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DEVELOPING THE SAHEL: AN ANALYSIS OF THE RECOMMENDATIONS OF THREE INTERNATIONAL ORGANIZATIONS

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October 23, 1976

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DEVELOPING THE SAHEL: AN ANALYSIS OF THE RECOMMENDATIONS OF THREE INTERNATIONAL ORGANIZATIONS

INTRODUCTION

"These structures are normally interrelated in patterns and paths so complex and so enormous no one person can understand more than a small part of them in his lifetime. The overall name of these interrelated structures, the genus of which the hierarchy of containment and structure of causation are just species, is a system."
Robert Pirsig, Zen and the Art of Motorcycle Maintenance

Many national and international organizations have analyzed the long-term economic development potential of the Sahelian countries.[1] Prominent among these organizations are the Food and Agricultural Organization of the UN (FAO), the French consulting groups Societe d'Etudes pour le Developpement Economique et Social (SEDES) and Societe Centrale pour l'Equipement du Territoire/International (SCET), and the International Bank for Reconstruction and Development (IBRD).[2]

Each of these organizations have recommended changes to certain economic, social, and ecological aspects of the Sahel. Their recommendations, which I call their goals, involve variables which vary in their aggregation and which also involve different time horizons. Their general goal is to increase food production per capita to meet the increasing food demands of the region.

To achieve these goals, the organizations have advocated a multitude of actions or interventions, which I will call their policies. These policies also involve economic, social, and ecological variables which vary in aggregation and in time. Examples of such policies include loans, grants, training and commodity aid. Policies may also involve changes or additions to traditional economic and social relationships among the Sahelian people and to ecological relationships among the people, livestock, and the soil. Examples of such policies include those which affect agricultural prices, agricultural extension services, and range management practices.

To link these goal and policy variables, the organizations have expressed an understanding of a complex set of intervening relationships among the dominant

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[1] Sahel means, unless otherwise stated, the six countries: Mali, Mauritania, Chad, Upper Volta, Senegal and Niger.

[2] The respective reports of these organizations are: FAO, Etude Prospective pour le Developpement Agricole des Pays de la Zone Sahelieene, Rome, 1976; SEDES/SCET, Attempt to Outline an Anti-Drought Strategy in the French-Speaking Sahelian Countries of Western Africa, Summary of Main Report, October 1975 and Possible Strategies for Controlling Drought in the West African Sahel: A Survey, Summary of Consolidated Report, January 1976; IBRD, World Bank Approach to Economic Development of Sahel, March 1975.

economic, technical, and social variables. The organizations usually describe this set of relationships, which I call a system, in the prose of their report, and sometimes in mathematical equations. Such representations of a system are called models. There is only one system, but there can be many different descriptions, or models, of that system depending on the area of interest and level of understanding.

Many development policies are expert judgements derived from one or more expert's understanding of the system, which I will call their mental models. Other development policies are derived from formal mathematical models of the system.

A major reason that mathematical models are constructed is that proposed policies may be tested relatively easily before they are actually implemented. This is difficult to do with a mental model since the primary methods are conversations between experts or exchanges of monographs.

Another major reason for constructing mathematical models is that they generally can contain more variables and relationships between these variables than can a mental model. In the absence of an overall mathematical model of a system, people who institute policies usually rely upon many experts who must collaborate in a variety of informal ways.

Whether the models are mathematical or judgemental, they generally portray a system as it is now, or portray it as it is planned to be. The former I call a descriptive model, the latter I call a normative model. A difficulty with a normative model, in the absence of a descriptive model, is that it is difficult to judge the normative model's validity or suggest the actions necessary to pass from the present system to the normative one.

This paper uses a uniform method of analysis to describe each international organization's representations, or models, of the Sahel. These models are described in annex A. The following sections present the results of an analysis of those models. First, the Sahel development goals of each organization are presented. Then the different development strategies are analyzed and compared. An alternative approach to determining development policies for the Sahel is discussed at the end of this paper.

A note of caution. I have tried to faithfully represent each of the descriptions of the Sahelian system. I may have made errors of omission or misinterpretation. Also, the authors may have omitted describing many relationships that they know exist. A primary purpose of this paper is to provide a vehicle for discussion of alternative policy strategies using a a common method of presentation and analysis.

GOALS FOR THE SAHEL

The development goals for the Sahel of the various organizations are basically the same: increasing that region's contribution to their total food consumption per capita. The different goal statements are described in the following sections, summarized in table 1, and then compared to the general goals of the U.S. Agency for International Development (AID).

The Goal Statements

FAO

The FAO goal is to devise policies to increase regional production of basic food commodities by 1990 to meet projected regional demand.

To calculate this demand, FAO divides the Sahel population by country.[3] FAO then calculates 1990 demand for food based upon each country's projected population, projected private consumption expenditure (PCE) per capita, and the historical relationship between food consumption per capita and PCE per capita for each country, called the PCE elasticities of demand.

SEDES/SCET

The SEDES/SCET goal is to devise policies to increase regional production of cereals, meat, and other food commodities by 2000 to meet projected regional demand and provide buffer storage capacity to meet expected grain production shortfalls in drought years.

To calculate this demand, SEDES/SCET divides the Sahel population into 21 geographical regions. SEDES/SCET then calculated 2000 demand for food based on population growth and demand per capita in each region based on 3 different scenarios of migration and development policies.

IBRD

IBRD does not define specific goals for the Sahel.[4] Their general goal is to increase the ability of the region to meet the food demands of its populations. Additionally, an increase in income for the rural population is desired.

A Comparison With AID Goals

The general objectives for the Sahel which have been adopted by AID were developed at a donor conference sponsored by the Comite Inter-Etats pour la Lutte contre la Secheresse dans le Sahel (CILSS) in Bamako, Mali, March, 1974. They are:

1. The mitigation of consequences of future emergencies.

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[3] FAO includes The Gambia in its definition of the Sahel.

[4] IBRD excludes Senegal in its definition of the Sahel.

