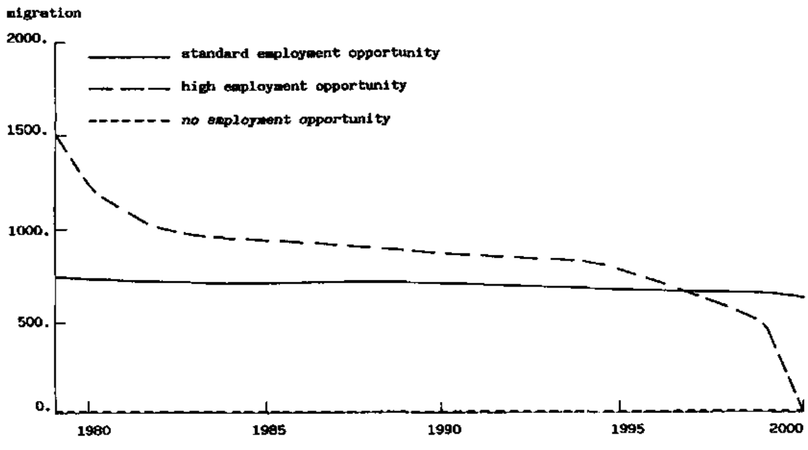

Fig. 25. The effect of various levels of employment opportunity on migration

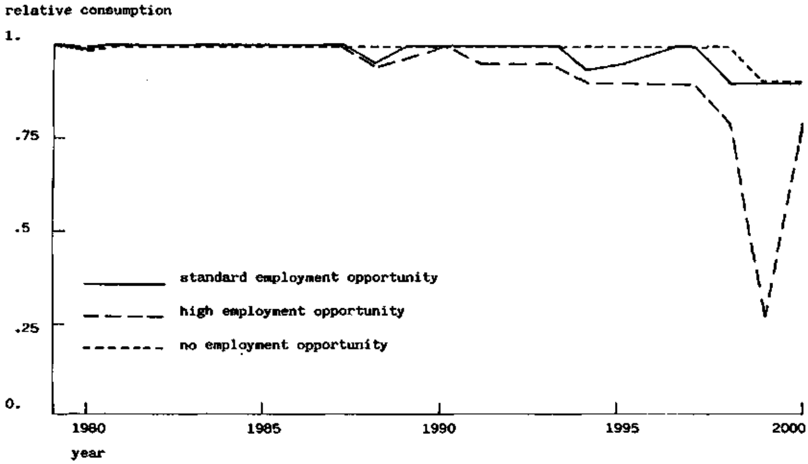

Fig. 26. The effects of various levels of employment opportunity on relative consumption (energy consumed energy required)

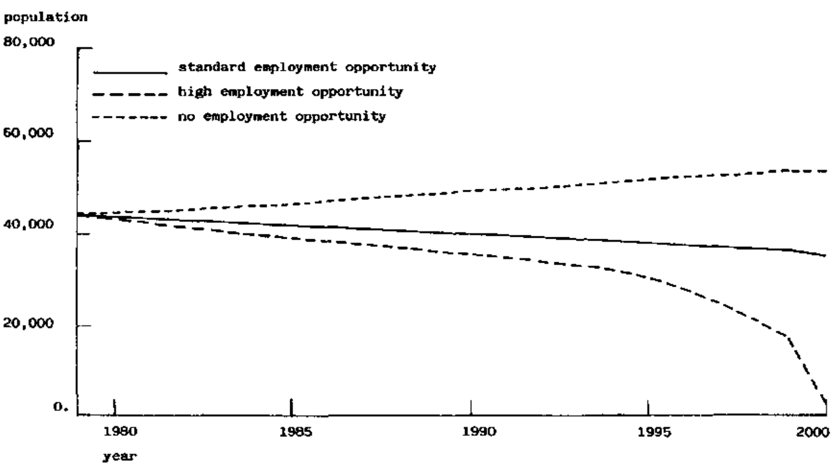

Fig. 27. The effects of various levels of employment opportunity on population

If there is no employment opportunity outside the rural area at all, there will be no migration, so that the population will gradually increase. As under these conditions the percentage of (young) adults remains at the same level, relative consumption will initially not be affected. When, however, at the end of the period under consideration two years of high rainfall occur, the sorghum production falls short of the requirement, so that the relative consumption decreases.

Effects of changes of veterinary facilities

Veterinary facilities can be improved in two ways:

- the area is protected from epizootics, such as Rinderpest and Contagious Bovine Pleuro Pneumonia (CBPP) by a broad eradication programme;
- the area is provided with regular veterinary services to control enzootic diseases.

It has been assumed, that it is of little use to provide an area with veterinary services without protecting it against epizootics. The options examined are therefore the following:

1. no improvement: no veterinary facilities and outbreaks of epizootics in 1983 and 1993 (vetfacilities 0, cfepizootics 3 in 1983 and 1993);
2. veterinary facilities for epizootics only (vetfacilities 0; cfepizootics 1);
3. veterinary facilities for epizootics and enzootics (vetfacilities 0.1; cfepizootics 1).

It appears from the figures 28 and 29 that veterinary facilities have only a slight effect on relative consumption and population size.

