SIMULATION AS A TOOL FOR PLANNING OF RURAL DEVELOPMENT PROGRAMMES
A case in Southern Sudan

Tjark Struif Bontkes
Agricultural University, Wageningen
The Netherlands

ABSTRACT

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 analyze, plan and implement their programmes separately.
This paper presents an example of how simulation modeling can be helpful for interdisciplinary analysis of rural areas in the Third World. The analysis of the Bor District, an area 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 the population, the foodconsumption, the agricultural production and the livestock production of the area.
Due to lack of data, a common problem in remote areas in 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 improvement of health services, veterinary services, the availability of water and schools, employment opportunity and the quantity of imported food, and of the introduction of improved agricultural methods.
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 unimportant in periods of stability, appear to become important when the system becomes unstable.

1. INTRODUCTION

When considering the results of the efforts in rural development in the Third World over the past 25 years, one may reach the conclusion that substantial progress has been achieved in certain areas, e.g. a tremendous increase of the total food production. Nevertheless one cannot escape the conclusion, 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. Even projects, designed to improve the situation of the poor, were often not effective due to a lack of understanding of the complex of factors that are involved (Saeed, 1986).
One of the causes of this problem is that rural development programmes are often based on the contribution of a limited number of specialists, who view the problems from their own disciplinary angle. As these specialists are not able to grasp the problem situation 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 total problem situation.
This problem has been recognized since many years and though efforts have been undertaken to develop approaches to overcome these difficulties (e.g. integrated rural development and farming systems research), little progress has been made so far.
In this paper, the author attempts to show how the construction of a System

Dynamics model can help to better understand the problem situation of a region and the possible effects of various interventions.
The region that has been selected for this purpose is the Bor District, an area in Southern Sudan, where the author has been working as an agronomist from 1979 to 1983.

2. A BRIEF DESCRIPTION OF THE BOR DISTRICT

In this paragraph a description of the problem situation is given. A structural representation of the situation, consisting of the underlined words, is presented in fig. 1.
The area is situated on the eastern bank of the Nile, at a latitude of app. 6° NL. The rainy season lasts from April till October with an average annual rainfall of 900 mm, but varying between 600 and 1200 mm.
The landscape can be characterized as flat with heavy, impermeable clay soils. This causes on the one hand flooding in years with high rainfall and on the other hand severe drought-effects in dry periods as the soil does not absorb much moisture. This means that sorghum production is seriously affected in dry years as well as in wet years.
The population of the area (Dinka) are semi-nomads. Their life is primarily based on self-subsistence: the products of agriculture and livestock are almost totally consumed by the local population and there is little trade. An important cause of this is the isolated position of the area: there are no all-weather roads and the Nile-steamer is irregular.
Facilities in the area are very scanty: there are a few primary schools (education), but it is difficult to motivate teachers to work in this area, because of the low level of facilities: there are no markets, shops, watersupply points or medical facilities nor an agricultural extension service or veterinary services. This means, that the population has to spend much time to obtain goods, medical care and water. Lack of water at the end of the dry season prevents the farmers from timely preparing their fields.
Periodical food shortages and diseases seriously affect the health of the population, causing a high mortality rate and reducing the labour capacity. The population lives mainly on sorghum and milk. In bad years food is shared among the population, but when the available food is less than the required quantity (a low relative consumption), cattle is sold in Bor town to be able to purchase grain, which is imported from Northern Sudan by Nile steamer. However, sometimes these imported quantities (market grain) are even not sufficient to feed the population, especially as the population of Bor town, that entirely depends on imported food, increases very rapidly.
Since a number of years young people, who finished primary school, start migrating to Bor town and other urban areas. Migration is further enhanced by an increasing employment opportunity. This changes the age structure of the population and causes a decrease of labourcapacity and consequently a drop in the area cultivated. Although there is no immigration, it is assumed that under certain conditions immigration may take place: when food production largely exceeds the food requirement of the rural population. In that case the farmers will start selling their surplus production in order to increase their herd size.
Although all households produce livestock and crops, these activities are quite separated. Cattle is herded by young people in large herds while the married people produce sorghum.
Cattle are kept for milkproduction but provide meat as well. They play an important role in the social and cultural life of the Dinka. The population of the area is very reluctant to sell their cattle, unless they are forced to do so by lack of food. The milkproduction is low and the death rate high due to a limited availability of good quality grass (available feed) during part of the year and due to various diseases.
Due to the high deathrate the herdsize remained stable over the past 25 years.

Crops are produced in a shifting cultivation system. As the soil is relatively fertile, it is possible to continue to grow crops on the same plot for approximately 10 years. As long as the population density remains low, the area can sustain shifting cultivation; however with an increasing population density the cultivated area may rise above a critical level, which would cause the soilfertility to decline.