Table 1

SUMMARY OF GOALS FOR THE SAHEL

Organization	Variable To Be Changed	Goal	Area Affected	Time Horizon
Food and Agricultural Organization of the United Nations (FAO).	Production per capita of 14 major commodities.[1]	Regional production equals the demand for each commodity based on projected population and private consumption expenditures per capita.	Seven Sahel countries.[2]	1990
Societe d'Etudes pour le Developpement Economique et Social/ Societe Centrale pour l'Equipement du Territoire (SEDES/SCET).	Production per capita of grains and meat.	Regional production equals demand based on internal migration patterns, population growth, and projected consumption per capita.	Six Shael countries.[3]	1985 2000
International Bank for Reconstruction and Development (IBRD).	Food consumption per capita and income per capita.[4]	Production equals demand for food supplies based on basic nutrient requirements and population growth.[4]	Five Sahel countries.[5]	Not Specified

[1] These commodities are: wheat, paddy rice, coarse grain, tubers, raw sugar, pulsa, unshelled groundnuts, vegetable rice, cattle, sheep and goats, poultry, eggs, fish, and whole milk.
[2] The countries are: Mali, Mauritania, Chad, Upper Volta, Niger, Senegal and the Gambia.
[3] The countries are: Mali, Mauritania, Chad, Upper Volta, Niger and Senegal.
[4] Based on the author's interpretation since only general issues of social and economic development were discussed.
[5] The countries are: Mali, Mauritania, Chad, Upper Volta and Niger.

Sources: FAO, Perspective Study on Agricultural Development in the Sahelian Countries, 1975-1990; SEDES/SCET, Attempt to Outline An Antidrought Strategy in the French-Speaking Sahelian Countries; and IBRD, World Bank Approach to Economic Development of Sahel.

2. The attainment of self-sufficiency in food staples.

3. The acceleration of economic and social development with particular emphasis on the least developed countries. [5]

The first objective is addressed directly only by SEDES/SCET. They specifically include in their analysis the relationships between droughts of certain severity and their policies to increase food production. IBRD discusses the problems of drought. The FAO does not specifically include the effects of drought in their analysis.

The second objective is discussed by all organizations. Both FAO and SEDES/SCET have as goals the satisfying of regional food demand by regional food production. They differ in their definitions of demand. IBRD discusses the Sahel in the context of achieving food self-sufficiency without defining demand or supply.

The third objective is addressed only by the IBRD discussion of general economic development policies for the Sahel.

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5. United Nations Sahelian Office, An Approach to Recovery and Rehabilitation of the Sudano-Sahelian Region, New York, November, 1974, p 35.

DEVELOPMENT STRATEGIES FOR THE SAHEL

The strategies provided by the different organizations contrast in: (1) the comprehensiveness of their descriptions of the Sahel and their available policy options; (2) the ability to validate their different representations; and (3) the usefulness of their different approaches. These topics are discussed in the following sections.

Each Organization's View of the Sahel

Both the FAO and SEDES/SCET representations of the Sahel are more complex in terms of aggregation than the IBRD description. FAO has 20 potential combinations of area and rainfed crop farming techniques and 3 irrigated crop farming techniques in 7 countries. SEDES/SCET has 15 geographical regions for rainfed crop farming, 5 irrigated crop farming techniques in 3 river regions, and 2 zones for livestock in 3 regions. IBRD discusses only three regions.

However, the IBRD discussion is much more complex in the types of relationships included. They include explicit relationships between: (1) soil fertility and soil protection capita; (2) the population unemployed and workers required per land planted; (3) income and its various sources, especially remittances from migrant workers in coastal countries; (4) farmer income and cereal and export crop price; (5) cereal and export crop production and their respective prices; (6) foreign exchange earnings, foreign demand for export commodities, export prices, and development assistance in coastal countries; (7) available range and increasing Sahelian population; and (8) migration and disparities between food consumption and income.

FAO and SEDES/SCET do not include any of the above relationships in their model. For instance, SEDES/SCET treats export crop production as only a function of the agricultural population. Both omit the effects of price on food supply and demand.

SECES/SCET and IBRD do include investment in buffer stock capacity for shortfalls in grain supply due to drought which is not included by FAO.

All three omit important relationships. For example:

1. Allocation of land between food crops and cash crops depends on such factors as relative prices, income requirements, risk, etc.[6]

2. Food consumption and import substitution of food are effected by the price of domestic cereals.[7]

3. Population growth rates are effected by food consumption per capita and development assistance to health services.[8]

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[6] Berg, Elliot, The Recent Economic Evolution of the Sahel, Center for Research on Economic Development, University of Michigan, June 1975, page 39.

[7] Ibid, page 102.

[8] AID, Development Assistance Program, 1976-1980, Volume 1, November 1975, page 154-160.

4. Animal offtake percent is a function of price, income requirements, risk, forage availability, etc.[9]

The Validity of Each View

A formal approach to validating a mathematical model is to (1) assign historical values to all variables not determined by other model variables, called exogenous variables; (2) use a computer to create historical values for the variables determined by the model, called endogenous variables (this is simulating the model); and (3) check whether the simulated values of the endogenous variables are approximately equal to their actual values. A judgemental approach, available for mathematical and nonmathematical models, is to have experts review the model to determine whether all the individual relationships seem valid, whether important relationships are missing, etc.

It is impossible at this time to make a formal evaluation of whether the three descriptions accurately represent the Sahel socio-economic system.

The FAO and SEDES/SCET models are mathematical, normative models. They do not represent an existing system and cannot be simulated over a historical period. The fact that these models are normative causes an additional problem. The authors do not provide descriptive models, and, thus, can give no indication how the present system will react to their suggested changes on the policies necessary to achieve the normative state. For instance, in the SEDES/SCET model, what motivates a pastoralist to continue his nomad existence? What could cause him to change his traditional customs and move to stock support center? In the FAO model, what causes farmers to use their traditional farming techniques? What could cause them to use one of the five techniques proposed?

The IBRD representation is not mathematical but a prose description of several expert's view of the Sahel. Thus, their view cannot be formally tested.

A judgemental evaluation of the three views can only be made by qualified experts examining the models presented in annex A. However, based on the discussion in the preceeding section, all representations are missing important relationships.