It is at first sight surprising to notice, that an improvement of veterinary services causes initially even a lower relative consumption (fig. 28) and so a faster reduction of the population size (fig. 29). The reason is, that the outbreak of epizootics causes a higher deathrate of cattle, so that more meat is available for the population. When veterinary facilities improve, there will be no epizootics, so that the herdsize remains on a higher level (fig. 30). However under these conditions, there will be less feed per animal, resulting in a lower calving rate (fig. 31) and milk production per cow. This is in agreement with the finding

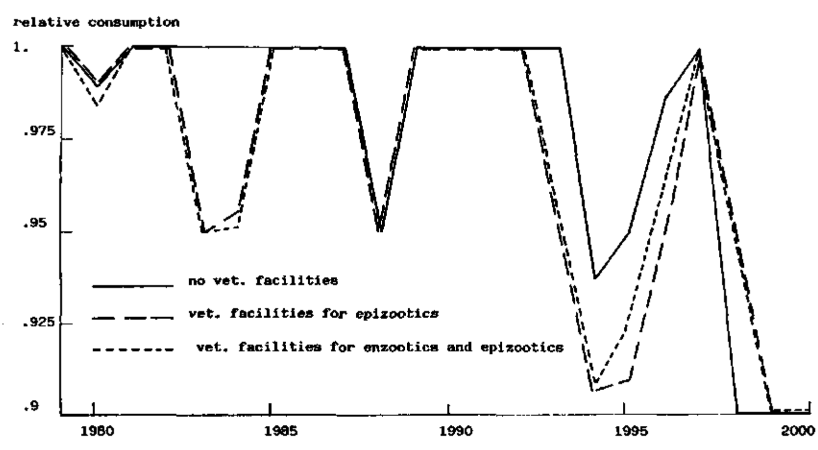

Fig. 28. Effect of various levels of veterinary facilities on relative consumption (energy consumed energy required)

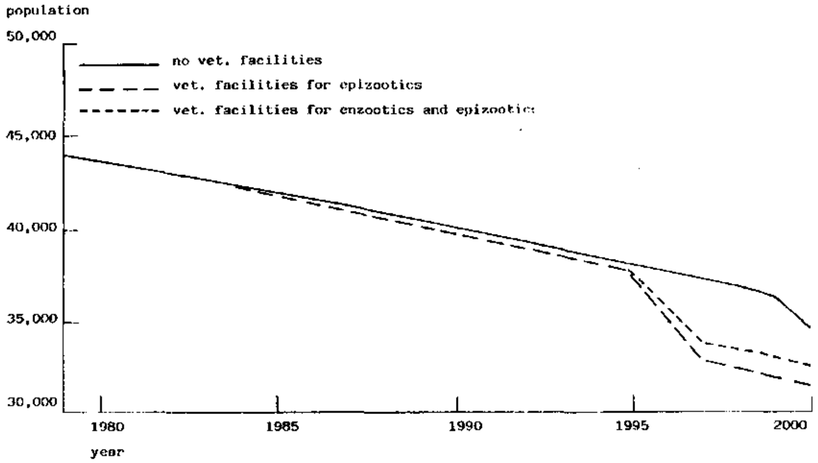

Fig. 29. Effect of various levels of veterinary facilities on population

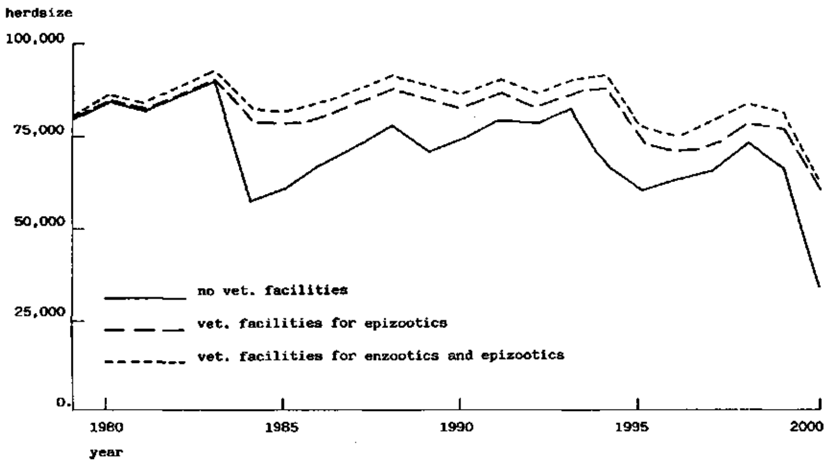

Fig. 30. Effect of various levels of veterinary facilities on herdsize

in the area, that most animals die from starvation (ILACO, 1981a).

It is therefore concluded, that introduction of veterinary facilities has a limited effect on the quality of life of the population of the area.

Effect of a combination of facilities.

Here a comparison is made between the effects of single interventions and the effect of all interventions combined:

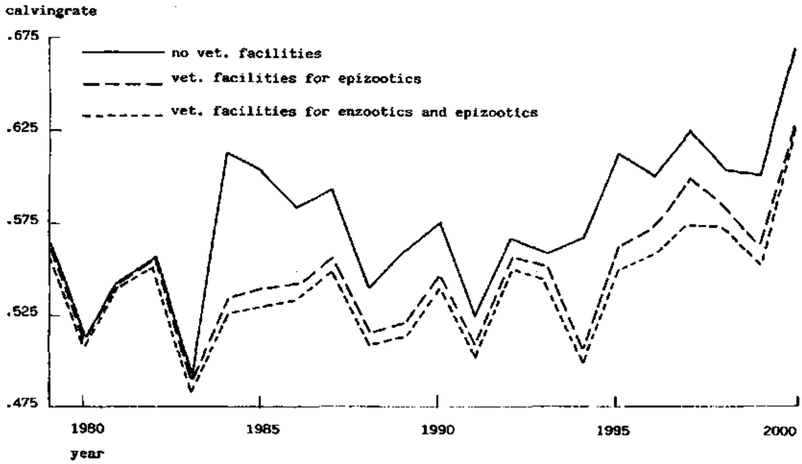

Fig. 31. The effect of various levels of veterinary facilities on calving rate (calves mature cow–1.year–1)

1. a continuation of the level of facilities as they were in 1979;
2. the effect of good medical and other facilities (medical facilities coefficient 0.3 and general facilities coefficient 3);
3. the effect of a good employment opportunity (employment opportunity factor 2);
4. the effect of good veterinary facilities (vetfacilities 0.1 and cfepizootics 1);
5. the effect of all facilities combined.