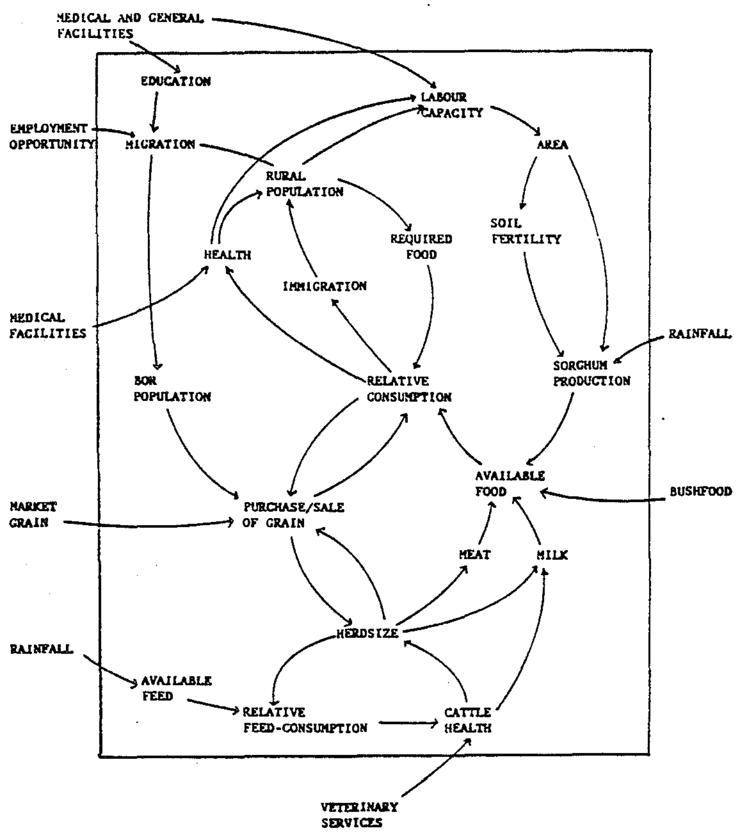

Fig.1. Causal diagram, representing the general structure of the system.

This study has been undertaken with the objective to identify interventions that
- improve the health of the rural population, particularly in terms of occurences of famine;
- stabilize the population of the rural area, in order to avoid an urbanization rate, that exceeds the absorption capacity of these towns.

These objectives should be achieved under the following conditions:
- the herdsize should remain stable in order to avoid either overgrazing due to an overpopulation of cattle or a desintegration of the socio-economic structure because of a decrease of the herdsize to such an extent, that the system of bridewealth cannot be maintained anymore.
- the cultivated area should not exceed the critical size, beyond which the average level of soilfertility will decline;
- 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 costs itself.

The following assumptions have been made:
- the conditions of the main roads will remain poor as 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 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 clean drinking water, improved local roads, good quality school buildings.
- Improvement of medical facilities: better trained staff in the rural health centers, mass immunisation 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 and that they can only be effective if accompanied by a proper supply of clean drinking water.
- Improvement of veterinary facilities, such as vaccination campaigns against rinderpest and Contagious Bovine Pleuro-Pneumonia (CBPP) and control of parasitic worms (Howell, et al., 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, maintaining 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 covers the period from 1979 to 2000

3. THE MODEL

The model has been divided into four submodels: a population submodel, a food consumption submodel, a sorghum production submodel and an animal production submodel.

In this paper only a qualitative overview of these submodels will be presented (for a more detailed theoretical and quantitative background, see Struif Bontkes, 1990).

the population submodel

Figure 2 shows a diagram giving a simplified representation of most important relationships within the population submodel. The population has been divided according to age and gender.

The population size is directly determined by the number of births, the number of deaths and the number of persons that migrate. The number of births depends on the number of fertile females and their fertility, which is affected by age and the availability of food.

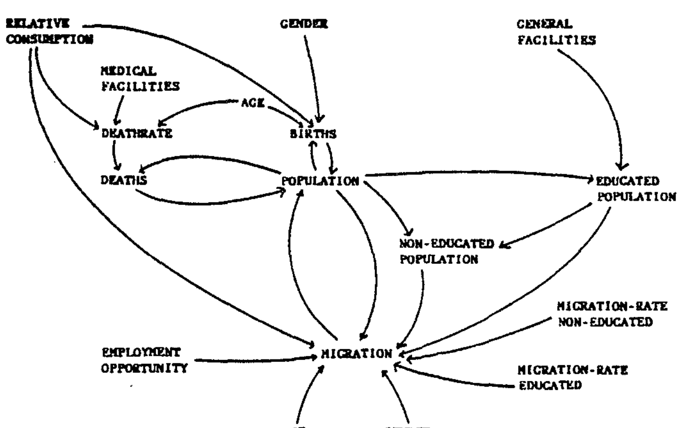

Fig.2. A simplified causal diagram of the population submodel.

