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A SIMULATION MODEL OF THE NIGERIAN AGRICULTURAL ECONOMY:

PHASE I - THE NORTHERN NIGERIAN BEEF INDUSTRY

A progress report to the Agency for International Development submitted under the auspices of Contract No. AID/csd-1557, Agricultural Sector Models, by Michigan State University.

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April 26, 1968

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PART I

INTRODUCTION

The basic objective of this study is to develop a simulation model which will prove useful to policy and decision makers in formulating and evaluating programs intended to improve agricultural sector productivity[1/]. Since adequate evaluation of policy alternatives is often very difficult in ad hoc policy situations, an accurate yet simplified model of current interactions and potential changes in the economy can be quite useful to researchers and decision makers involved in joint evaluation of development policy alternatives. By transforming this description into a computer simulation model of the economy and introducing policy changes computer simulation model of the economy and introducing policy changes into the model, the likely consequences (over time) can be swiftly calculated. These descriptive results could be utilized by researchers, policy and decision makers involved in the planning and evaluative effort. These might include host country planners, officials, and politicians, USAID officials, potential investors and planning consultants.

While the research and modeling effort is initially directed toward the Nigerian agricultural economy (with emphasis on the beef industry during the first year), the simulation capability and many specific model components which are being developed are intended to be transferrable and relevant to development environments in both underdeveloped and developed economies. The following report will briefly describe the methodology employed in the modeling of the Nigerian economy, indicating

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1/ For a full description of the objectives of contract no. AID/csd-1557, see either the official contract or the Agricultural Sector Models: Plan of Operation - July 1, 1967-September 30, 1968, submitted to USAID, November 13, 1967.

the relationship of the techniques utilized to those which have been utilized in similar research endeavors. Further, the research procedure will be explained in detail. This report will describe the components of the task force assembled for this research endeavor and the process of conceptualizing the development problem in Nigeria. Further, it will relate the modeling activity to both the perceived problem areas and the available sources of information in the literature in Nigeria, and in the persons of experienced African researchers in residence in the United States. The current simulation model of the Nigerian beef industry will next be presented with a detailed description of the model structure and the sources of current and potential data necessary to quantitatively apply the model to various policy situations. The sensitivity analyses which were carried out on particular parameters in the model are described. Further, some examples of simulating the Nigerian beef industry under selected policy alternatives are examined illustrating the applicability of the current model. After the description of the accomplishments to date, some tentative evaluations and critiques are presented.

Suggested refinements of the beef industry model are considered, and tentative priorities are established for the structural modifications and tests to be done during the next six month period. Since the beef industry model is viewed only as an important element of the global model of the Nigerian agricultural economy, research which should be done during the next six months to link current efforts smoothly into larger modeling objective is elaborated. This will involve development and elaboration of other major production, processing, infrastructure and related sectors which have substantial impact in their own right on the entire agricultural economy in addition to specific and important

interactions with the beef industry. Thus some elaborations of the current model and transitional phases into a more complete global model of the agricultural economy are contemplated during the remainder of the currently funded period, overlapping into the early part of 1969.

The transitional phases of the modeling process are selected according to the interdependence of that particular sector or sectors with the beef industry and the more overriding consideration of importance in the global economic model. Thus, the questions which are addressed include: (1) what are the major interacting sectors and functional relationships within the entire agricultural economy which must be included to some degree in the global model? (2) what are the priorities among these sectors, in terms of (a) likely changes in productivity or efficiency, (b) the ability of the decision making agency to have influence on some factors affecting the development in that sector, (c) the degree of elaboration and data necessary (and likely to be available) for the modeling to be both useful and feasible to implement as a planning tool, and (d) the time and research resources available to accomplish the modeling? The answers to these questions have provided initial guidance into the choice of transitional modeling efforts, while suggesting the direction in which the long run modeling efforts should be directed. Finally, a tentative evaluation of both our current efforts and the potential usefulness of simulation as a planning tool is presented.

PART II

RESEARCH TO DATE

Research accomplishments during the first six months of the contract are presented in Parts II and III. First, contributions of previous work on simulation and relevant Nigerian research are briefly described. Second, the research methodology and mode of operation employed to attain the project objectives are sketched. In Part III, the computer model of the Nigerian beef industry is described in detail and sample results of sensitivity analyses and policy evaluations using the current simulation model are presented and appraised.

Relation to Previous Research on Simulation and Nigeria

The methodology applied in the research is along the lines of that employed in a number of previous studies dealing with macro-economic systems (S3, S7, S15, S23, S24, S25, S26). Experience has indicated that it is meaningful to model such systems by (usually) large sets of differences and/or differential equations. Systems of this type can be simulated using general purpose programming languages such as FORTRAN or by the use of one of many special purpose simulation languages such as DYNAMO (S11), MIDAS (S20), or MIMIC (S21). The specific simulation vehicle selected for this study is the general purpose programming language FORTRAN augmented by the special simulation features of FORDYN (S22). In addition to providing compatibility with most computer installations in the United States and many in the underdeveloped countries, this selection makes it possible to couple simulation models to linear program programming routines and other computational tools of systems analysis. Also, the FORTRAN/FORDYN system selected permits a "building block"

approach to systems modeling which makes feasible the accumulation of a library of general purpose sub-models useful in various specific simulation applications. Some additional features of previous simulation models are described below, with special emphasis on their relevance to simulating the economic environment in an underdeveloped economy.

In a study by Halter and Dean (S18), computer simulation was applied to a large scale California ranch composed of 25,000 acres of foothill rangeland and a feedlot of 5,000 head capacity under one management unit. As are most farm managers, the management is faced with two sources of uncertainty -- weather and prices. Weather affects the quantity, quality and time distribution of the range forage, and future prices of inputs and products must be estimated. The high degree of interdependence between the two operations, feedlot and range creates some problems which are different than if they were operated independently. Since feedlots are one modern beef production alternative currently being explored in Northern Nigeria, this model has some relevance for the current study. Although this work was conducted under modern technical conditions in the United States, it has applicability in the technically underdeveloped Nigerian beef industry.

Computer simulation can be used to facilitate learning for managers at the firm level or decision makers at the macro policy level of an economy or sector of an economy. "Simfarm", developed by Dr. Warren Vincent at Michigan State University, simulates a farm business via a computer program designed specifically for teaching farm management as a dynamic game. The student makes decisions on the enterprise mix and the technology levels adopted in his farm enterprise; the computer

performs the arithmetic and immediately presents the student with the results of his management. In this manner the student may experiment with a number of decisions without being burdened by the numerous computations involved. A similar procedure can be followed with macro simulation models of the type developed herein with host country and USAID policy makers and decision makers.

Simulations of entire industries exemplify features of an economy that are not usually reflected in simulations of individual competitive firms -- for example, the price determining forces and problems of aggregation. In general, an industry model or a macro model of an economy will contain fewer exogenous variables, requires a greater degree of aggregation, and shows a more complex structure than does the micro model. Examples of such models are the Manetsch plywood industry simulation (S23) and the Balderston and Hoggatt (S15) simulation of the lumber marketing system.

Simulation models intended specifically for planning purposes are complicated by the fact that there are numerous modernization or improvement possibilities and multiple goals which must be considered. For example, in river basin planning, efficiency of water use is desired for a multiplicity of purposes such as agricultural, industrial, minicipal, navigation, flood control and hydroelectric power. With all the complexities of such planning projects, simulation is a means of organizing and deriving estimates of the benefits and costs from implementing various projects. In the case of river basin planning (S7) simulation provides a visible integration of the hydrology and the

and the technology with the economics of a planning problem, and it encourages the assembling of all relevant information and data since the computations can easily be handled on a high speed computer.

Simulated macro models of an economy or sector of an economy can have many of the characteristics of the models discussed above for industry and planning models. A macro model simulation is an abstract model of an economy which can be operated on a computer. The abstract model, based on past observations and theories, is designed to behave as much like the real world as possible; dynamic interactions, nonlinearities, discontinuities, time delays and irreversibilities can be embodied in the model. Since the model can be run on a computer on a speeded up time scale, the researcher can run the model for hypothetical time periods for both short and long run conditions. Also, adjustments and manipulations of the model and its component can provide the results of alternative policies or plans.