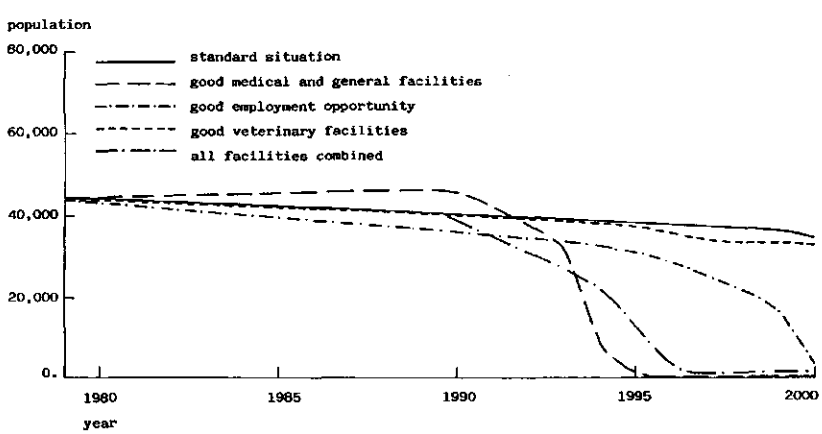

Fig. 32. Comparison of the effect of single interventions and of all interventions combined on population

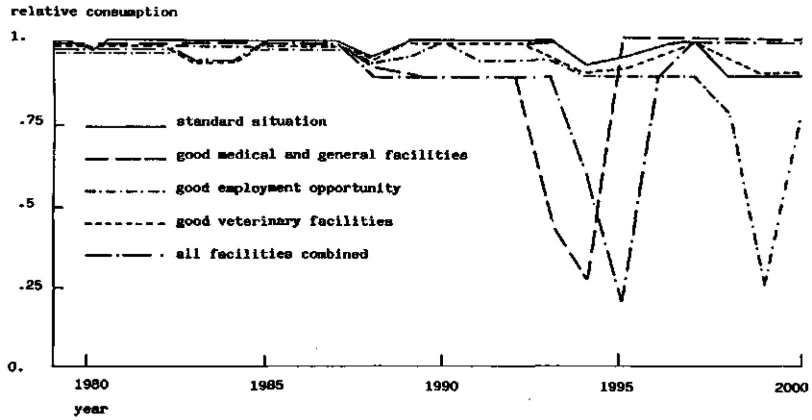

Fig. 33. Comparison of the effect of single interventions and of all interventions combined on relative consumption (energy consumed energy required)

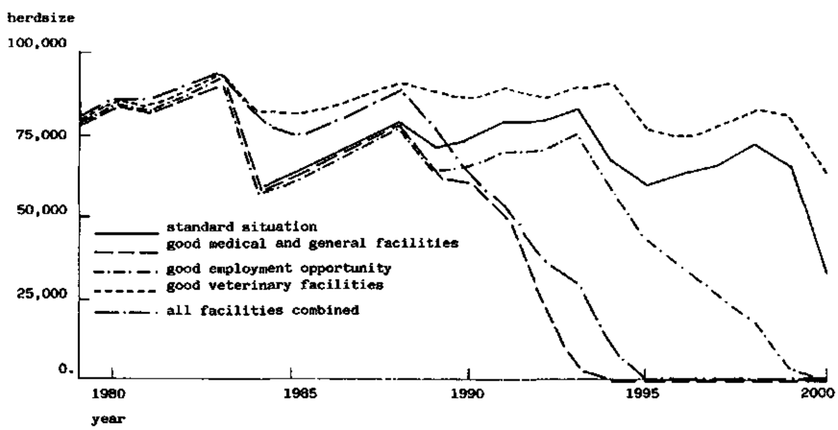

Fig. 34. Comparison of the effect of single interventions and of all interventions combined on population

It appears from figures 32 and 33 that an improvement of the medical and general facilities, such as schools, roads and water supply alone would be the worst option: the population would drop to approx. 250 in 1995, due to a severe shortage of food. When all facilities are combined, a similar effect occurs, though somewhat mitigated by the effect of the other improvements. At the end of the century, the size of the population will be the highest if no new facilities are introduced. The largest herdsize occurs when only veterinary facilities are introduced (fig. 34). From these comparisons it is concluded, that certain interventions that seem to enhance the quality of life of the rural population, may after all turn out to be detrimental to it.

The effect of a complete lack of facilities

It is interesting to know how an absence of facilities would affect the system either when the food supply from outside the area would be good or poor. Four situations are compared:

1. the situation as it was in 1979 continues with an annual increase of imported food of 3%;
2. all facilities disappear with effect from 1979, except the annual increase of imported food is maintained;
3. the situation as it was in 1979 continues, however without an annual increase of the imported food;
4. all facilities disappear with effect from 1979 and there is no annual increase of the imported food.

By no facilities is meant:

- medical facilities coefficient = 1;
- general facilities = 0;
- employment opportunity factor = 0;
- veterinary facilities = 0.

It appears that the population increases when all facilities are removed. If the facilities, as they were in 1979 are maintained, the population will gradually decrease (fig. 35). This is caused by the fact, that there is no migration if there are no schools and no employment opportunities. Without migration from this area, the population growth of Bor town will slow down and so does the annual increase of the food requirement of Bor town. Therefore a relatively larger share of the food will remain available for the rural population. A second consequence of halting the migration is that the young adults and the adults will cultivate their fields and so be producers rather than just consumers in town, who compete with the rural population for the imported food (fig. 36).

When the quantity of imported food does not increase, the maintenance of the facilities, that were available in 1979, would keep the system intact for a longer period than without facilities. This is due to the assumption, that the presence of certain facilities influence the labour productivity positively. Nevertheless after a few years there will be no people left in the country-side.