The number of deaths depends on an age-specific deathrate, the availability of food and (for children) on the level of medical facilities.
Migration is determined on the one hand by the level of employment opportunity outside the rural area and on the other hand by the level of education and occurrence of famine in the area (relative consumption). The propensity to migrate differs per ageclass and gender, except in case of famine. The level of education depends on the availability of schools and teachers (general facilities) and on age and gender (the percentage of boys that go to school is higher than that of girls).

the foodconsumption submodel
The total quantity of food (expressed in units of energy) depends on the size and the age structure of the population. Under normal conditions the main sources of food are sorghum, meat from cattle that died, milk and minor sources of food, such as maize, cowpea, bush meat etc. Some of the sorghum, that is consumed, is received from relatives in town. When the foodsupply from these sources will fall short of the requirement a certain strategy to cope with this problem is followed. The assumption as to how the Dinka will cope with famine is based on own observations and on findings in other areas of Sudan (Evans-Pritchard, 1940; Corbett, 1988). At first the population will sell cattle in order to be able to purchase grain, that is imported from Northern Sudan. For this purpose they will first sell their less productive cattle: male cattle and old, dry cows. It is thereby assumed that the population of Bor town will first satisfy its own requirement, before allowing the rural population to purchase food. When there is no sufficient grain at the market to satisfy the requirement, the exchange rate between cattle and grain will deteriorate, so that more heads of cattle will have to be sold to acquire the same quantity of grain (Sen,1981; Cutler,1984 and 1986). When relative consumption drops to 95 % they will start killing their less productive cattle in an attempt to maintain their energy intake at this level. When relative consumption gets below 90 % they will also slaughter their productive animals (emergency killing) and start migrating to other areas.

the sorghum production submodel
The total production of sorghum in the area depends on the area cultivated, the soilfertility and the rainfall. The area cultivated depends on the availability of labour and the labour productivity (ILACO, 1981). The labour productivity is influenced by the availability of food per worker (FAO, 1987) and by the access to facilities, such as medical care and drinking water.
It is assumed, that the maximum production per ha under the existing conditions is 1250 kg per year. Whether this production will be attained depends on the rainfall and the soilfertility. When the rainfall is low, the crop will suffer from drought and when it is high the crop suffers from flooding. As the population is practising shifting cultivation, it is assumed that the average soilfertility remains at the same level as long as the land under cultivation does not exceed a certain area; this area is, quite arbitrarily, put at 8000 ha.

the animal production submodel
The herdsize is determined by the number of calves that are born, the cattle that die, are sold/purchased or are killed (fig. 3). The number of calves that are born depends on the number of mature females and the availability of feed per animal. The quantity of feed per animal is determined by rainfall and number of animals (Breman and de Ridder, 1990). The number of animals, that die, is influenced by the feedsupply and the incidence of animal diseases. The deathrate of male calves is furthermore affected by the quantity of milk they are allowed to drink: when the people are 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, starting with the relatively less productive cattle, whereby aspects of the Dinka culture play an important role, e.g. some of the castrated male animals are kept as "songbulls", which have a special relationship with a particular person (ILACO, 1982).
Milkproduction depends on the number of calves that are born and on the feed-supply (Breman and de Ridder, 1990).