Usefulness of the Different Approaches

The usefulness of the different approaches to analyzing the Sahel can be judged by several standards. Three primary standards are:

1. The analysis of the system must be judged to be an accurate representation of the Sahel. As noted previously, a comparison between the alternate descriptions causes doubt as to whether any of the three representations are comprehensive descriptions of the Sahel.

2. The analysis should allow combinations of policy options to be tested. It seems that the FAO model can more easily test its policy options

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[9] Ibid, pages 40-51.

than can the SEDES/SCET model. The IBRD approach does not easily allow policy tests.

3. It should be easy in each analysis to add or change relationships to test their effect on recommend policy. It would be difficult to do with the FAO or SEDES/SCET models. This is particularly so with the inclusion of relationships that represent, for instance, economic or scientific behavior. The IBRD approach does not easily allow policy tests.

AN APPROACH TO OBTAIN IMPROVED DEVELOPMENT STRATEGIES

The preceeding analysis indicates that the representations of the Sahel for use by policy makers can be significantly improved. The FAO and SEDES/SCET models do not give us a description of the Sahel system as it exists now; do not allow formal validation of their structure; and do not allow the incorporation of many important relationships, such as price behavior. The IBRD description does not allow formal validation of its structure and does not allow tests to determine the effects of different policies.

There is a need for a technique which would combine the complexity of the IBRD description with the ability of the FAO model to test policies. Specifically:

1. For FAO and SEDES/SCET, they need a technique which allows them to construct a descriptive model of the Sahel.

2. For IBRD, they need a technique which allows them to construct an analytic model.

3. For all three groups, they need a technique which allows them to include all of the important social, economic, and technical relationships present in the Sahel that they are now missing.

One approach would be the time-honored judgemental analysis of one or more experts on the Sahel. However, as indicated by the IBRD description shown in annex A, the system can be very complex. In fact, most of these interrelationships involve delayed nonlinear feedback effects which are time variant.[10] It is possible for experts to understand portions of the system fairly well., But to put more than a few of these relationships together in an internally consistent manner without a formal technique is almost impossible. Feedback systems exhibit behavior that cannot be anticipated by studying isolated portions of the system. The difficulty multiplies when considerations of policy changes and revisions in data are needed.

The approach being used by the author to develop a model of agricultural supply and demand for Senegal allows the construction of complex formal models from both available data and the knowledge of experts. This approach combines a diagramming technique, which was used to present the different representations of the Sahel in annex A, with a simulation technique, known as Systems Dynamics.[11]

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[10] A delayed effect may be due to a physical delay, i.e., grain in transit, or an information delay, i.e., a delay in communication of price change. A relationship between price and land planted is nonlinear if the percentage change in land planted that results from a change in price is a variable function of the value of the initial price. A feedback effect is when a change in a model variable causes changes in other model variables that eventually cause a change in the original variable. A time variant effect means, for example, that the change in land planted resultant from a change in price may vary depending on the time period.

[11] Forrester, Jay, Industrial Dynamics, Wright-Allen Press, 1972.

The causal influence diagram (CID) is used to portray complex systems in a simple manner. It is a way, other than through words, to describe a system.

Besides the advantage of being simple to understand, it can be used to compare different models of a common system that have been described in different ways. The essential features of the FAO, SEDES/SCET, and IBRD models are portrayed and compared with CIDs. This is despite the fact that the FAO and SEDES/SCET models are mathematical in nature, while the IBRD model is simply a prose description of the Sahel.

In addition to the use of a CID in portraying an existing model or description of a system, the CID can be used to construct an initial model. This may be done by an expert, or an analyst questioning experts and also consulting the literature. This technique is being used now for the agricultural model of Senegal.

Systems Dynamics provides a technique for progressing from a verbal or graphical description of a system to a mathematical representation which can be programmed and simulated on the computer. The Systems Dynamics technique can be shown through the following example. The computer language is discussed in annex C.

Examinimg the IBRD description which is summarized in Figure A-3 in annex A, one sees two types of relationships in the model. Some relationships are simply definitions, called accounting relationships. For instance, cereal production equals the product of land planted times yield. Other relationships represent human decisions or scientific relationships, called behavioral relationships. For instance, land planted depends on price.

It is the behavioral relationships in a model that are the most difficult to represent mathematically: the relationships are often controversial, the data may be scarce, etc. But, if experts feel, through direct experience with the system, that such relationships have an important effect on the system, they should be included in the model. The idea is to create the best mathematical representation of the system that is known at the time.

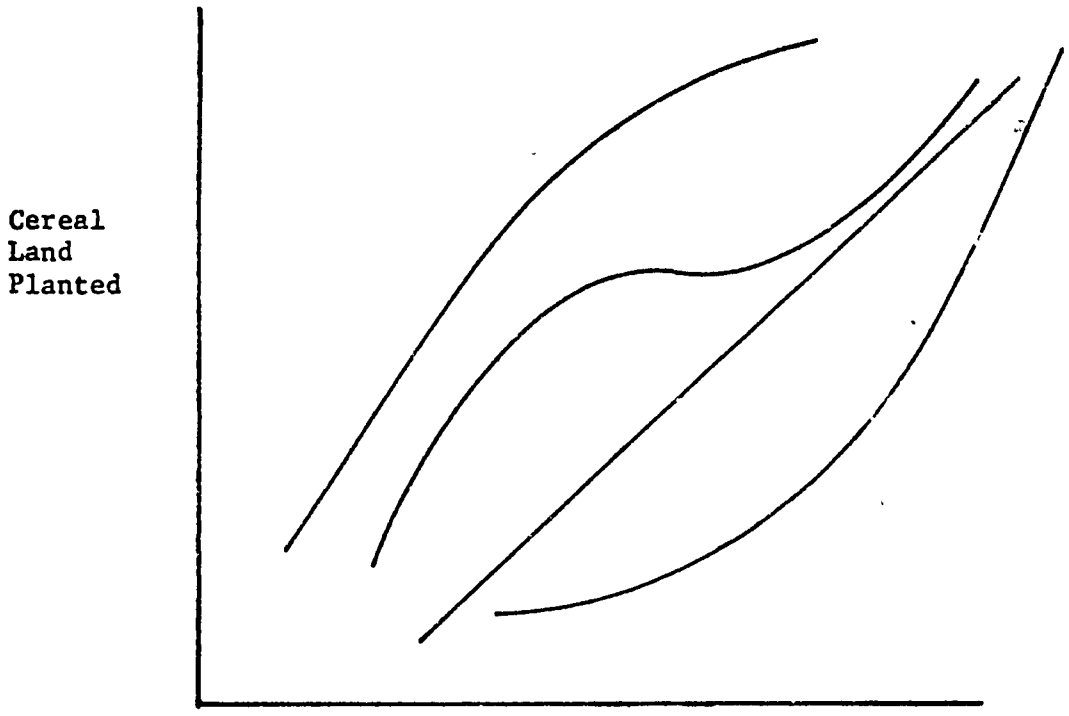
For example, the relationship between cereal land planted and cereal price to farmers shown in Figure A-3 may be open to question. The IBRD authors evidently believe the relationship has a positive slope, but they do not give a specific functional equation. There may be limited data, the data may be in error, and in any event the data probably represent a very small range of possible values. The relationship could take any of the forms shown in Figure 1.