Effects of intercropping

In many years the sorghum production is below optimum due to the flooding of the fields. In a number of experiments it appeared that intercropping sorghum and rice provided a possibility to maintain crop yields under conditions of flooding at the same level as under optimal rainfall conditions, i.e. the reduction of the sorghum yield is balanced by an increase in the yield of rice (Struif Bontkes, 1986). It is therefore assumed that the practice of intercropping prevents low crop yields, when rainfall causes serious flooding. This means that the rainfall effect will change when intercropping is practiced (table 45).

Figure 37 shows that intercropping has a positive effect on relative consump-

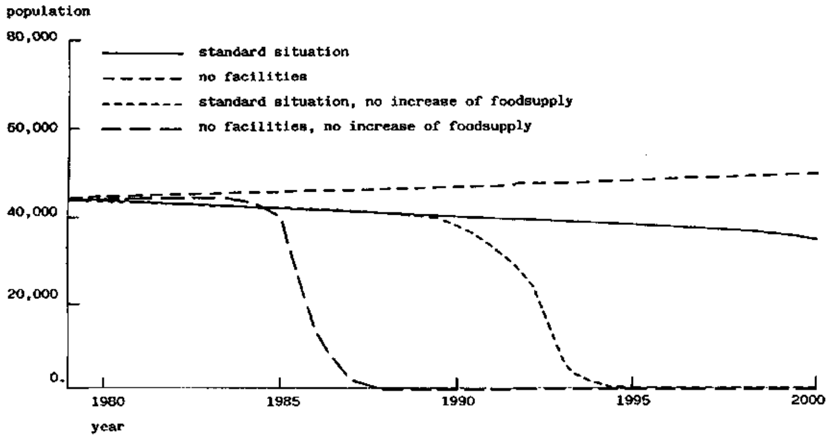

Fig. 35. Effect of an absence of facilities, with and without an annual increase of imported grain, on population

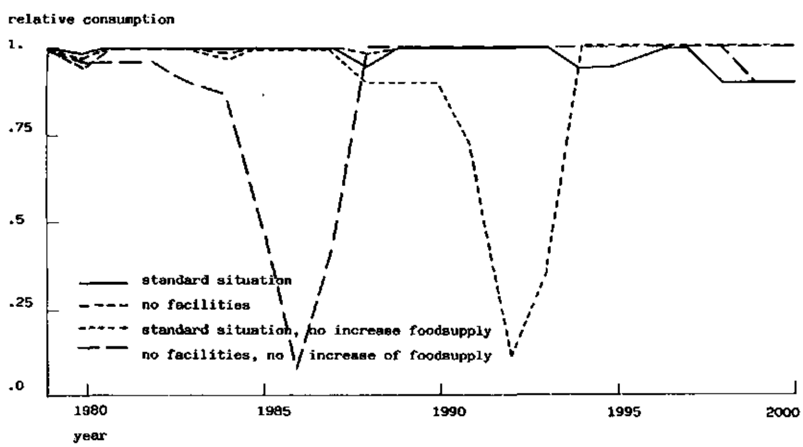

Fig. 36. Effect of an abscense of facilities, with and without an annual increase of imported grain, on relative consumption (energy consumed energy required)

tion under standard conditions. Initially, intercropping does not affect population size; however at the end of the century an (slight) acceleration of the decline of the population size does not occur as is the case under standard conditions (fig. 38).

Also under conditions, where the annual increase of imported sorghum is

Table 45. The effects of rainfall on the yields of a pure sorghum crop and on a mixture of sorghum and rice

rainfall	rainfall effect sorghum	sorghum/rice
600	0.7	0.7
700	0.9	0.9
800	1.0	1.0
900	0.9	1.0
1000	0.7	1.0
1100	0.5	1.0

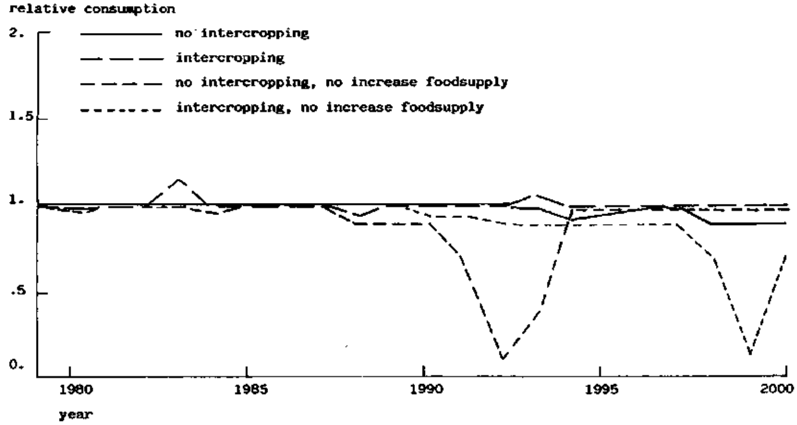

Fig. 37. Effect of intercropping on relative consumption (energy consumed energy required) under standard conditions and under conditions without annual increase of imported grain

zero, intercropping sorghum and rice gives the system a bit more resilience, though it is not able to prevent a collapse.