A number of macro model simulations have been constructed for economies or sectors of developing countries similar to the model discussed below for the Nigerian beef industry. Holland's and Gillispie's works on the Indian economy (S25), and Holland's Venezuelan economy model (S20) are examples of macro models that illustrate the complexities of attempting to simulate an entire economy. The Ligomenides, Manetsch and Ramos simulation model of the cotton sector of the Northeastern agricultural economy of Brazil (S24) illustrates the application of simulation under conditions not unlike those found in Nigeria.

Each of the earlier simulation models (see the attached simulation bibliography) has provided experience and techniques useful in developing appropriate means for simulating the Nigerian agricultural economy. With this background as a springboard, the simulation techniques deemed most appropriate for the given problem and computation facilities were selected. However, the actual quantification of these models has been heavily dependent upon the available Nigerian research literature which describe the current environmental and economic interactions in Nigeria as well as many modernization alternatives.

While one always wishes for a greater amount of information specifically intended to answer specific questions, a substantial amount of literature on Nigerian agricultural and similar tropical agricultures is available in the United States (see the attached Nigerian bibliography). The Consortium for the Study of Nigerian Rural Development (CSNRD) has accumulated many of the published sources available. Major published information sources include Werhahn (B1), Ferguson (B16), FAO (G13), Rain (MG8), and a multiplicity of research bulletins from the research station at Samaru, Ahmadu Bello University. These and other documents have provided descriptive material which forms the basis for the structural relationships incorporated in the models constructed to date. These same sources have also furnished initial estimates for many model parameters. Further, the CSNRD personnel and reports have been helpful in filling information gaps and suggesting important development possibilities in some areas. Further assistance has come from several agricultural scientists who have been recently associated

with the Michigan State University program to assist the University of Nigeria. Supplemental published and unpublished information was obtained through a research trip to Nigeria bv Thomas Manetsch in November and December of 1967. He obtained a great deal of information during this trip from GON and USAID personnel.

Methodology and Model of Operation

A preliminary macro model of the beef sector of the Nigerian agricultural economy has been developed. This model incorporates the interrelationships among the traditional Nigerian beef production sector, available resources for beef production, consumption and export sectors. Selected modern production and managerial alternatives are incorporated into the model in order to explore the likely sources and mechanisms of change in the industry. Thus, the influence of investments or other policy decisions affecting the rate of modernization can be readily evaluated.

The development of the computer simulation model followed a number of planned steps. First, the problem was defined in terms of the objectives to be accomplished by the research project, namely: what are the basic biological, environmental, and economic interrelationships which need to be considered when evaluating alternative development policies for the Northern Nigerian beef industry and what specific modernization programs and policies should be evaluated in this environment?

The problem can be illustrated by considering the traditional cattle husbandry of Northern Nigeria. It is estimated that there are eight million cattle in Northern Nigeria, more than 90 percent of these cattle are owned by the nomadic Fulani. During the rainy season, more than half of the herds are concentrated in the tsetse-free zone which stretches in the North over a belt 140-220 kilometers wide. During the dry season, the majority of cattle leave this zone and are driven into the fly-infested area in the South in search of fodder and water. Their movements are directed towards the middle belt and in particular to the flood plains of the major rivers. At the onset of the rains, the northbound trek commences, and around June or July most herds have returned to their wet season range in the North. It is clear that the periodic movements bring about a seasonal fluctuation of the cattle density and constitute the response of the nomadic herdsman to the variation in carrying capacity of the range. The overgrazing of the current range and the encroachment of food crop cultivation into grazing areas contribute substantial stress to the economic productivity of the beef sector.

The first step in the modeling of the beef industry of Northern Nigeria was the development of a qualitative model of the industry. This broadly identified relevant sectors, endogenous variables, exogenous variables and policy variables such that a mathematical model incorporating these elements would answer relevant policy questions.

Following this qualitative model of the Nigerian situation, mathematical equations were programmed in FORTRAN IV programming language, and the simulation model was run on the Michigan State University CNC 3600 computer. The computer runs consisted of three types. The first was the de-bugging of the program, i.e., finding the errors in variable definition or equation specification and programming logic in general. Second, various parameter values were estimated and sensitivity tests run. These tests provided a basis for evaluation of the model as to its correspondence to the real situation and indicated high priority information gaps. Particular parameters were found to have a considerable effect upon the behavior of the system, indicating further analysis or data investigation in these areas may have a large payoff. Further, the tests suggest developmental research areas that might warrant high investment priority. Sensitivity runs were also made with "good" and "bad" combinations of parameter values giving the reviewer a range of possible outcomes.

When the team of researchers developing the simulation model was satisfied that some version of the model came as close to the actual situation as data would provide, then various policy alternatives were tested by further computer runs. The various policies tested provided for varying levels of investment in such alternatives as fly eradication from fly-infested areas, feed crop stimulation, grazing reserve development and various management alternatives in regard to the marketing of males and females from the population.

The research team which has developed and implemented this research from its initiation include: Dr. Glenn L. Johnson, Dr. Marvin L. Hayenga, Dr. Albert N. Halter, Dr. Manfred Leupolt, Earl Kellogg, and Norman Veliquette, all agricultural economists, and Dr. Thomas J. Manetsch and Kioumors Paaryani, systems scientists; and Dr. Robert Deans and Dr. Beryl Koch, animal scientists. In addition, many other scientists with Nigerian experience have been consulted on specific issues and problems. The team approach has made it possible to develop some specialization within the group while reaping the benefits of interdisciplinary efforts in simultaneously reviewing available literature, developing the model structure, and experimenting with the simulation model on the computer.