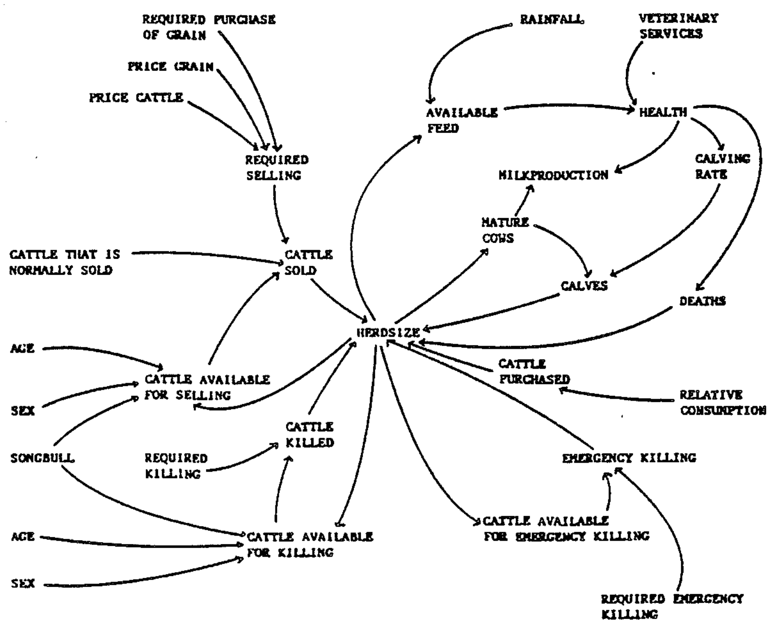

Fig.3. A simplified causal diagram of the animal husbandry submodel

4. VALIDITY OF THE MODEL
Various ways of model validation have been considered, such as comparing the results of the model with historical data, checking whether the model shows a plausible behaviour under standard conditions and checking the appropriateness of the parameter values.
A major problem in the construction of this model was the paucity of data: most of the empirical data have been used to construct the model, so that virtually no data remained for validation. As most of the empirical data pertain to a limited period (one to three years), it was impossible to obtain a reliable estimation of the parameters. Some of the parameters were therefore derived from studies in other (but similar) areas and some were the result of informed guesswork. In order to determine to what extent errors of judgement will invalidate the model a number of sensitivity analyses have been carried out.
the standard run
To judge the plausibility of the model, the behaviour of a number of key variables in the standard run have been examined: size of population, relative consumption and herdsize. In this standard run no new interventions were considered, although some exogenous variables vary: rainfall, the incidence of epizootic diseases and the quantity of grain that is annually imported. It is assumed, that in 1983 and 1993 an outbreak of rinderpest occurs and that the quantity of imported grain increases at a rate of 3 % per year.
According to the standard run the population will decrease from 44000 in 1979 to 35000 in 2000. (fig.4). This is caused by a high level of migration and a declining relative consumption (fig.5).

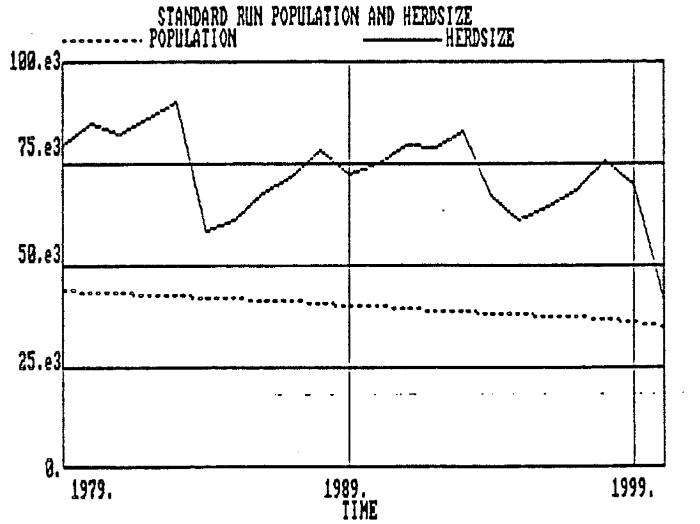

Fig.4. The development of the population and herdsize in the standard run.

There are two major causes for the high level of migration. One is the employment opportunity outside the area and the other is the increasing number of school-leavers: almost all school-leavers try to find a job outside the area and the non-educated young people are attracted by the towns as well, though to a lesser extent.
The scarcity of food is caused by several factors:

- due to the migration of young people, who significantly contribute to the production of sorghum, the production decreases more rapidly than the food requirement of the population;
- the rapid growth of Bor town requires every year a larger share of the imported food and so reducing the availability of imported grain for the rural population in years of a crop failure.

Initially the herdsize tends to increase as no epizootics occur. However in times of epizootics (1983 and 1993) the herdsize is seriously affected (fig.4). After each epizootic, the herd is able to quickly recover as the quantity of feed that is available per animal increases and the readiness of the population to sell their animals decreases in order to enhance a quick recovery of the

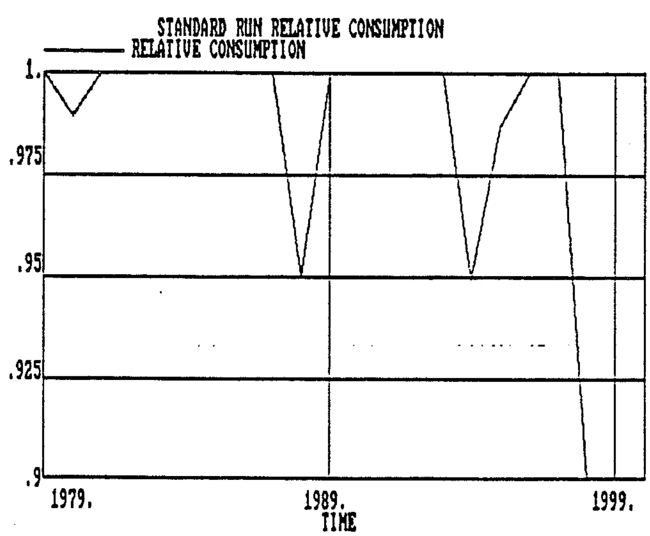

Fig.5. The development of the relative consumption in the standard run.

herd. At the end of the century, the availability of food for the population has been reduced to such an extent, that the population is forced to sell and kill large numbers of animals to avoid famine, resulting in a quick decline of the herdsize.

sensitivity

Based on sensitivity analyses, three categories of parameters were identified:

a. parameters that do not significantly alter the behaviour of the model, when their values are changed;
b. parameters, that always significantly alter the behaviour of the model when their values are changed.
c. parameters, that only significantly alter the behaviour of model, when their values are changed, in case of a structural shortage of imported grain;

The parameters that belong to the first category mostly pertain to the animal production. As an example the effect of feedsupply for the cattle on calving rate is taken. In one case the effect of variations of the supply of feed is assumed to be weak and in the other case to be strong. Figure 6 shows that these variations hardly affect the herdsize.