Effects of a temporary disruption of facilities

In this experiment it is attempted to simulate a disruption of the normal situation, whereby food supply is severely limited and facilities have come to a standstill. It is hereby assumed that the disruption occurs from 1985 to 1990; after 1990 many efforts are undertaken to rehabilitate the area:

1. medical facilities
   - remain at the same level until 1985 (medical facilities coefficient 0.8);
   - are absent from 1985 until 1990 (medical facilities coefficient 1);

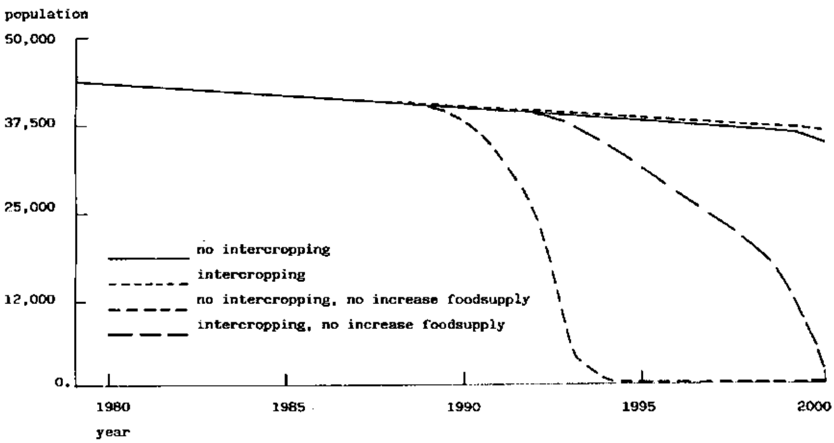

Fig. 38. Effect of intercropping on population under standard conditions and under conditions without annual increase of imported grain

  - in 1991 the medical facilities are improved to level 0.8, in 1992 to 0.6 and from 1993 onwards to 0.3;
2. the general facilities (e.g. roads, schools and water supply)
   - remain at the same level until 1985 (facility coefficient 1.5);
   - there are no such facilities from 1985 until 1990 (facility coefficient 0);
     - in 1991 these facilities are restored to 1.5, in 1992 improved to 2 and from 1993 onwards to 3;
3. employment opportunity
   - remains at the same level until 1985 (employment opportunity factor 1);
   - there is no employment opportunity from 1985 to 1990 (employment opportunity factor 0);
   - in 1991 opportunity for employment increases to 1 and from 1992 to 2.
4. grain supply in the market
   the grain supply between 1979 and 2000 is presented in table 46.

The effects of this situation are compared with a situation in which the above mentioned changes occur as well, but where intercropping of sorghum and rice is practiced.

The results of this experiment show that the effects on the population are disastrous as can be concluded from figures 39 and 40.

Due to the lack of imported grain in 1985, there is no grain available in the market for the rural population, so that they are forced to kill their cattle to avoid starvation. This causes a rapid decline of the herd size and thus of the available meat and milk, resulting in 1989 in a relative consumption, that is too low to enable the population to produce sorghum. This gives rise to starvation and to migration to other areas in search for food. When most people have

Table 46. The annual supply of grain in the market between 1979 and 2000

year	supply of grain (MJ*E+6)	year	supply of grain (MJ*E+6)
1979	78	1990	50
1980	80.5	1991	90
1981	83	1992	95
1982	86	1993	100
1983	86	1994	105
1984	80	1995	110
1985	50	1996	116
1986	50	1997	122
1987	40	1998	129
1988	35	1999	136
1989	40	2000	144

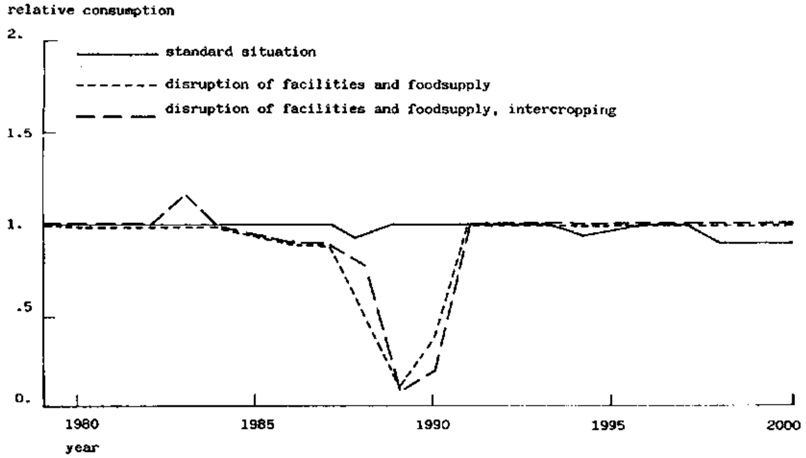

Fig. 39. The effect of a temporary disruption of facilities in the area, without and with intercropping, on relative consumption (energy consumed energy required)

died or have left the area, the situation improves for the population that is left, as the quantity of sorghum, that the population of Bor town uses to provide to the rural population, is now sufficient to meet the food requirement. As can be seen intercropping has virtually no influence on this development.

Although this development seems a logical consequence of such conditions, it is not likely, that there would be no resettlement after improvement of the situation. Therefore the original model has been changed to allow for resettlement of the population when the situation improves after 1991.

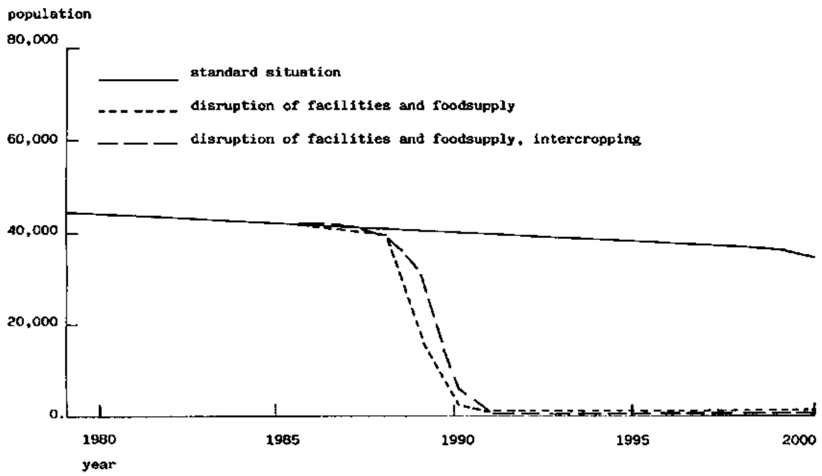

Fig. 40. The effect of a temporary disruption of facilities in the area, without and with intercropping, on population

In this model it is assumed that immigration depends on the average relative consumption over the past two years and on the area of fertile land that is available. The higher the relative consumption and the higher the area that is available, the higher the immigration will be. The area that is available is calculated as follows:

area available = 9000 – area already occupied

The immigration is determined as follows:

immigration = average rel.consumption coefficient * maximum immigrants

The maximum number of immigrants depends on the area that is available for settlement. The assumed relationship between the available area and the maximum numbers of immigrants is presented in table 47.
The average relative consumption coefficients represent the relationship between the average relative consumption over the past 2 years and the percentage of maximum immigrants that immigrates into the area (table 48).