It is possible to represent the relationship that conforms best to the expert's knowledge. The line can be represented with discrete pairs of points. The data may be supplied from published sources or from expert judgement. The computer can then compute a value of land planted for any given price in the range by interpolating between the given points. It is not necessary to know the exact form of the equation to represent it. The line may be moved to wherever it is consistent with the expert's knowledge. If precise time-series for the individual variables becomes available, exact equations developed using regression analysis may be substituted.

The rest of the behavioral equations in the model may be represented in a similar manner. During the simulation the behavioral relationships, for which there may be different opinions as to their form, can be shifted to determine the effect of the change on the system. If there is a major change, then there is an indication that an investment should be made in establishing the true relationship.

Figure 1

The Relationship Between Cereal Price to Farmers and Cereal Land Planted in the IBRD Description



This approach meets the standards for usefulness stated in the preceeding section. The model produced can be tested both formally, that is by simulation over a historical period, and by judgemental valuation. It is easy to add or change relationships in the model. Finally, and of major importance, it is easy to test policy options to determine their effect on goal variables.

An important point to remember is that this approach will provide a model based on the best information available about the Sahel. It provides no fancy statistical magic, but rather provides a reflection of a consensus of many experts' mental models. To the extent that there are many ill understood relationships, the error in model output will increase. The accuracy of the model will increase as our knowledge increases.

ANNEXES

ANNEX A

MODELS OF THE SAHEL

Each of the organizations described in the introduction to this paper have described their views of the Sahel. FAO and SEDES/SCET have done so mathematically and very precisely while IBRD has done so more generally. These descriptions provide each organization's model of the Sahel.

In the following sections these descriptions are presented in prose and graphs. Annex B explains this technique, known as a causal influence diagram, which simply shows the causal relationships in each model.

FAO

FAO describes a normative model of the Sahel. This is a model of a system which should act to maximize agricultural income where income is the sum of the products of production and price for each of 14 food commodities.[1] FAO uses a mathematical programming algorithm to determine an optimal mix of policies to maximize agricultural income.[2]

The commodity production indicated by the algorithm results in a deficit or surplus depending on the commodity requirements of the population. The following description of their model focuses on food crops, meat, and milk production, as does their report.

Income from each commodity is equal to the product of production times price. In each case, price is determined outside the model or exogenously.

Food crop production is the sum of rainfed plus irrigated food crop production.

Rainfed food crop production is determined by the amount of land planted and the yield on that land. To determine both the area planted and the yield, the land is divided into four geographical regions and five farming techniques are defined. The rainfed food crop land depends on the land that can be planted in the region and the rotation pattern. The rainfed food crop yield, the fallow to cultivated land ratio, the rotation pattern, and the land planted per active person are determined by the farming technique chosen. The amount of agricultural inputs, i.e. the fertilizer, animal traction, training, etc., is determined by the farming technique chosen and the area of land over which the techniques are applied.

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[1] The different commodities are: wheat, rice, coarse grain (maize, millet, and sorghum), tubers, sugar, pulses, groundnuts, vegetables, cattle, sheep and goats, poultry, eggs, fish, and whole milk.

[2] A linear programming algorithm is used which maximizes a linear objective function, i.e., the equation which defines agricultural income, based on linear constraints, i.e., the amount of land in each region must be less than a maximum amount, etc.

Export crop land is determined by the rotation pattern.

Irrigated food crop production is similarily determined by the amount of land planted and the yield on this land. In the irrigated case the necessary agricultural population for irrigated food crop production, irrigated food crop land, irrigated food crop yields, irrigation capital, and agricultural inputs are determined by three possible irrigation techniques.

The agricultural population for rainfed grain production is equal to the difference between the total active farm population minus the agricultural population for irrigated grain production. The total active farm population is assumed to be a certain percent of the total rural population.

Meat production is determined by the product of meat per head times the annual animal offtake. Meat per head is exogenously determined. Animal offtake is determined by the offtake percent and the herd size. The offtake percent is exogenously determined. The livestock herd size is determined by the offtake and the natural growth rate of the herd. The natural herd growth rate is determined by the available food supply per head of livestock.

The food supply per head of livestock is the quotient of the food supply for livestock divided by the livestock herd size. The food supply for livestock is determined by the amount of range lands, forage land and fallow lands, feed agricultural by-products. The range land, land planted for forage and agricultural by-products feed supply are exogenously determined. The amount of fallow land is equal to the product of the amount of rainfed grain land planted times the fallow to cultivated land ratio.

Milk production is determined by the livestock herd size, the percent of the herd lactating, and the milk per lactating animal. Both of the latter two variables are exogenously determined.

The commodity requirements are determined by the number of people and the commodity demand per capita.

The population is the sum of the urban population and the rural population. Each population is assumed to have its own growth rate.

The commodity demand per capita is determined by the private consumption expenditures (PCE) per capita in each country. PCE per capita is assumed to have two different set of values over time depending on two different scenarios: (1) a low projection with PCE per capita remaining constant, and (2) a high projection with PCE per capita increasing at 1 percent per year based on increasing urbanization and urban incomes remaining above the national average.