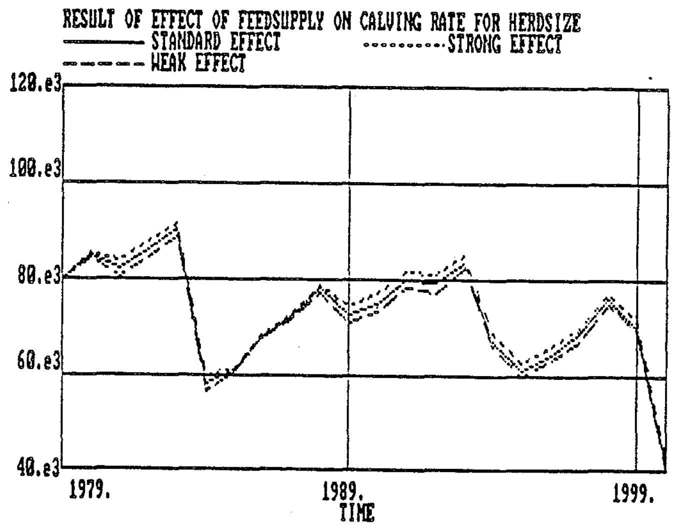

Fig.6. The effects of various strenghts of relationship between feed supply and calving rate on herdsize.

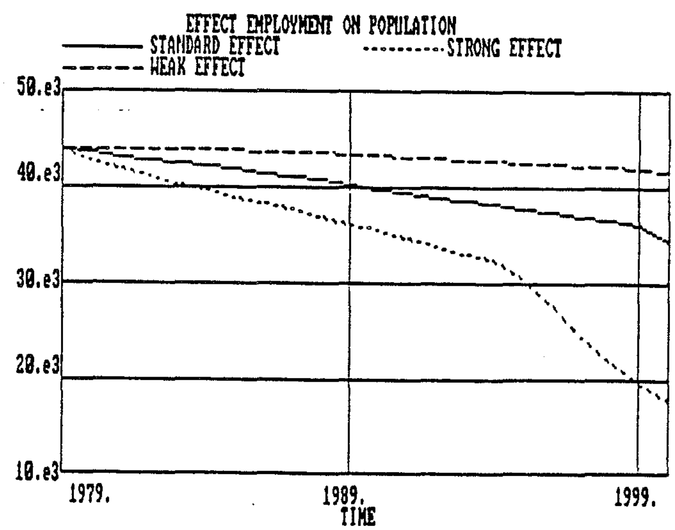

Fig.7. The impact of various levels the employment opportunity coefficient on the size of the population.

Parameters belonging to the second category are a.o. those determining the effect of employment opportunity and of the availability of schools on the propensity to migrate and the effect of the maximum yield of sorghum (under local conditions) and the effect of the rainfall on sorghum yield. Figure 7 shows that variations of the assumed effects of employment opportunity on migration (the employment opportunity coefficient) have a strong impact on population size.

Finally there is a large number of parameters to which the model becomes only sensitive under unstable conditions. Apparently in such circumstances small changes are sufficient to tip the balance from one side to the other, e.g. the effect of the consumption coefficient, representing the relationship between relative consumption and labour productivity, on population development (fig.8).

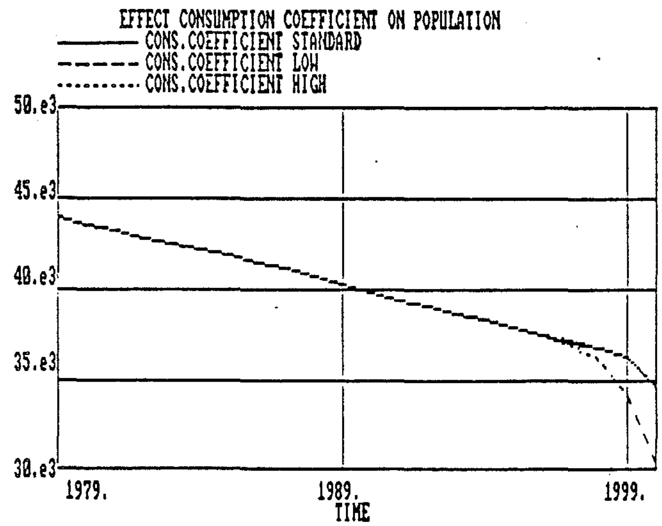

Fig.8 The effect of various consumption coefficients on population size.