It is assumed, that immigrants will consist of males of ages between 22 and 31 years and females of ages between 18 and 27 years.

Each immigrant is supposed to take a quantity of food along, that is sufficient to cover the energy requirement for a period of a year, and some cattle. It is assumed that the immigrants bring in 4 heads of female cattle and 0.5 head of male cattle per person.

Table 47. The relationship between the available area (ha) and the maximum number of immigrants

available area	maximum immigrants
0	0
1000	50
2000	125
3000	250
4000	500
5000	1000
6000	1500
7000	2500
8000	3750
9000	5000

Table 48. The relationship between the average relative consumption coefficient and the average relative consumption over the past two years

average relative consumption over the past two years	average relative consumption coefficient
1	0
1.1	0.1
1.2	0.25
1.3	0.6
1.4	0.8
1.5	1

Moreover when conditions improve, the rural population also starts purchasing cattle, which is made possible by a grain production, that exceeds their food requirement. The number of animals that are purchased depends on the produced food that is in excess of the required quantity, the price of grain and the price of cattle, whereby it is assumed, that female cattle is twice the price of male cattle.

purchase factor for female cattle =

$$= \frac{\text{bushfood} + \text{sorghum} + \text{milk} + \text{meat} - \text{required food}}{2 * \text{price cattle}} * \text{price grain}$$

purchase factor for male cattle =

$$= \frac{\text{bushfood} + \text{sorghum} + \text{milk} + \text{meat} - \text{required food}}{\text{price cattle}} * \text{price grain}$$

The way the money, earned by selling excess grain, is spent on the purchase of cattle is presented in table 49.

The effects of a temporary disruption of facilities simulated with this extended

Table 49. The relative allocation of the money, received from the sale of sorghum, for the purchase of cattle (in percentages)

female	
– calves	10%
– one year	10%
– two years	20%
– three years	20%
– four years	20%
male	
– four years	20%

model are shown in the figures 41 and 42. These figures show how an improved situation allows a gradual recuperation of population and herd.

In order to find out whether a new equilibrium would be reached, assuming that conditions will develop in the same way, the time horizon of the disrupted scenario has been extended to 2050, whereby after 2000 the annual increase of the quantity of imported grain is kept at 3% . Fig. 43 shows the development of the population and of the herdsize: the herdsize stabilizes around a level of 100,000 animals and the population between 16,000 and 20,000.

Although it is unlikely that there will be no significant change between 2000 and 2050 in this area, this thought-experiment suggests that a stable situation can be reached with a herdsize that is slightly higher but a lower population.

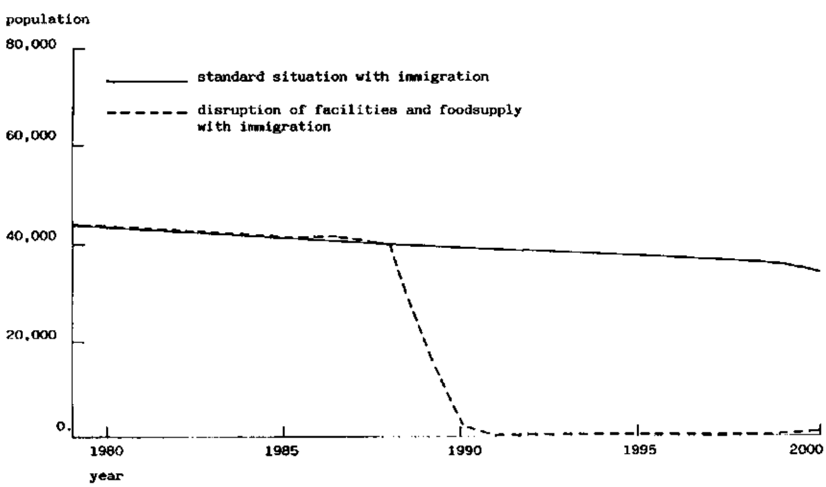

Fig. 41. The effect of a temporary disruption of facilities in the area on population, under the assumption of the possibilities of immigration and purchase of cattle

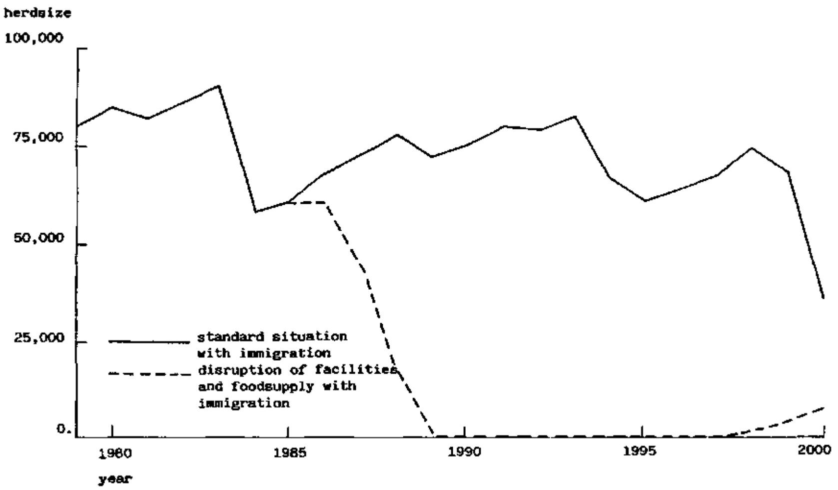

Fig. 42. The effect of a temporary disruption of facilities in the area on herdsize, under the assumption of immigration and purchase of cattle