The commodity balance is equal to the difference between commodity requirements and commodity production.

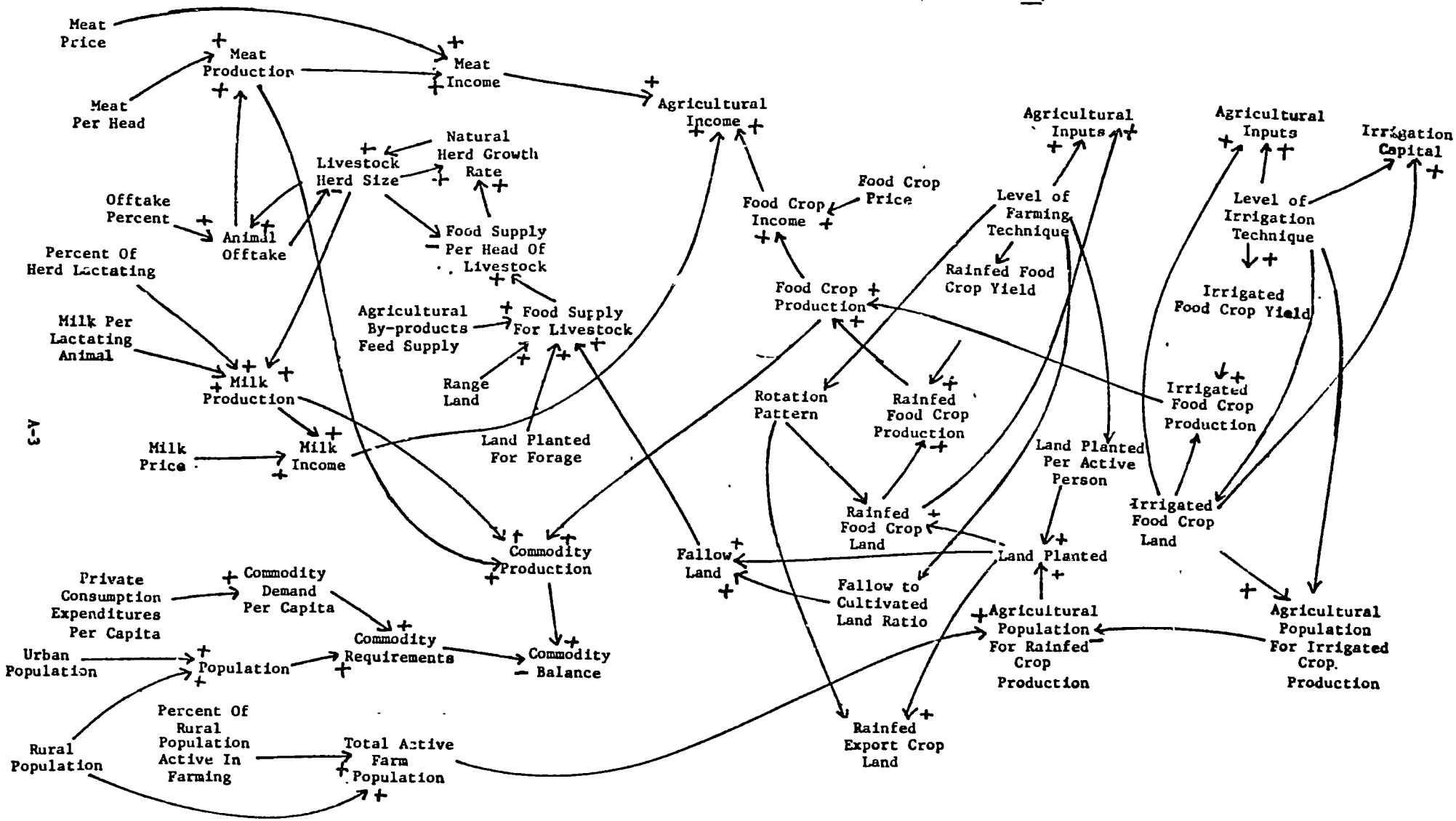
This model is represented in figure A-1

SEDES/SCET

SEDES/SCET also describes a normative model of the Sahel. They create a model of a system in which agriculture should be managed differently to maximize food production. They utilize, basically, an accounting model to keep track of land planted, yields, etc. The following description of their model focuses on grain and meat production.

Figure A-1

The Causal Relationships in the FAO Model of Sahelian Agriculture 1/



1. Food and Agricultural Organization of the UN (FAO), Etude Prospective pour le Developpement Agricole des Pays de la Zone Sahelieene, Rome, 1976.

Rainfed grain production, i.e., millet, sorghum, etc., is determined by the amount of land planted and the yield on that land. To determine both the area planted and the yield, the land is divided into 21 geographical regions which differ as to their resistance to drought of rainfed crops, irrigation potential, and access to external assistance. The rainfed land planted depends on the farming population in each region. The rainfed grain yield depends on the level of farming techniques utilized and the amount of rainfall that occurs. The amount of agricultural inputs depends on the farming technique and the amount of land planted. Both the level of farming technique and the amount of rainfall are exogenously determined.

Irrigated grain production, i.e., rice and wheat, depends on the land planted, the crops per year, and the yield per crop. The irrigated land planted depends on the farming population in each region. The investment in irrigation facilities, the yield per irrigated crop, and the crops per year depend on which of seven irrigated farming techniques is chosen. The amount of agricultural inputs depends on the chosen irrigation technique and the amount of irrigated land planted. The level of irrigation technique is exogenously determined.

Export crop production is a function of agricultural population. The magnitude and direction of the relationship are exogenously determined.

The grain stock at any time is determined by the grain storage capacity and the net historical grain balance. The grain storage capacity is exogenously determined.

Meat production is determined by the product of meat per head times the annual animal offtake. Meat per head is exogenously determined. Animal offtake is determined by the offtake percent and the herd size in the fattening zone. The offtake percent is exogenously determined. The livestock herd size in the fattening zone is determined by the offtake and the animal transfer from the breeding zone.