5. MODEL EXPERIMENTS

In order to obtain insight in effects of possible interventions on a number of key variables, model experiments have been carried out.
The interventions that are considered are:

1. the improvement of medical and general facilities; by general facilities are meant roads, transport, schools, shops and water supply. These improvements can be stepwise introduced. It is thereby assumed that an improvement of medical facilities will always be accompanied by an improvement of general facilities. It is also possible that the existing facilities will be removed.
2. improvement of the employment opportunity outside the area;
3. improvement of the veterinary facilities;
4. introduction of intercropping.

Figure 9 shows the effect of the improvement of medical and general facilities on population size. The levels of these facilities are represented by coefficients: the medical facilities increase with a declining medical facilities coefficient and the general facilities increase with an increasing general facilities coefficient.
Improvement of these facilities increases health and labour productivity, resulting in a population increase. However, due to the improved facilities, more children will go to school and when these children leave school, the number of migrants to Bor town will increase. This will stop the population increase and as these migrants consist of persons that otherwise would signi-

ficantly contribute to the production of sorghum. the proportion of productive versus unproductive people declines. This phenomenon plus the rapid increase of the population of Bor town will reduce the relative consumption in the rural area. People are forced to sell and later kill their cattle and start migrating, so that by the end of the century no cattle and very few people will be left.

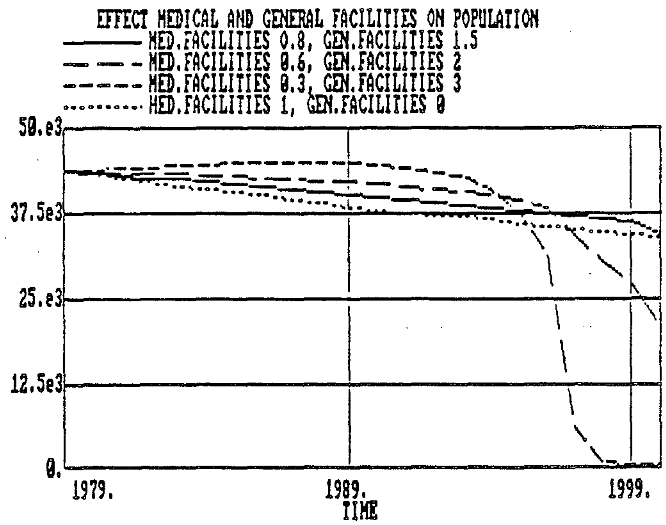

Fig.9. The effects of various levels of medical and other facilities on population.

When the existing facilities will be removed, the population will initially be lower, but as there will be no schools, the number of school leavers will decrease and after some time the number of migrants as well. Under these conditions a famine is avoided at the end of the century.
It should however be noted, that if the quantity of imported grain remains sufficient up to the year 2000, the population development will be different: in that case the population growth will be the highest under conditions of the best medical and general facilities (fig.10).

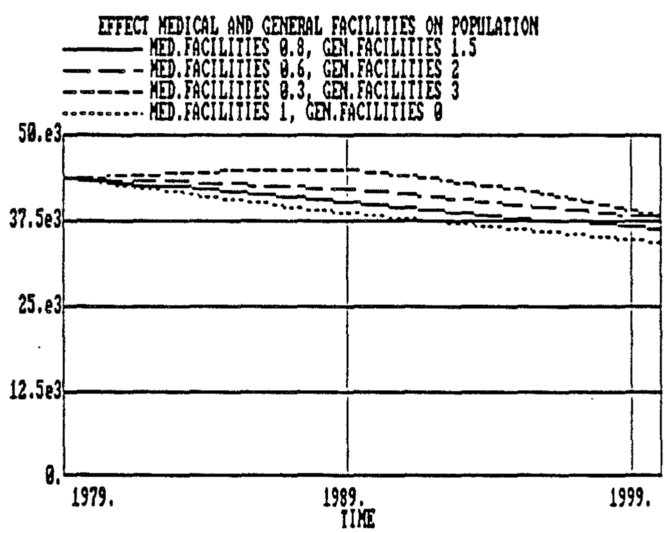

Fig.10. The effects of various levels of medical and other facilities on population size, when there is sufficient grain in the market.

A similar result is obtained when the employment opportunity outside the rural area changes: a higher employment opportunity attracts persons that contribute most to the production of sorghum, resulting in a lower relative consumption and in a lower population. When there would be no opportunity for employment at all, migration would stop and population would even increase.

Improvement of the veterinary facilities protects the herd from epizootics, so that the fluctuation of the herdsize will be smaller (fig.11), although at the end of the century the herdsize will be drastically reduced due to the shortage of food for human consumption.