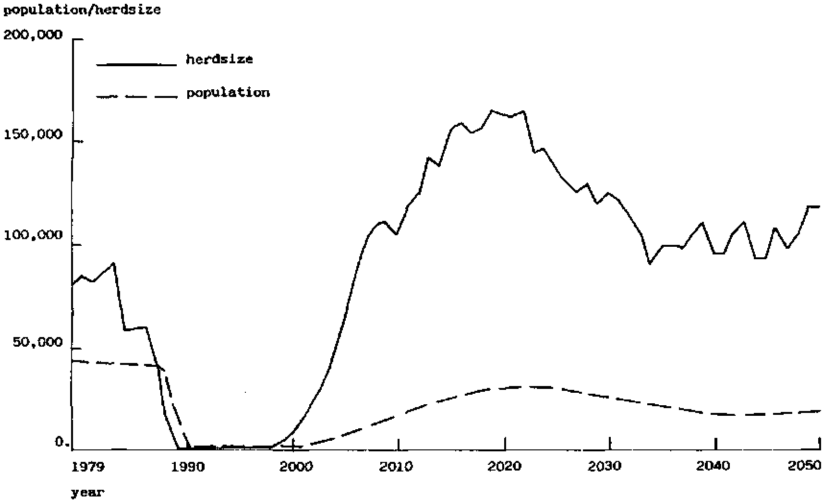

Fig. 43. The development of the size of the population and of the herdsize up to 2050 in the disrupted scenario under the assumption of the possibility of immigration and purchase of cattle

8. DISCUSSION

The discussion will cover three aspects of this exercise:
1. the validity of the model;
2. policy recommendations, based on the model;
3. applicability of this approach.

8.1. The validity of the model

As already discussed in chapter 6, the standard run shows a plausible behaviour when conditions do not significantly change: a continuing decrease of the population and a rather stable herd size until the moment that the quantity of imported grain is inadequate to provide the rural population with sufficient food. Moreover the model does not show impossible modes of behaviour under extreme conditions.

A number of sensitivity analyses has been carried out on various parameters and on a few combinations of parameters. These analyses resulted in the identification of three groups of parameters.

First a group of parameters was identified, that do not significantly change the behaviour of the model when their values are changed. Most of these parameters belong to the animal production submodel. The insensitivity of the model to changes in these parameters is caused by an important negative feedback structure in this submodel: an increase of the herd size reduces the quantity of available feed per animal, causing an increased deathrate. When an epizootic reduces the herd size, the available feed per animal increases and so speeding up the process of recovery of the herd. This process is further enhanced by reduced selling rates.

Changes in a second group of parameters do not significantly change the behaviour of the model under "normal" conditions, but do so when the quantity of imported grain drops for a number of years below the quantity, that is required to satisfy the energy requirement of the rural population.

The third group of parameters significantly affects the behaviour of the model, when their values are changed. This means that, for a better understanding of the system, it is necessary to carry out more research to determine these parameters with greater precision. This pertains to the following relationships:
- the effect of employment and the level of facilities (that affects the percentage of children that go to school) on migration;
- the effect of grain shortages in the market on health, fertility, labour productivity, distress migration and selling and killing of cattle;
- the maximum yield of sorghum per hectare and the effect of rainfall on sorghum production.

It should be realized, that no complete sensitivity analysis has been carried out: only a limited number of combinations has been studied and only under standard conditions (though under a gradually declining import of grain).

Another question is whether the variables, that have been included in the model, cover all the elements, that govern the behaviour of the system.
In the standard model, for example, it has been assumed, that immigration and purchase of cattle from outside the area are no important determinants for the development of the area. Although this may be true under the conditions of 1979, they may become important under other conditions, like after a temporary interruption of the existing facilities as outlined in chapter 7.

Another questionable assumption is that the reluctancy of the population to sell their cattle for commercial reasons and their readiness to share their food with others will not change in the near future. Whether this will prove to be true remains to be seen, but needs not necessarily be the case. It appears from other studies that many nomads and semi-nomads, who shifted gradually towards a commercialization of their herd, experienced social changes that enhanced a differentiation between households and between men and women (Bates and Conant, 1981; Dahl, 1979). To include such a development in the model, knowledge is required regarding causes, that trigger off commercialization, and regarding the ensuing social differentiation processes.

The role of the population of Bor town in the model is somewhat ambivalent: on the one hand the Bor population (successfully) competes for the imported grain, but, on the other hand, their number is not affected by e.g. a shortage of food supply or medical facilities.

It can therefore be concluded, that, though the model shows a plausible behaviour under the prevailing conditions of 1979, many questions remain regarding the validity of the model, especially under changing conditions.

8.2. Policy recommendations

After what has been said it is clear that one should be very cautious in formulating recommendations for interventions in this area, that are only based on this model.

Nevertheless, a number of recommendations are presented. These should be interpreted with the necessary care.

The primary objectives of this simulation study were to improve the health of the rural population and the stabilization of the population size in the rural area, whereby herdsize and soil fertility should remain at approximately the same level.

None of the model experiments has led to a reduction of the soil fertility, as the size of the rural population, and therefore the cultivated area, tended to decrease under almost all interventions.

However the model experiments suggest that it is very difficult to achieve the objectives with the possibilities for intervention, that were considered. Many interventions even deteriorate, rather than improve, the situation if compared with a development without any intervention at all (see e.g. figs. 32, 33 and 34).