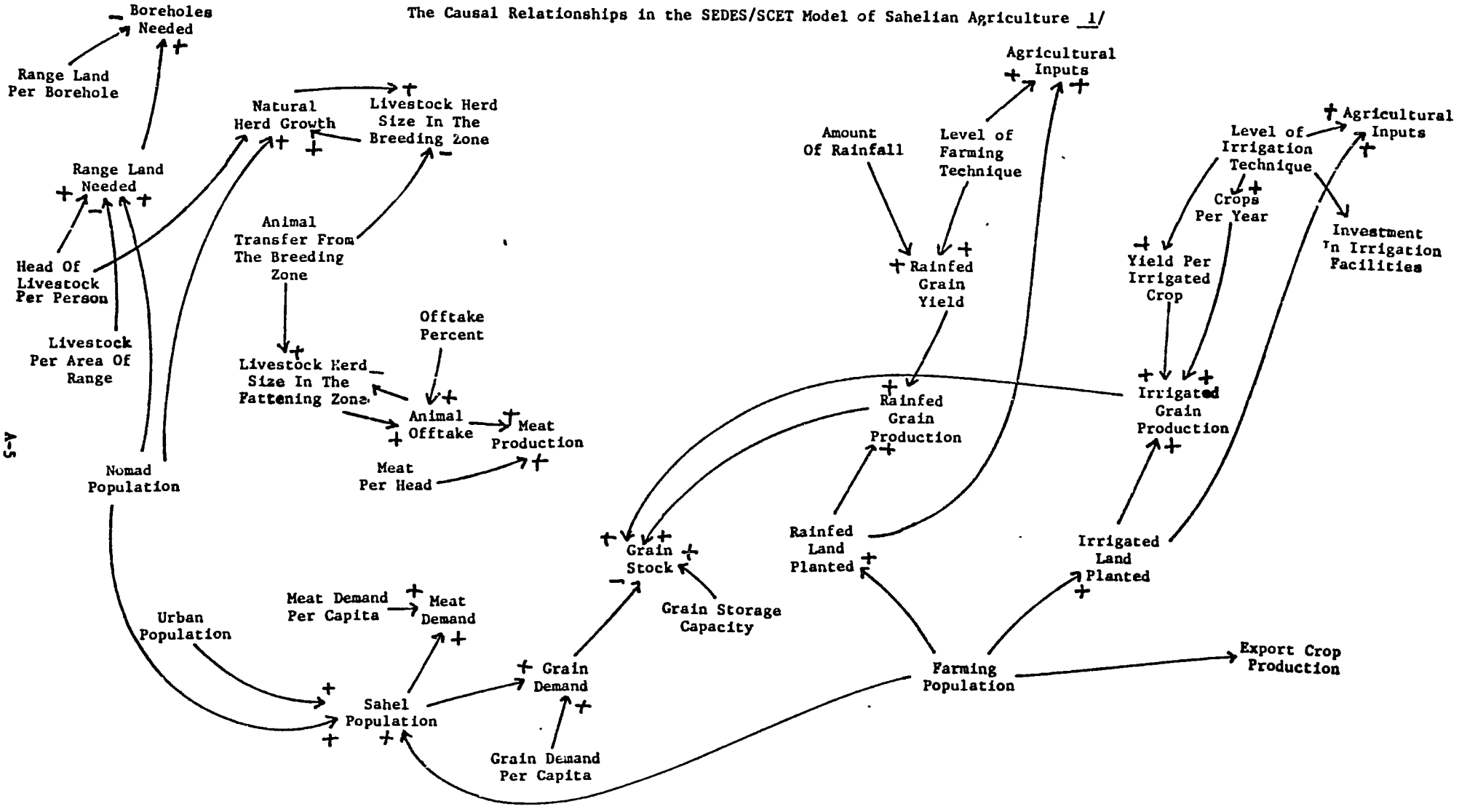
The livestock herd size in the breeding zone is determined by the natural herd growth rate and the animal transfer from the breeding zone. The natural herd growth is determined by the nomad population and head of livestock per person. The range land needed is determined by the nomad population, the head of livestock per person, and the livestock per area of range. The number of boreholes needed is determined by the quotient of the range land needed divided by the range land per borehole. The head of livestock per person, the range land per borehole, the animal transfer from the breeding zone, and the livestock per area of range are exogenously determined.

Rainfed grain, irrigated grain, and meat demand are determined by the product of the total Sahel population times the total demand per capita for each food. The Sahel population is the sum of the farming population, the nomad population, and the urban population. All populations and the food demand per capita are exogenously determined.

The model is represented in figure A-2.

Figure A-2

The Causal Relationships in the SEDES/SCET Model of Sahelian Agriculture 1/



1. Societe d'Etudes pour le Developpement Economique et Social (SEDES), Societe Centrale pour l'Equipement du Territoire/international (SCET), Attempt to Outline an Anti-Drought Strategy in the French-Speaking Sahelian Countries of Western Africa, Summary of Main Report, October, 1975.

IBRD

IBRD provides a descriptive model of the Sahel. In this model, the Sahelian countries are split into three regions: the Sudan, the river, and the Sahel regions. The following subsections describe the model.

Sudan Region

The Sudan population is determined by its natural growth and migration from the area. Migration from the area is the sum of migration to the Sahel region and to the coastal countries. Both types of migration are caused by perceived differences in either income per capita, food consumption per capita, or both. Food consumption per capita is determined by cereal production and population.

Cereal production is equal to cereal land planted times cereal yield. Cereal land planted is equal to the land required by the desired cereal production. Desired cereal production is determined by the number of Sudan people. The cereal yield is a function of the amount of rainfall, agricultural inputs, and soil fertility. Both agricultural inputs and land planted can be effected by cereal price. Cereal price to farmer is effected by government price policy. The number of extension service workers is a function of government expenditures on agricultural services.

The soil fertility is determined by the percent of farm land fallow and the soil protective capital installed. The percent of farm land fallow is the quotient of the total land planted divided by the total farm land. The total land planted is the sum of the cereal land planted and export crop land planted. The soil protective capital is increased by investment in protective capital and decreased by the capital deterioration rate. Investment in soil protective capital is a function of government expenditures. The capital deterioration rate is a function of the capital stock.