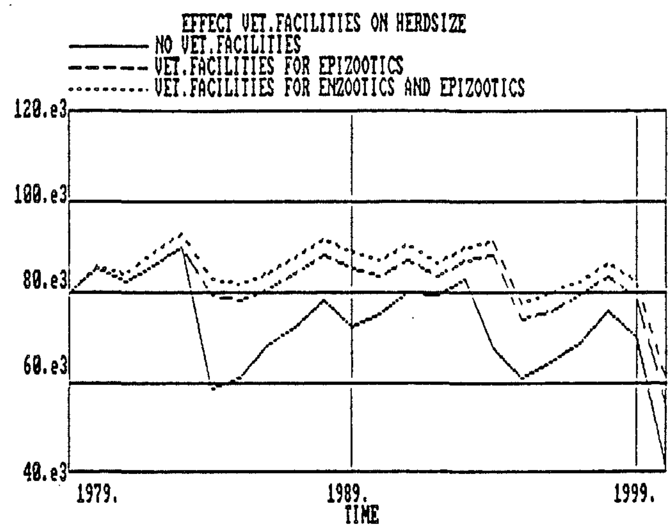

Fig.11. The effects of improvements of the level of veterinary facilities on herdsize.

At first sight it is surprising to see that the population will be lower when veterinary facilities are introduced; this can be explained however by the fact that without these facilities the death rate of the cattle is higher, so that more meat will be available to the rural population (fig.12).

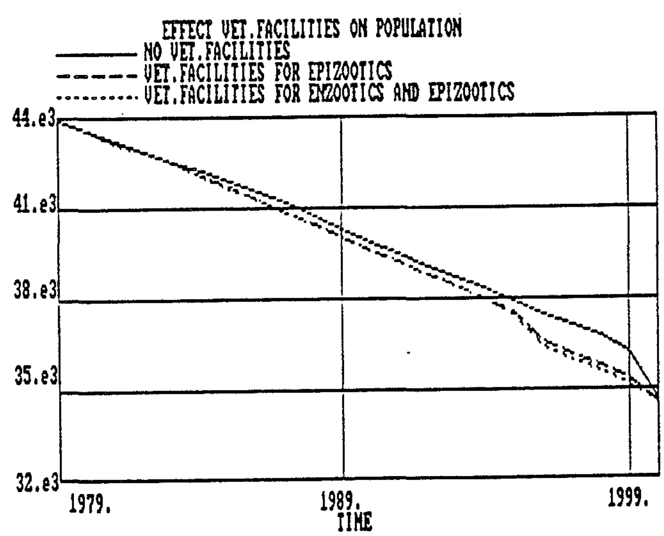

Fig.12. Effects of improvements of the level of veterinary facilities on population.

In figure 13 the effect of introducing intercropping of sorghum and rice on population size are compared: the standard situation with and without intercropping and the situation in which there is no annual increase of the imported food. It can be concluded from this figure that, although introduction of intercropping cannot prevent a disaster when market supply of grain does not increase, it does slow down the effect.

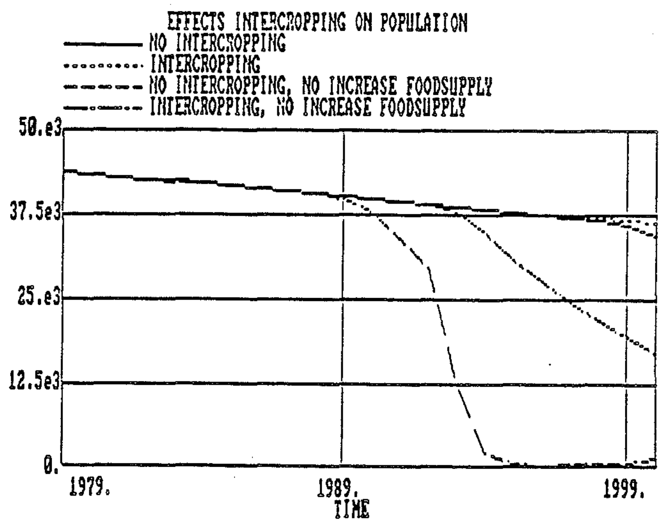

Fig.13. Effects of intercropping on population with and without a good food supply.

In the last simulation, the time horizon has been extended till 2050. Although it is not assumed that this will provide a realistic picture, this thought-experiment may contribute to our understanding of the system. It appears that, directly after the turn of the century, population and herdsize drop to very low levels (fig.14), whereafter the herdsize increases to a level of around 95,000 and the population to a level between 15000 and 17000.