Examples of this are the improvement of medical and other facilities (see figs. 22 and 23). This intervention initially improves the health of the population and slightly increases the size of the population. As under these conditions education increases as well, the migration of the active part of the population increases after a few years. This makes the area more dependent on food imports, resulting in a disaster when the food supply falls short of the food requirement. A similar fate can be expected when the employment opportunity outside the rural area is increased.

The model results even suggest that withdrawal of the existing facilities and a reduction of the employment opportunities in Bor town is a means to a slight, but steady increase of the population (figs. 35 and 36). This however should not be considered as a realistic and desirable option as one cannot deny people access to education and basic medical care.

An intervention, that is crucial for the area is to secure a regular and increasing import of grain. It appears that food production in the rural areas of Bor District is in some years not sufficient to supply the rural population with an adequate quantity of food (fig. 14). In those years the rural population has to rely on the import of grain. Initially this does not create problems: the rural population barter their cattle for grain. Due to the rapid increase of the population of Bor town, the quantity of imported grain that is required to feed this population should increase at a similar speed. If this is not the case there will not enough imported grain be left for the rural population in years of crop failure. The exchange rate between cattle and grain will then deteriorate and finally the rural people will kill their cattle and migrate in order to survive. This can be avoided by securing an adequate import of grain (fig. 24).

Interventions directed at an improvement of veterinary facilities do increase the herd size due to a lower death rate of the cattle (fig. 30). This means however, that less meat (of cattle that died) will be available, initially causing a reduction of the relative consumption. Later on, the increase of the herd size will reduce the quantity of feed, that is available per animal, resulting in a lower calving rate and milk production. It is concluded that an improvement of veterinary facilities will have a very limited effect.

Introduction of a sorghum-rice intercropping system, that prevents grain production from dropping to low levels under conditions of high rainfall, seems to be an interesting possibility to increase the resilience of the system, as long as the situation does not get too bad (figs. 37 and 38). An important advantage of such a system is, that it does not require a continuous input from outside. Thus it is not affected by a cessation of facilities provided by a project or by the government.

The results of an experiment, whereby all facilities are disrupted for some time (including the import of grain) and that allows a resettlement of the population after the situation has improved, suggest that a stable situation can be reached with a population between 16,000 and 20,000 (fig. 43), that has approximately the same age structure as in 1979.

Considering the above mentioned possibilities for interventions in the area, one may arrive at the conclusion, that interventions that seem at first recommendable, may after all have effects, that should at least give reasons for reconsideration.

8.3. Applicability of the approach

What can be concluded about the usefulness of this type of modelling?
In the first two chapters, the following objectives concerning the applicability of the approach were stated:

- the method would contribute to a better understanding of the dynamics of rural development;
- the method would facilitate an interdisciplinary approach to the analysis and planning of rural development;
- the method would be applicable in situations where an extensive data-base is lacking.

As shown above, the paucity of data and the lack of knowledge about processes render it difficult to formulate reliable predictions about the way an area will develop. It is therefore correct to conclude, that such a model is not suitable to be used as a black box by planners, who are only interested in the input and the output. However, this does not mean, that modelling is only useful when a large data-base is available as well as sufficient knowledge regarding the elements and the processes, that are considered essential for the purpose of the study.

Very often decisions have to be made when information is lacking e.g. when starting a project in an area of which little, scientifically verified, knowledge is available, when preparing a survey to collect data or when designing research programmes that address the problems of a particular area. Modelling in such a stage can help to develop a consistent hypothesis of the situation on the basis of which meaningful research questions can be formulated and priorities be defined. For instance in the chapter on validation it was shown, that it was more important to acquire information about factors, that affect migration than about factors that directly pertain to the cattle. In other words this approach is helpful for analysis rather than for the formulation of precise and reliable predictions about the way an area will develop.

The emphasis some modelers put on the importance of data, may also be misleading: data are facts of the past and can therefore help to understand the past, but one may wonder to what extent they help to understand the future;

especially when a project is considered, whereby the interventions may change the development processes in a different direction! This means that at least attention should be given to possible sources of new developments, as shown in chapter 7, where immigration becomes important under conditions of a high relative consumption and availability of fertile land.

Another important reason to start already modelling in the analysis stage is to bring various disciplines together from the beginning onwards. It provides planners and researchers from various disciplines with an overall framework, allowing – but also forcing – them to pay attention to the interrelationships between the various disciplines. This helps avoiding that each discipline starts approaching the problem situation from their own disciplinary angle, to discover only later that these approaches are not compatible.

Besides that, the model can also be helpful to structure discussions about possible solutions for the problems and to become aware of the fact that some solutions, that seem promising at first sight, appear to be disastrous in the long run.

Another subject for discussion is the question as to what should be included in the model and what not. In a stable situation it may seem that changes in some variables do not affect the overall behaviour of the system, while, when the situation becomes unstable, small changes in these variables may be able to bring the situation from stability into a downward spiral. System Dynamics makes it easy to experiment with the model and so detecting possible sources of instability.

Finally a point of criticism and caution should be raised. Developing models of problem situations is a very exciting and rewarding job. It provides the modeler with new and unexpected insights. However, although the idea to model a problem situation may be inspired by a genuine sympathy with those who have to face the problems, the modeler may easily be carried away by his work behind the computer and so detaching him more and more from the real situation. This means that the modeler and the users of the model should always be aware of the fact, that the model is just a subjective representation of reality and one should always remain very critical about the results of models!

In order to render the model as useful as possible, it is necessary on the one hand to develop a model in continuous interaction with the target group and on the other hand to avoid formulating decisions exclusively on the basis of the model. The model should rather be considered as a helpful tool in understanding the problem situation. It should, however, be realized that there will be many factors, that are not included in the model, but could nevertheless play an important role in the decision. It is therefore important that methods be developed that facilitate interaction between modelers and target group and so enabling a more participatory approach.

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