PART III

THE MACROSCOPIC MODEL

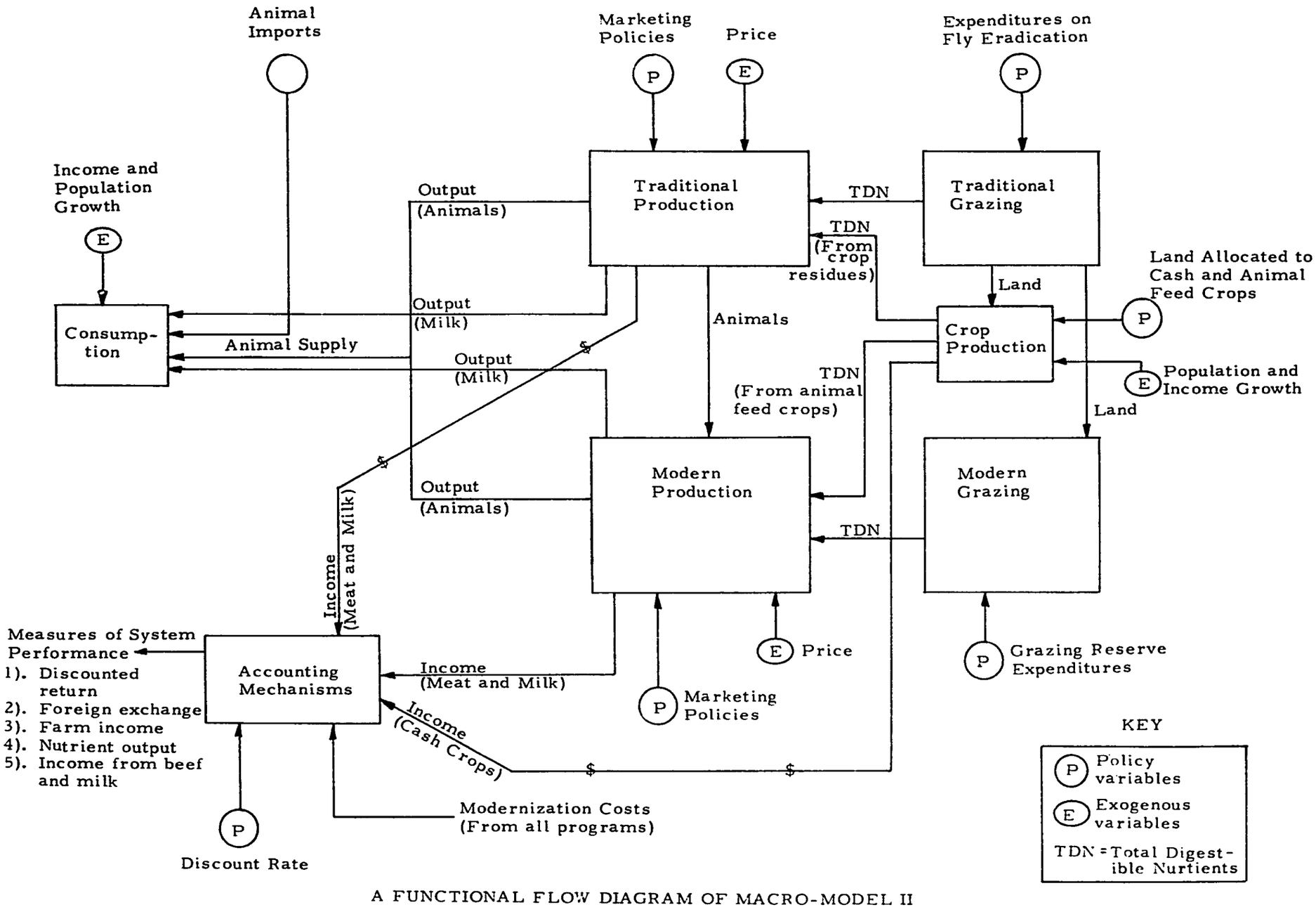
Initially, a detailed qualitative model of the Northern Nigerian beef industry (partially described in the Plan of Operation dated 13 November 1967) was assembled which microscopically examined sub-sectors of the industry, specifying the relevant inputs, outputs and the intermediate transformations, and the connecting links between sub-sectors. Some inputs and outputs considered include: managerial and technical personnel, skilled and unskilled labor, and equipment inputs to modern sectors; educational institution outputs of livestock assistants, range management assistants, extension workers, equipment maintenance personnel; and inputs to various classes (classified by age, sex and management practice) within the livestock population, including water, supplemental feed, forage and veterinary care. It became apparent that the construction of a model at this level of detail would consume a significant part of the resources allocated to the study during the first year and that it would be many months before operational computer models could be evaluated. The decision was therefore made to construct a macroscopic model which would broadly display the significant system interactions and the influences of major industry modernization policies. It was felt that such a model would be relatively easy to construct, provide insight into system behavior, illuminate areas where greater modeling detail are necessary, and provide a basis for the more detailed models to follow. A refined version of this macroscopic model, which is now operational on the CDC-3600 computer at Michigan State University, is described in detail in what follows. This model should not be regarded as final, since testing

and modifications are likely to continue for some time. Following description of the model structure (termed "Macro Model II"), results of some trial simulation runs are presented.

General Model Description

In the model (see Figure 1), the livestock population of Northern Nigeria is disaggregated into two populations -- one traditional and one managed using modern techniques. The "traditional" cattle population (belonging to nomadic Fulanis) is assumed to subsist on the tsetse-free grazing land of Northern Nigeria during the wet season. During the dry season, crop residues and additional grazing land (which becomes available as the habitat of the fly recedes southward during dry months) also add to the nutrient supply. Grazing land and, hence, total digestible nutrients (TDN) for the traditional population are endogenous model variables which are related to any food crop acreage expansion to feed a growing human population, to expansion of cash and animal feed crop acreages, and to increased tsetse-free grazing land areas as a result of fly eradication and grazing reserve programs. Expenditures on fly eradication and grazing reserve programs are policy variables which can be varied during model tests.

The "condition" of the traditional grazing land, which influences grass yields per acre, is computed as a function of the number of animals grazing on an area relative to an equilibrium number. Male and female livestock populations and sales are computed as functions of calving rates, death rates and marketing strategies, the latter being policy variables which may be varied during model tests. Calving rates and death rates are endogenous model variables determined by the per-animal digestible nutrients supplied



A FUNCTIONAL FLOW DIAGRAM OF MACRO-MODEL II

Figure I.

by grazing land and crop residues. Animals in the "modern" sector are assumed to be situated on grazing reserves where adequate nutrition is available from properly managed grassland (range productivity in the modern sector is not deteriorating) and supplemental feed obtained from cropland is devoted specifically to animal feed production. Land allocated to animal feed crops is a policy variable which can be substituted for land allocated to cash crops (another policy variable). Range land available for "modern" grazing is determined by expenditures on grazing reserve programs. Male and female population sizes and sales, calving rates and death rates are computed using virtually the same functional relationships but different input levels compared to the traditional sector.

Several alternative criteria functions which might influence a policy-maker's choice of development programs are calculated at both interim and final stages of a simulation experiment. Farm level incomes derived from meat, milk and cash crops are computed, as are capital investment and operating costs incurred through implementing various modernization policies being explored in successive simulation runs. Thus, several relative benefit/cost relationships for various modernization policies are summarized by computed criterion functions which include discounted net cash flow, foreign exchange balance, farm incomes, net beef imports and domestically produced nutrient outputs. The ability of the industry to meet the (forecasted) increase in demand for beef is determined by computing imports necessary to satisfy the projected demand.

Detailed Model Description

Certain aspects of this section are necessarily mathematical in nature. It should, however, increase the understanding of the model for the "lay" reader. All readers are urged to devote some attention to this section so as to provide a better basis for interpreting the subsequent description of model tests. A glossary in the appendix defines symbols used in the following technical model description.

Simulation of Animal "Demography"

Using subroutines written in the FORTRAN programming language, it was possible to simulate the behavior of both traditional and modern animal populations over time with one general model. Subroutine DEMOG performs this function in the simulation model.

A subroutine of a system model is to the system model what a sub-system is to a system. It can be viewed as receiving certain inputs from the system model and supplying outputs which, in turn, are inputs to the system model. In the case of subroutine DEMOG, the primary inputs (from the system model) are:

i) TDMA -- Total digestible nutrients per animal (tons/year)

ii) SF, SM -- Sales of females and males respectively per year (K animals/year)

iii) A number of parameters which determine birth rates, death rates, time delays, etc.

iv) RFT, RMT -- Rate at which females and males are transferred from traditional to modern production sectors.

The primary outputs supplied by this subroutine are:

i) PF, PM -- Population of females and males respectively (K animals)

ii) DF, DM -- Deaths of females and males respectively (K animals/year)

iii) ER -- Extraction ratio (percent offtake) feasible at the given level of nutrition without changing population size.

An important attribute of this (or any) subroutine is that given a set of inputs, a corresponding set of outputs will be computed. In this case, if "traditional" or "modern" inputs are supplied, then "traditional" or "modern" outputs respectively will be computed. Thus, one sub-program can be used to simulate two or more sub-systems which are alike in structure but differ in input and parameter values. The implications of this concept for efficient economic model building are significant.

In what follows, the equations which define subroutine DEMOG will be discussed in detail. A printout of the entire simulation model, including subroutine DEMOG, appears in the appendix. Equation numbers below correspond to the equation numbers of the simulation program.

Equation (1) of subroutine DEMOG computes the live birth rate as a function of level of nutrition.

(1) BR = TABLIE (VALB, SMALLB, DIFFB, KB, TDNA)

Where:

BR = Live birth rate -- proportion of <u>all females</u> calving per year.

TABLIE = A simulation sub-program which approximates arbitrary 1/ functional relationships by straight line segments.

VALB = An array of numbers which defines the dependent argument of the function.

1/ This sub-program is a table-look-up algorithm which interpolates linearly between data points.

TDNA = Total digestible nutrients (tons per animal year) -- the independent argument of the function.

SMALLB = Smallest value of TDNA in the data which defines the function.

DIFFB = The fixed difference between values of TDNA.

KB = The number of line segments used to approximate the birth rate function.