Export crop production is the product of export crop yield times export crop land planted. Both export crop yield and export cropland planted are effected by export crop price. Export crop price is effected by the world export crop price and investment in transportation facilities in the coastal countries. Foreign exchange revenues from export crops is determined by the world demand for export crops, available export crop production, and the export crop price. Export crop price to farmer is effected by government price policy.

The agricultural workers employed are equal to the product of the land planted times the workers required per area planted. Unemployed agricultural workers is equal to the quotient of agricultural workers employed divided by the agricultural population.

Income per capita is equal to the quotient of the total income divided by population. Total income is equal to the sum of agricultural income to farmers plus income from wage earners plus income from remittances from migrant workers in coastal countries. Agricultural income to farmers is equal to cereal crop income and export crop income. Cereal and export crop income are determined by crop production and crop price to farmer. Remittances from migrant workers is determined by the number of migrant workers in coastal countries.

River Region

Irrigated cereal production is determined by the irrigated land planted, crop per year, and yield per crop. The irrigated land planted depends on the cost per hectare of land developed and on the total past investment in irrigation capital.

Sahel Region

The Sahel population is determined by its natural growth and migration from the Sudan zone.

Cereal production is equal to the product of cereal land planted times cereal yield. The factors that affect cereal land planted and cereal yield are similiar to those in the Sudan sector. In the Sahel sector, however, the total farm land can be increased by the farm land development rate. The farm land development rate is determined by the desired cereal production and the cereal land planted.

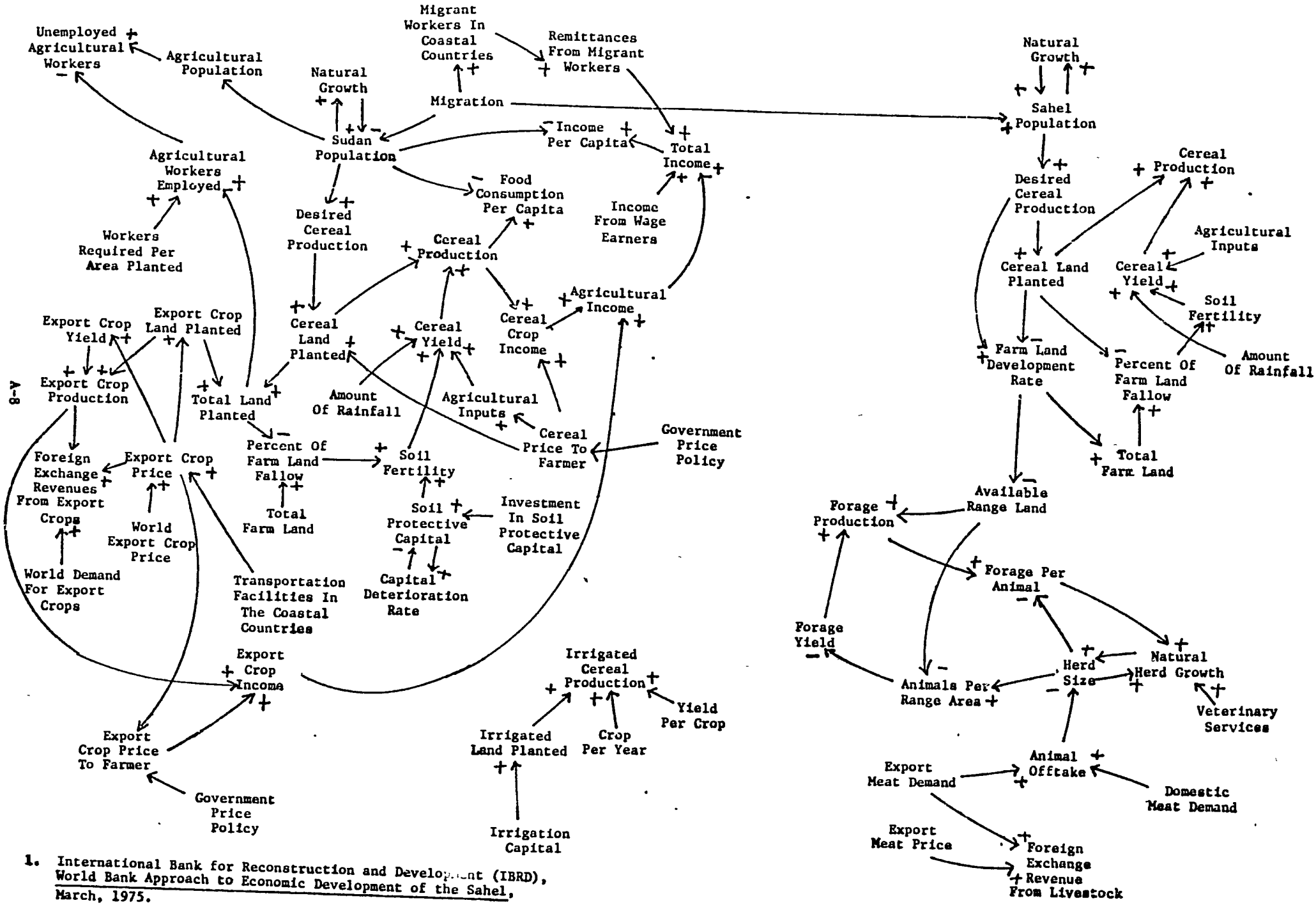
The herd size is determined by the natural herd growth and animal offtake. The natural herd growth is determined by the availability of veterinary services and forage per animal. Forage per animal is the quotient of range forage production divided by the herd size. Forage production is equal to the product of the available range land times the range's forage yield. Available range land is increased by the development of water resources and decreased by the farm land development rate. Forage yield is determined by the number of animals per range area. The animals per range area is the quotient of the herd size and the available range land.

Animal offtake is determined by export and domestic demand. Foreign exchange revenue from livestock exports is determined by export demand and prices. Export demand for livestock is increased by increased development assistance to the coastal countries.

The model is represented in Figure A-3.

Figure A-3

The Causal Relationships in the IBRD Model of Sahelian Agriculture 1/



1. International Bank for Reconstruction and Development (IBRD), World Bank Approach to Economic Development of the Sahel, March, 1975.