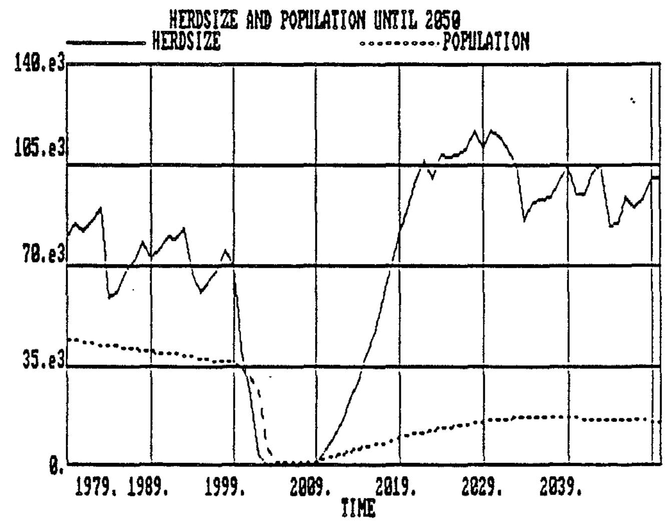

Fig.14. The development of the population and the herdsize when the time horizon is extended till 2050

This behaviour can be explained as follows: towards the end of the century the quantity of food that is available for the population living in the rural area declines due to migration of young people and due to the declining share of imported grain that is available for the population outside Bor town. However, when most of the people have left the area, the quantity of food that is available per person, will increase to such an extent that immigrants will be attracted to the almost empty area. As these immigrants are young people, sorghum production will greatly exceed the quantity that is required for survival, so that sorghum will be sold in order to build up a new herd. Moreover the immigrants are assumed to bring a few heads of cattle when they settle in the area. Therefore the population and the herdsize increase again, approaching a more or less stable situation, in which they are fully independent of the imported grain.

6. DISCUSSION

One may wonder what the use is of a model, that seems to evoke more questions than to produce answers: lack of data and knowledge about processes render it difficult to formulate reliable predictions about the way this area will develop and the effects of interventions. 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 modeling is only useful, when a large data base and sufficient knowledge regarding the elements and the processes, that are considered essential for the purpose of the study, are available. Very often decisions have to be taken, when information is lacking e.g. when starting a project in an area of which little scientifically based knowledge is available, when preparing a survey to collect data or when designing research programmes, that address the problems of a particular area. Modeling in such a stage can help to develop a consistent hypothesis of the situation on the basis of which meaningfull research questions can be formulated and priorities be defined. For instance it was shown in the chapter on validation, that it was more important to acquire information about factors that affect migration than about factors that directly pertain to cattle. In other words this approach is helpful for analysis rather than for the formulation of precise and reliable predictions.

Nevertheless also planners can benefit, e.g. when discussing possible consequences of certain interventions: some interventions that at first seem to improve the situation may at the end appear to create problems. This is illustrated in this paper by the effects of improving medical and general facilities: while this will initially cause an increase of the population in the rural areas, later on the size of the population will be rapidly reduced to almost nil.

The importance, some modelers attach to the availability of data may sometimes 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. A clear example is provided by this model: based on the existing situation in 1979 one may come to the conclusion that immigration into the area and selling grain do not occur; however, when these phenomena are introduced in the model they can make a large difference in periods of disastrous developments.

Finally a point of caution should be raised. Developing models of a problem situation can be a very exciting and rewarding job, as it often 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 the problems of those who have to face these problems in reality, the modeler may easily be carried away by his work at the computer and so detaching himself more and more from reality. 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 should attempt to build and validate these models in a continuous interaction with the targetgroup!

REFERENCES

Breman, H. et N. de Ridder (eds). 1990. Manuel sur le pâturage des pays saheliens (en prep.). Paris: Karthala.

Corbett, J. 1988. Famine and household coping strategies. World Development 16(9)1988 pp. 1099-1112.

Cutler, P. 1984. Famine forecasting: prices and peasant behaviour in Northern Ethiopia. Disasters 8(1)1984 pp.48-56

Cutler, P. 1986. The response to drought of beja refugees in Sudan. Disasters 10(3)1986 pp.181-188

Evans-Pritchard, E.E. 1940. The Nuer. Oxford: At the Clarendon Press.

FAO. 1986. Manual for the application of the FAO/WHO/ONU energy requirements recommendations (draft). Rome: FAO

Howell, P., M. Lock and S. Cobb (Eds.). 1988. The Jonglei Canal, impact and opportunity. Cambridge: Cambridge University Press.

ILACO. 1982. Bor Dinka: the social and economic setting.Pengko Pilot Project. Arhhem, The Netherlands: ILACO.

Saeed, K. 1985. Poverty, Hunger and Development Policy. in D.F. Andersen, N.B. Forrester and M.E. Warkentin (eds.): Proceedings of the 1985 International Conference of the Systems Dynamic Society, Keystone, Colorado, U.S.A., pp. 728-743.

Sen, A. 1981. Poverty and Famines. Oxford: Clarendon Press.

Struif Bontkes, T.E. 1986. Sorghum-rice intercropping, a security system for the poorly drained soils of Southern Sudan. Netherlands Journal of Agricultural Science 34(1986) 193-198

Struif Bontkes, T.E. 1990. The use of simulation for rural analysis, (mimeo). Wageningen, Agricultural University.