Since birth rates in the traditional and modern sectors are different functions of TDNA due to differing health and management practices, the model includes the two birth rate versus TDNA functions shown in Figure 2. Equation (1) therefore defines traditional or modern birth rates depending upon whether VALB is supplied with traditional or modern data. The data in Figure 2 are rough estimates based on available literature and conversations with animal scientists familiar with Fulani animals.

In like manner, Equation (2) computes traditional and modern herd death rates as a function of nutritional levels.

(2) DR = (VALD, SMALLD, DIFFD, KD, TDNA)

Where:

DR = Death rate -- proportion of total population dying per year.

VALD = An array defining the dependent argument.

TDNA = As defined above.

SMALLD, DIFFD, KD = As defined in Equation (1).

Important in establishing this functional relationship is the concept of "maintenance TDN" or the level of nutrition required to maintain weight but no growth. Below this level of nutrition, starvation rapidly ensues and the death rate increases rapidly. In the macroscopic model, a herd average level of maintenance TDN was calculated from estimates of maintenance TDN for

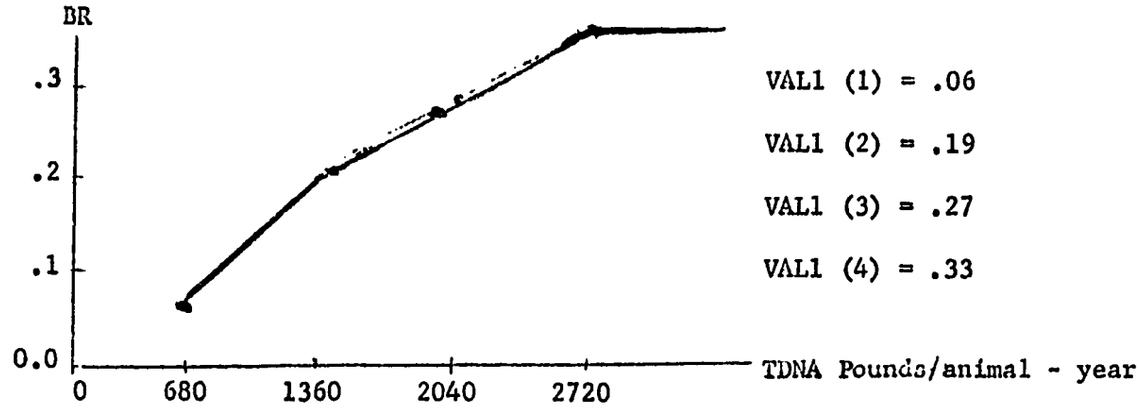


Figure 2 (a) TRADITIONAL BIRTH RATE VS. TDNA

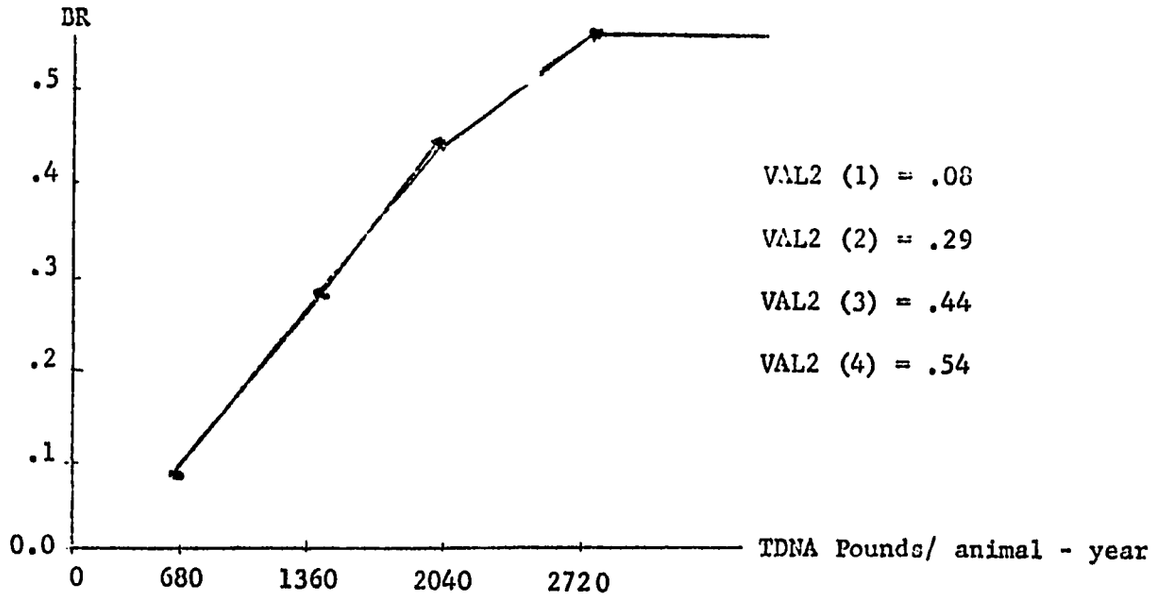


Figure 2 (b) MODERN BIRTH RATE VS. TDNA

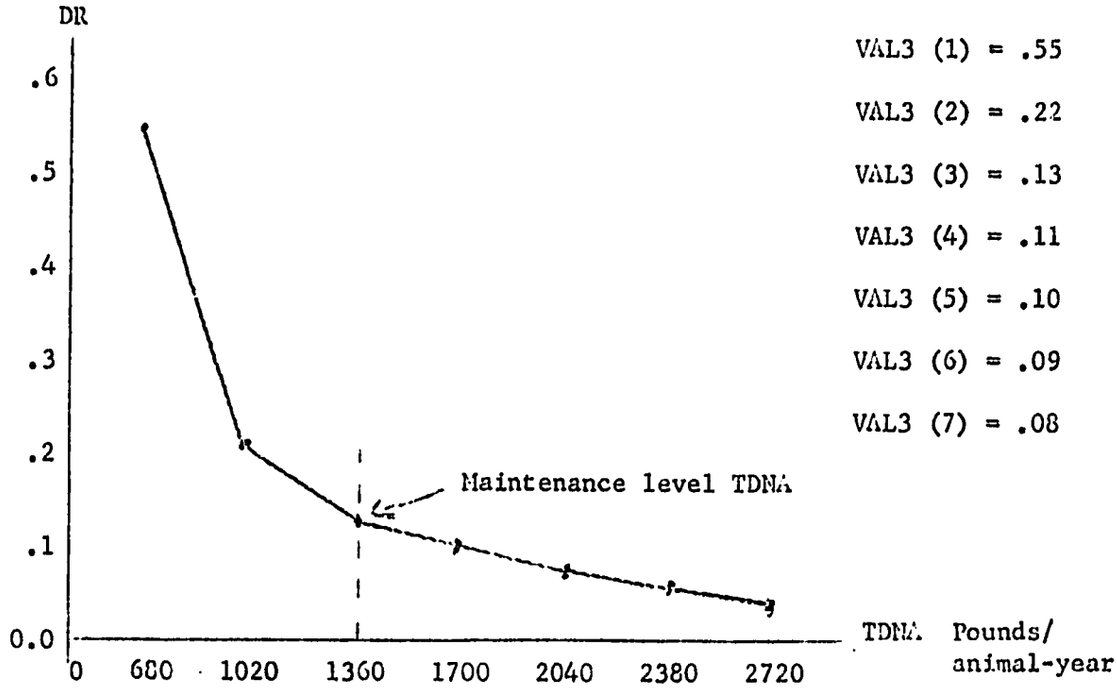


Figure 3 (a) TRADITIONAL DEATH RATE VS. TDNA

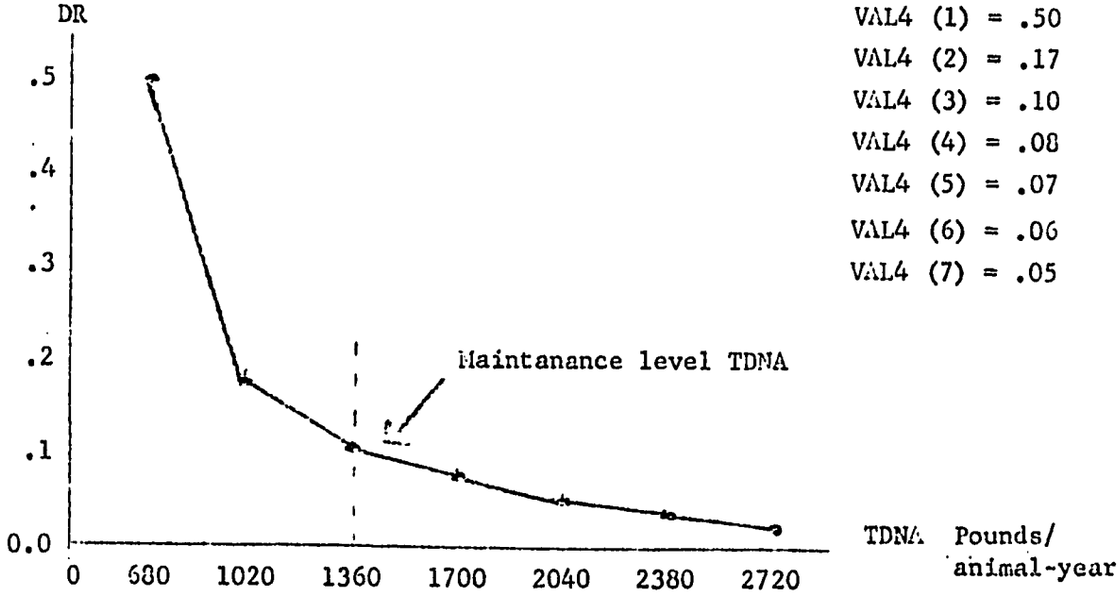


Figure 3 (b) MODERN DEATH RATE VS. TDNA

various ages of Fulani cattle and data on the age distribution of Fulani cattle due to Mallam Tigani (B1). The resulting herd average for maintenance was 1360 pounds of TDN per animal year. The death rate curves of Figure 3 were developed in consultations with knowledgeable animal scientists.

Equation (3) of subroutine DEMOG computes the extraction ratio or "off-take" that is feasible at various levels of nutrition.

(3) ERP = PF * BR/(PF + PM) - DR

Where:

ERP = Unlagged extraction ratio -- proportion of herd that can be removed annually without changing herd size.

PF, PM = Number of herd females and males.

BR, DR = Birth and death rates as defined above.

Equation (3) is derived by finding the sales rate that will exactly balance the excess of herd births over deaths and dividing this rate by the total herd population.

In reality, births, deaths, and extraction ratios do not change instantaneously with changes in nutritional levels and/or population sizes, but rather lag behind changes in these variables. The variables BR, DR and ERP must therefore be operated on to introduce these lag effects. Equations 4, 5, 6, 7, 8, 9, 10, 13, 14, 16 and 17 perform this function. Equation (4) computes the auxiliary variable A1 used in later computations:

(4) A1 = BR * PF

Where:

A1 = Total live births/year -- K animals/year.

BR = Proportion of females yielding live calves per year.

PF = Population of females - K animals (recall that this subroutine can apply to either the traditional or modern herd).

In the case of animal births, introduction of an appropriate lag is somewhat more complicated than for deaths and extraction ratios. This is due to the fact that a natural increase in female population does not influence the calving rate for several years, but a natural decrease in population has a much more rapid influence (a delay approximating the gestation period). This difference in delay, depending upon whether the population is increasing or decreasing, is accounted for by Equations (5-10). Equation (5) computes an exponential average of A1:

(5) A1P = A1P + (DT/.3) * (A1 - A1P) 1/

Where:

A1P = An exponential average of A1.

DT = Time increment used in the simulation (years).

A1 = As computed in Equation 4.

It will be noted that the variable (A1 - A1P) is proportional to the derivative dA1/dt and, therefore, has the same sign as the rate of change of A1. 2/ Statements (6-9) of the subroutine assign one value (D1) to the delay if (A1 - A1P) is negative and a larger value (D2) if this quantity is zero or positive. Finally, Equation (10) computes A2 which is a lagged version of A1. (The lag here is first order exponential).