ANNEX B

AN EXPLANATION OF A GRAPHICAL TECHNIQUE FOR PRESENTING MODELS

A technique, called a casual influence diagram, presents variables that have been identified in a system, their interrelationships, and the effects of changes in value or intensity. The technique is illustrated with a simple model of dust generation in the Sahel.[1]

The author's hypothesis is that plant cover is determined by the amount of annual rainfall and the northern reach of the monsoon. As the amount of rainfall increases or as the monsoon goes further north, the plant cover increases.

The amount of dust generation is determined by the amount of plant cover and the wind. As plant cover increases, dust generation is decreased. As wind increases, dust generation increases.

The amount of rainfall and the northern reach of the monsoon are determined by climatic changes and the amount of dust generation. As more dust is generated, the amount of rainfall decreases and the monsoon does not reach as far north.

This hypothesized model indicates that droughts tend to "feed on themselves." If a monsoon does not produce much rain and does not reach as far north as normal, plant cover decreases and more dust is generated. The extra dust increases the severity of the drought.

This model is presented in Figure B-1. The arrows indicate the direction of effect. The sign at the head of an arrow indicates the change of direction caused by an increase in value or intensity of the variable at the tail of the arrow. A plus sign indicates an increase in value or intensity, a negative sign indicates a decrease in value or intensity. If there is no sign, the direction of effect depends on the values of the other causal factors.

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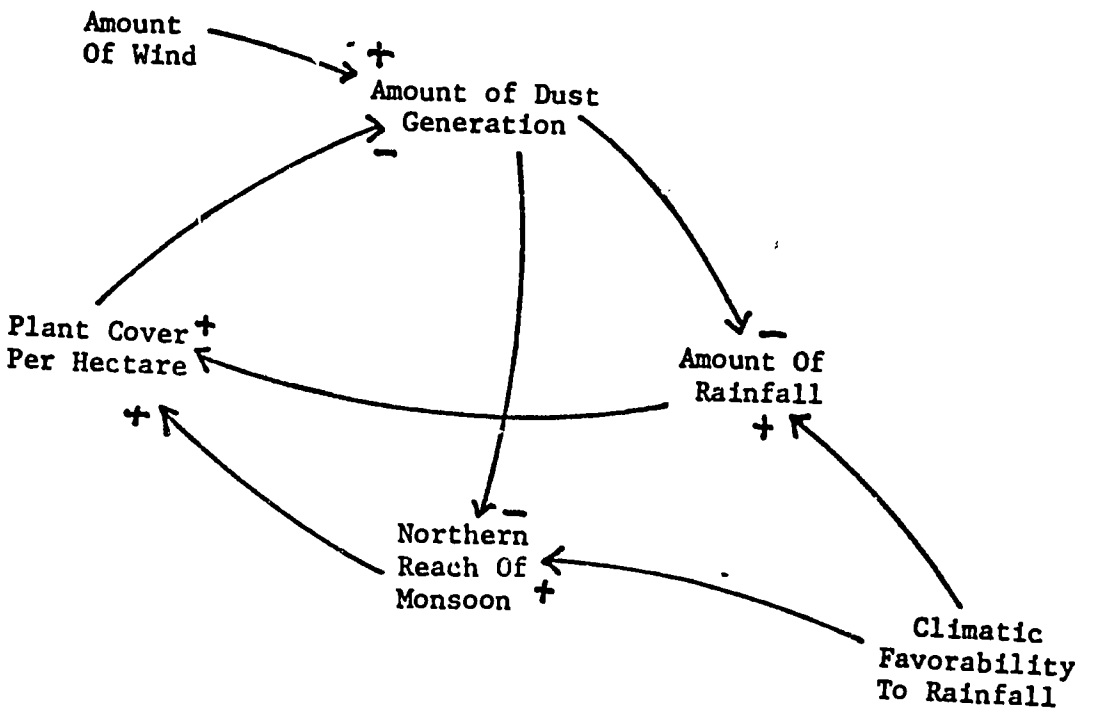
1. MacLeod, N., "Dust in the Sahel: Cause of Drought?," The Politics of Natural Disaster, ed. Michael Glantz, Praeger Publishers, New York, 1976, p 214-231.

Figure B-1

CAUSAL DIAGRAM OF DUST GENERATION IN THE SAHEL



ANNEX C

A PROGRAMMING LANGUAGE FOR COMPUTER SIMULATION OF MODELS

The behavioral and accounting relationships discussed on page 10, once mathematically represented, may be simulated on a computer with the programming language DYNAMO.[1] DYNAMO is primarily used to compile and execute simulation models where the behavior of the system depends more on aggregate flows between variables than upon discrete events. These types of models are called continuous simulation models. Typically there are many closed feedback relationships in such systems. DYNAMO orders the relationships in the form of recursive difference equations, simulates the system behavior on the computer, and prints the simulated values of the model variables.[2]

The major advantages of DYNAMO are: (1) it is an efficient way to simulate large continuous simulation models with many feedback relationships; (2) it allows the inclusion of behavioral relationships, through specified equations or numerical approximations; (3) it allows the inclusion of physical or information delays between variables through specified equations or numerical approximations; (4) it provides easy to read graphical and tabular output; and (5) it provides easy to use rerun capability for sensitivity and policy tests.

DYNAMO, though a convenient tool for simulation, is not an all-purpose language. Although it would be possible, it would be much easier to program the SEDES/SCET model in such languages as FORTRAN or APL. It would not be possible to program the FAO model, a linear programming model, in DYNAMO.

Linear programming is used to determine the conditions necessary to maximize (or minimize) a variable based on certain constraints. It is a useful technique that can be used to describe a system that is known to maximize a given variable. However, it is a cumbersome technique to use to simulate variables that change over time It is impossible to include in a linear programming model either feedback relationships between variables or numerical approximation of relationships. A more likely use of a linear programming model would be to provide a normative description of a system, such as the FAO model, or as input to a larger simulation model.

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[1] Pugh, Alexander, Dynamo User's Manual, MIT Press, Cambridge, 1976.

[2] A difference equation is an equation whose variables can take different values depending on time. A recursive set of equations means that it is possible, by starting with the initial value of any endogenous variable and the values of all exogenous variables, to proceed iteratively to calculate the values of all other endogenous variables.