1/ It should be noted that in this and all subsequent equations with the same variable appearing on both sides of the equal sign, a time lag of DT years exists between the right and left hand values of the variable in question. This is a consequence of the iterative nature of the simulation wherein all variables are updated every DT time units.

2/ More precisely, this technique should be applied to the variables PF and BR separately. The assumption implicit here is that the lag effects due to PF and BR are identical. This modification can, and perhaps should, be made at a later date.

(10) A2 = A2 + (DT/BRDEL) * (A1 - A2)

Where:

A2 = Live births (K animals/year)

DT = Time increment of the model - years

BRDEL = D1 (A1 - A1P) ≤ 0

= D2 (A1 - A1P) > 0

A1 = Unlagged live births

It is assumed in the model that births are evenly distributed between males and females. Equations (11) and (12) compute BF and BM as .5 A2 where BF and BM are respectively the female and male births per year. Equations (13-17) compute the actual (lagged) deaths of females and males, DF and DM, and the lagged extraction ratio ER:

(13) A3 = PF * DR

(14) DF = DF + (DT/D3) * (A3 - DF)

(15) A4 = PM * DR

(16) DM = DM + (DT/D4) * (A4 - DM)

(17) ER = ER + (DT/D5) * (ERP - ER)

Where:

PF = Population of females (K animals)

PM = Population of males (K animals)

DR = Unlagged death rate.

DF = Female deaths (K animals/year)

DM = Male deaths (K animals/year)

ER = Actual extraction ratio

ERP = Unlagged extraction ratio

The next two equations of subroutine DEMOG compute respectively the number of animals in the female and male populations as time integrals of population flow rates.

(18) PF = PF + DT * (BF - DF - SF - RFT)

Where:

PF = Population of females (K animals)

BF = Female births per year

DF = Female deaths per year

SF = Female sales per year

RFT = Rate females are transferred from the traditional sector to modern grazing reserves (K animals/year)

(19) PM = PM + DT * (BM - DM - SM - RMT)

Where:

PM = Population of males (K animals)

BM = Male births per year

DM = Male deaths per year

RMT = Rate males are transferred from the traditional sector to modern grazing reserves (K animals per year)

It can be seen that Equations (18) and (19) are discrete numerical approximations to the continuous integrals which determine PF and PM.

Equations (20) and (21) of subroutine DEMOG compute the quantity and value of milk produced by the traditional and modern herds:

(20) QM = PF * PFCA * YMA * TABLIE (VAL5, 1360., 1360., 2, TDNA)

(21) YM = QM * PRM

Where:

QM = Quantity of milk produced - thousands of pounds (avoir.) per year

PF = Female population - thousands

PFCA = Proportion of females lactating

YMA = Average annual output per animal - pounds per animal

TABLIE (VAL5 . . .) = A sub-program which introduces a milk production factor determined by level of nutrition - TDNA

YMI = Income from milk - thousands of pounds/year

PRMI = Price of milk - £/pound

The Master Simulation Program

In this section the structure of the simulation program which controls the operation of subroutine DEMOG, provides for the introduction of alternative modernization policies, generates output data and performs other executive functions will be described. Discussion will begin with a description of policy options which are presently built into the model. (Others can be included as the need arises.)

Policy Variables: At the beginning of each simulation run, certain modernization policies are established and the model then generates the consequences through time. The model is constructed so that a number of simulation runs can be processed sequentially. Equation numbers below refer to equations of the simulation program included in the appendix. Equations (181) and (182) allocate new crop land to cash crops and animal feed crops. (The expansion of food crop land in the model is exogenously determined by the rate of population growth.)

(181) RLC2 = C17

(182) RLC3 = RLTT - RLC2

Where:

RLC2 = Rate at which land is transferred to cash crops in fly free Northern Nigeria (K-acres/year)

RLC3 = Rate at which land is transferred to animal feed crops in the fly free area (K-acres/year)

RLTT = Total rate at which land is transferred (from grazing land) to cash and feed crops (K-acres/year)

C17 = A policy parameter less than RLTT

The assumption is made here that cash and feed crops compete for a limited amount of land (RLTT) converted annually.

Expenditures on fly eradication and grazing reserve development are introduced as policy variables by Equations (183) and (184).

(183) EFE = C18

(184) EXGR = C19

Where:

EFE = Expenditure on fly eradication (K pounds/year)

EXGR = Capital expenditures on grazing reserves (K pounds/year)

C18 = A policy parameter (K pounds/year)

C19 = A policy parameter (K pounds/year)

At the present time the policies embodied in Equations (181-184) are static, i.e., they do not change through time. It is certainly possible to make these change through time, and it may well be of interest later to use the simulation to explore alternative dynamic policies.

Equations (185-193) introduce herd management policies through control of sales rates.

(185) SFT = PFT * (C20 + ELAS1 * SFT * (PA - PAO)/ (PFT * PA))[1/]

(186) SMT = C21 * (PMT - C22 * PFT) + C35 * PMT

Where:

SFT = Sales of females in the traditional sector (K animals/year)

SMT = Sales of males in the traditional sector (K animals/year)

1/ This equation is derived from a supply curve of the form SFT = PFT * (C20 + C * (PA - PAO)) and application of the definition of supply elasticity.

PFT, PMT = Population of females/males in the traditional sector (K animals)

ELAS1 = The price elasticity of supply

PA = Price of animals (pounds/head)

PAO = "Normal" price of animals (This is the value of price about which linearization of the supply curve took place.)

C20, C21, C22, C35 = Parameters which permit exploration of alternative sales policies.

These policies were designed with flexibility to permit simulation of the current behavior of Fulani tribesmen and exploration of alternative policies. Equation (185) describes a positively sloped supply curve. Current parameters allow only little supply response, which appears consistent with limited available data. Equation (186) permits control of the sex ratio by making male sales a function of the difference (PMT - C22 * PFT), the parameter C22 (a number between 0-1) being the desired ratio of males to females. Sales vary in proportion to this difference and tend through time to establish the desired sex ratio, C22. (The fact that Fulani herds are approximately 70% female and 30% male suggests that herdsmen have, in fact, attempted to control the male proportion of the herd.) Response to price is implicit in Equation (186) since female sales changes on the basis of price changes will induce changes in male sales through the sex ratio adjustment mechanism described above. More direct male price response can be added later if the need arises.

Similar relationships (Equations 190-191) exist for management of the modern herd, except that total modern population is also controlled to maintain a prescribed level of nutrition (1/C16 pounds of TDN per animal-year).

Animal price, PA is taken as an exogenous variable as defined by Equation (194).

(194) PA = PAO * (1 + C33T + C34 * SIN (6.2816.T)

Where:

PAO, C33, C34 = Constants

T = Time

This equation makes possible the investigation of effects of secular and seasonal changes in animal price.

Model Structure: The following structural equations complete the mathematical definition of the macro model.

(195) LC3 = LC3 + DT * RLC3

Where:

LC3 = Total land in animal feed crops in fly free Northern Nigeria (K acres)

RLC3 = Rate of change of animal feed crop land (K acres/year)

This equation computes land (a level or stock) as the integral of a flow rate. In an exactly parallel manner, Equations (225) and (221) (appearing later in the model) compute food crop and cash crop land areas:

(225) LC1 = LC1 + DT * RLC1

(226) LC2 = LC2 + DT * RLC2

Where:

LC1 = Total land in food crops (K acres) in fly free area of Northern Nigeria.

LC2 = Total land in cash crops (K acres) in fly free area of Northern Nigeria.

Equations (196), (197), and (203) compute the grazing land area in modern grazing reserves:

(196) AUK3 = EXGR * C2

Where:

EXGR = Capital expenditures on grazing reserves (K pounds/year)

C2 = Acres modernized per pound of capital expenditures (or equivalently K acres per K pounds since the units in the model are K-acres and K-pounds)

AUX3 = Unlagged (ex-ante) rate of land modernization (K acres/year)

A gestation lag is introduced in grazing reserve development by Equation (197).

(197) Call DELAY (AUX3, AUX4, CROUT2, GRGDEL, DT, 3)

Where:

DELAY is a FORDYN(S22) subroutine which introduces distributed delays with various properties.

AUX3 = As defined in Equation 196.

AUX4 = Actual (lagged) rate at which land becomes operational as grazing reserve (K acres/year)

GRGDEL = Gestation delay in grazing reserve development - years

CROUT2 = An array of intermediate rates necessary in simulation of the gestation delay (S22)

Equation (203) computes the total land in grazing reserves, LGM, as the time integral of AUX4:

(203) LGM = LGM + DT * AUX4

Equations (1971-1976) compute the rate at which animals enter the modern sector (and hence leave the traditional) as a function of the additional TDN made available by new grazing reserves and additions to acreage in animal feed crops. (It is assumed that feed crops are only supplied to animals in the grazing reserve sector.)

(1971) RTDN = AUX4 * C9 + RLC3 * C10

Where:

RTDN = Total rate of increase of TDN in the modern sector - K pounds/year^2 (where TDN itself is a flow rate K pounds/year)

AUX4 = Rate of increase in grazing land

C9 = K pounds TDN/acre-year

RLC3 = Rate of increase of animal feed crop land

C10 = K pounds TDN/acre-year

The rate that animals can be added to the modern sector as a result of increased nutrition is computed by Equation (1972):

(1972) RAA = RTDN * C16

Where:

RAA = Rate animals are added to modern sector (K animals/year)

RTDN = Rate of increase of TDN (K pounds/year^2)

C16 = The reciprocal of the TDN required per animal year under "modern" nutritional standards (K animal years/K pounds of TDN)

It is now necessary to determine the number of males and females which, summing to RAA, are added to the modern population. It is initially assumed in the model that the sex ratio of transferring animals is the same as that of the traditional population (this could also be a policy variable) or that:

(1973) RFTT = RAA * (PFT/(PFT + PMT))

(1974) RMTT = RAA - RFTT

Where:

RFTT = Rate females are transferred <u>out of</u> the traditional sector (K animals/year)

RMTT = Rate males are transferred <u>out of</u> the traditional sector (K animals/year)

RAA = Rate animals are added to the modern sector (K animals/year)

PFT, PMT = Female and male populations in the traditional sector (K animals)

The rates animals leave the modern sector are the negatives of RFTT and RMTT (negative departures are arrivals):

(1975) RFTM = -RFTT

(1976) RMTM = -RMTT

Equations (1973-1976) have computed the input variables required by subroutine DEMOG and have utilized some of its outputs, PFT and PMT.

Equations (198) and (199) introduce fly eradication programs into the model and compute the rate at which land is being freed of tsetse fly.

(198) AUX1 = EFE * C1

Where:

AUX1 = The unlagged rate at which land is being freed of fly (K acres/year)

EFE = Expenditures on fly eradication (a policy variable) - (K pounds/year)

C1 = Reciprocal of the eradication cost per acre (K acres/K pounds)

Statement (199) introduces a time lag (1) to account for delays in program implementation:

(199) CALL DELAY (AUX1, AUX2, CROUT1, FEGDEL, DT, 3)

Where:

AUX1 = As above

AUX2 = Actual rate at which fly freed land becomes available for grazing.

FEGDEL = Fly eradication gestation delay - years

Food crop land (LC1) is assumed to grow exponentially with time and population growth as determined by Equation (201):

(201) RLC1 = AL2 * LC10 * EXP (AL2 * T)

Where:

RLC1 = dLC1/dt where LC1 is the food crop land in <u>fly free</u> Northern Nigeria

LC10 = The value of LC1 at time zero (the start of the model)

AL2 = A model parameter (very nearly the annual population growth rate)

T = Time in years

We are now in a position to compute the fly free grazing land of Northern Nigeria, LG, as a function of previously computed variables. This is done by Equation (202):

(202) LG = LG + DT * (-RLC1 - RLC2 - RLC3 + AUX2)

Where:

LG = Fly free grazing land of Northern Nigeria (K acres)

RLC1 = Rate of change of fly free crop land (K acres/year)

RLC2 = Rate of change of cash crop land (K acres/year)

RLC3 = Rate of change of animal feed crop land (K acres/year)

AUX2 = Rate at which land is being cleared of tsetse fly (K acres/year)

Equations (203) and (204) compute respectively the grazing land in the modern and traditional sectors:

(203) LGM = LGM + DT * AUX4

Where:

LGM = Land in modern grazing (K acres)

AUX4 = Rate at which grazing reserves are being established (K acres/year)

(204) LGT = LG - LGM

Where:

LGT = Grazing land (fly free) in the traditional sector (K acres)

LG = Total fly free grazing area (K acres)

LGR = Land in grazing reserves (K acres)

Many reports indicate that the condition of the traditional grazing land in Northern Nigeria is deteriorating because of overgrazing. This effect is introduced into the model by Equations (205) and (206):

(205) GRT = LGT/(PFT + PMT)

Where:

GRT = Grazing rate in the traditional sector (acres/animal)

LGT = Total fly free grazing area (traditional)

(PFT + PMT) = Total traditional animal population

(206) RCON = RCON + DT * C4 * (GRT - GRE)

Where:

RCON = Range condition (a dimensionless number)

GRE = Equilibrium grazing rate (which results in constant range condition) - acres/animal

GRT = Actual grazing rate as computed in Equation (205)

C4 = A parameter that determines the extent of influence of grazing rate upon range condition

Range condition is prevented from diminishing below an unrealistic limit by Equation (2061) which establishes a lower bound for RCON. These equations stipulate that range condition increases or decreases over time if GRT is respectively greater than or less than GRE.

Given range condition, it is now possible to compute the total TDN available from the fly free grazing land.

(207) TDNGT = RCON * C3 * LGT

Where:

TDNGT = Total (traditional) TDN from grass in fly free Northern Nigeria (K pounds/year)

LGT = Total fly free grazing area available to traditional herds (K acres)

RCON = Range condition

C3 = TDN yield per acre - K pounds/K acres

The definitions of RCON and C3 are interdependent. If RCON is assigned the value one at the start of a simulation run (corresponding to a particular year) then C3 is the yield per acre <u>in that year</u>. If RCON is assigned a value one corresponding to maximum climax vegetation, then C3 is the maximum climax yield per acre.

The TDN available to the traditional sector from crop residues is computed by Equation (208):

(208) TDNRES = C5 * LC1 + C6 * LC2

Where:

TDNRES = TDN available to traditional animals from crop residues (K pounds/year)

LC1, LC2 = Land in food/cash crops - fly free Northern Nigeria

C5, C6 = K pounds TDN/K acre - year

Equation (209) computes the total TDN in the traditional sector:

(209) TDNT = TDNGT + TDNRES + C7 * C8 * LGF

Where:

TDNT = Total TDN available to the traditional sector (K pounds/year)

TDNGT = TDN from fly free grassland

TDNRES = TDN from fly free crop residues

LGF = Grassland in fly region - K acres

C8 = Proportion of fly infested grassland that is available to animals during the dry season when the fly recedes

C7 = K pounds of TDN/acre

The last term in Equation (209) represents TDN which animals acquire in fly infested areas during the dry season from LGF - fly infested grazing land. More precisely, LGF should change with time due to growth of crop land, etc. (as does LG), but this second order effect was not included in the model

Equation (210) computes the per animal TDN in the traditional Sector -- an important input variable for subroutine DEMOG:

(210) TDNAT = TDNT/(PFT + PMT)

Where:

TDNAT = TDN per animal in the traditional sector - K pounds/ K animal-year

TDNT = Total TDN

PFT, PMT = Female and male population sizes in the traditional sector

Equations (211-214) compute the corresponding per animal TDN for the modern sector:

(211) TDNGM = LGM * C9

(212) TDNFC = LC3 * C10

(213) TDNM = TDNGM + TDNFC

(214) TDNAM = TDNM/(PFM + PMM)

Where:

TDNGM = TDN from grass in the modern sector - K pounds/K acre-year

TDNFC = TDN from (animal) feed crops - K pounds/K acre-year

LGM = Land in modern grazing reserves - K acres

LC3 = Land in animal feed crops - K acres

C9, C10 = K pounds TDN/K acre-year

TDNM = Total TDN in the modern sector

TDNAM = Per-animal TDN

PFM, PMM = Sizes of female and male populations in the modern (grazing reserve) sector

Statements (215) and (216) of the simulation program call subroutine DEMOG twice: the first time to compute all variables associated with the traditional animal population and the second to compute modern herd variables. The remaining model statements and equations compute a number of variables useful in assessing various modernization policies and provide for the printing of model output data.

Equations (200), (217) and (210) compute demand, supply and imports of beef:

(200) DEM = DI * EXP (AL1 * T)

Where:

DEM = Total Nigerian demand for beef - K animals/year

DI = Initial demand (at the beginning of a given simulation run)

AL1 = A model parameter which determines rate of growth of demand

T = Time

This equation assumes that demand grows exponentially due to population and income effects.

(217) SUP = SFT + SMT + C11 * (SFM + SMM) + C12 * (DFT + DMT) + C13 * (DFM + DMM)

Where:

SUP = Supply - K animals/year (from Northern Nigerian herds)

SFT, SMT, SFM, SMM = Sales of females and males in the traditional and modern sectors - K animals/year

DFT, DMT, DFM, DMM = Natural deaths - K animals/year

C12, C13 = Proportion of natural deaths which are marketed - dimensionless

C11 = A factor, greater than one, to account for heavier animals produced in the modern sector

Imports necessary to satisfy demand are computed as the residual between demand and supply.

(218) CIMP = DEM - SUP

Where:

CIMP = Computed imports - K animals/year

DEM, SUP = Demand and supply

Equations (219) and (223) compute respectively the incomes derived from livestock and cash crops:

(219) YA = SUP * PA

Where:

YA = Income derived from the beef industry - K pounds/year

PA = Price - K pounds/K animals

Equation (220) computes the operating costs of grazing reserve programs

(220) COGR = LGM * C14

Where:

COGR = Operating costs of grazing reserves - K pounds/year

LGM = Total land in grazing reserves - K acres

C14 = Costs of operating grazing reserves - K pounds/K acres

(223) YCC = C15 * LC2

Where:

YCC = Income derived from cash crops - K pounds/year

C15 = K pounds/K acres

LC2 = Land in cash crops in fly free area - K acres

The depreciation of grazing reserve capital is computed by Equation (2231).

(2231) CALL DELAY (EXGR, GRDEP, CROUT3, GRDEPD, DT, 3)

This equation specifies that capital has a mean useful life of GRDEPD years. Given the costs and incomes computed above, it is now possible to compute an overall discounted cash flow criterion function which may be one evaluative measure useful in evaluating alternative modernization policies. Equation (226) performs this function:

(226) CF = CF + DT *((YA + YCC + YM + EXGR - COGR - EFE - GRDEP) * EXP (-AL3 * T))

where:

CF = Cash flow - K pounds

YA = Income derived from beef - K pounds/year

YM = Income derived from milk - K pounds/year

YC = Income derived from cash crops - K pounds/year

EFE = Expenditure on fly eradication - K pounds/year

EGR = Capital expenditures on grazing reserves - K pounds/year

COGR = Operating costs of grazing reserves

GRDEP = Depreciation of grazing reserve capital - K pounds/year

AL3 = The discount rate

T = Time

It should be noted that this cash flow function, by including farm income generated from meat and animals, implicitly includes the effects of range deterioration and associated reduction in available TDN. It does not, however, include soil deterioration or related capital losses which may be caused by overgrazing. While the incomes are farm incomes, the expenses are (assumed to be) government expenses. Consequently, other criterion functions may be more appropriate for particular decisions.

The macro model also includes a number of other performance measures which may be useful in evaluating alternative modernization policies. These are as follows:

(229) FARMI = YA + YM + YCC

Where:

FARMI = Total income (K pounds per year) generated from meat, milk and cash crops in fly-free Northern Nigeria

(230) FARMIA = FARMIA + DT * FARMI

Where:

FARMIA = Accumulated farm income - K pounds

(231) FOREX = C27 * YCC - C28 * CIMP * PA

Where:

FOREX = Foreign exchange earnings of fly free Northern Nigeria - K pounds/year

YCC = Income from cash crops - K pounds/year

CIMP = Cattle imports - K animals/year

PA = Price per animal

C27, C28 = Price adjustment factors (All model prices are producer prices.)

(232) FOREXA = FOREXA + DT * FOREX

Where:

FOREXA = Accumulated foreign exchange earnings - K pounds

(233) ANPROT = C20 * SUP + C30 * QM

Where:

ANPROT = Animal protein - K pounds/year

SUP = Supply of animals - K animals/year

QM = Total milk output - K pounds/year

C29, C30 = Pounds of protein/pound

(234) CERPROT = C31 * LC1

Where:

CERPROT = Cereal protein - K pounds

LC1 = Land in food crops in fly free Northern Nigeria - K acres

C31 = Pounds of protein/acre

(235) GRCAP = GRCAP + DT * (EXGR - GRDEP)

Where:

GRCAP = Value of capital investment in grazing reserves - K pounds

EXGR = Capital investment in grazing reserves - K pounds/year

GRDEP = Capital depreciation of grazing reserves - K pounds/year

(236) VALCAP = (PFT + PMT + C11 * (PFM + PMM))* PAA + GRCAP

Where:

VALCAP = Total value of animal population and related industry capital - K pounds

PAA = Average value per animal - pounds

PFT, PMT, PFM, PMM = Animal populations - K animals

C11 = A factor to increment the value of animals in the modern sector.

Summary -- Model Description

The macroscopic model described above contains a number of implicit assumptions in addition to those explicitly stated above. Some of the more obvious and important ones will be mentioned here. Firstly, this model assumes that trained specialists are available to develop, operate and maintain modern programs such as fly eradication and grazing reserves. The costs associated with these programs should include certain educational expenditures and the "gestation" lags might well be influenced

by the time delays in educating necessary personnel. A careful look at the education sector is necessary in order to adequately establish all program costs and gestation lags in the many development programs. A second major assumption built into this model is that a marketing system exists which provides necessary inputs for the various sectors and purchases outputs of the production sectors. Again, a study of marketing development, costs and associated gestation lags is necessary in order to assign realistic values to certain macro model parameters. Another major assumption is that grazing rate and marketing policies in the modern production sector can be enforced or, in other words, that policies can be made compatible with the given socio-political environment.

These assumptions are among the more obvious; there are perhaps other, more subtle ones, which affect the relevance of this model to development problems in Northern Nigeria. All model assumptions should be carefully re-examined -- preferably by objective experts who have not participated in the construction of the model. Such an evaluation can lead to further model improvements and is a logical next step in the development of an operational simulation model.

Tests of Macro Model II

In the course of research to date, three types of model tests were carried out: "debugging" tests to eliminate logical errors, sensitivity analyses on key model parameters and preliminary runs exploring alternative strategies for modernization. The latter two are discussed in this section.

Sensitivity tests were preceded by a careful assignment of numerical values to the many parameters of the model. These assignments were based upon the large volume of available secondary data and the educated guesses of experts with Nigerian experience. The objective was to establish a set of probable or "nominal" values for these parameters. These individual parameters were then varied to determine the sensitivity of the model to errors in measuring these parameters. Such knowledge improves allocation of research resources to further data acquisition. Further, knowledge of these sensitivities is helpful to policy makers who have to choose among alternative programs.

Table I presents the results of sensitivity analyses for eleven parameters in the traditional sector. These parameters are considered both important and inaccurately known. Future model tests will examine other relevant parameters for sensitivity.

Run 1, the so called "standard run," was made with all parameters assigned their nominal values. The model printout of the appendix lists all nominal parameter values used in these runs. Table I also tabulates values of certain endogenous variables after 30 years of simulated time. These variables provide a means of measuring effects due to changes in individual parameters and are as follows:

SENSITIVITY ANALYSIS -

RUN	C3	C4	C5	C6	C7	C8	C12	GRE	LG_o	PFT_o	PMT_o
	PARAMETER VALUES										
1	156	.003	547	128	241	.2	.65	8	37000.	5840	2160
2	172	"	"	"	"	"	"	"	"	"	"
3	156	.0033	"	"	"	"	"	"	"	"	"
4	"	.003	602	"	"	"	"	"	"	"	"
5	"	"	547	141	"	"	"	"	"	"	"
6	"	"	"	128	265	"	"	"	"	"	"
7	"	"	"	"	241	.22	"	"	"	"	"
8	"	"	"	"	"	.2	.715	"	"	"	"
9	"	"	"	"	"	"	.65	8.8	"	"	"
10	"	"	"	"	"	"	"	8	40700.	"	"
11	"	"	"	"	"	"	"	"	37000.	"	2376
12	"	"	"	"	"	"	"	"	"	6424	2160
13	"	"	360	100	200	.1	"	15	"	5840	"
14	"	"	950	150	362	.33	"	5	"	"	"

TABLE I
- TRADITIONAL SECTORS

MODEL VARIABLES @ T = 30 YEARS						
PFT	PMT	RCON	FARMI	CK	FOREX	REMARKS
5715	2067	.671	84.4	1.15	21.7	standard run
5843	2111	.662	85.7	1.17	22.5	C3 changed
5673	2051	.639	84.0	1.15	21.5	C4 changed
5979	2166	.660	87.0	1.17	23.2	C5 changed
5722	2070	.670	84.5	1.15	21.8	C6 changed
5842	2113	.664	85.7	1.16	22.4	C7 changed
5842	2113	.664	85.7	1.16	22.4	C8 changed
5715	2067	.671	85.4	1.17	23.1	C12 changed
5620	2030	.602	83.5	1.15	21.2	GRE changed
5931	2145	.702	86.0	1.17	22.9	LG_o changed
5713	2067	.671	84.4	1.15	21.7	PMT_o changed
5709	2064	.664	84.4	1.18	21.7	PFT_o changed
3262	1154	.216	60.4	.983	8.4	worst nutrition case
8988	3274	.866	116.5	1.37	39.6	best nutrition case

PFT = Population of females in the traditional sector (thousands)

PMT = Population of males in the traditional sector

RCON = Range condition - ratio of grass yield per acre in the 30th year to that in the first year

FARMI = Farm Income (meat and milk) in the 30th year - millions of pounds/year

CF = Cash Flow-accumulation of 30 year milk and meat incom stream discounted at 6% - billions of pounds

FOREX = Foreign eschange - millions of pounds/year

With the nominal data values of Run 1, the traditional herd size remained virtually constant over the thirty year period (8 million initially and 7.8 million at the end of 30 years) and the range condition deteriorated to 67% of its initial value.

In runs 2 through 12 of Table I, individual parameters are successively increased by 10% and the influence on PFT, PMT, RCON, FARMI, CF and FOREX are tabulated. For convenience, the 11 parameters tested for sensitivity are defined below:

C3 = #TDN/acre in fly free grazing areas

C4 = Parameter determining rate of range land deterioration as a function of the difference between actual and equilibrium grazing rates

C5 = #TDN/acre from food crop residues

C6 = #TDN/acre from cash crop residues

C7 = #TDN/acre in fly infested grazing areas

C8 = Proportion of fly infested grazing land of Northern Nigeria grazed during the dry season

C12 = Proportion of natural deaths marketed in the traditional sector

GRE = Equilibrium grazing rate, acres/animal year in fly free area - that grazing rate which will maintain the existing range condition (Since animals spend only part of the normal year in the fly free area, this rate is accordingly adjusted downward from yearly figures.)

LG_0 = Initial (at start of model run) area of fly free grazing land - K acres.

PFT_0 = Initial size of traditional female herd - K animals

PFM_0 = Initial size of traditional male herd

The data of Table I indicate that C3, C5, LG_0 and C12 more significantly affect model behavior than do the other parameters of the sensitivity analyses. Interestingly, changes in the initial population sizes, PMT_0 and PFT_0 do not strongly affect the behavior of model criteria variables. This is encouraging in light of the uncertainty existing vis a vis these numbers.

Runs 13 and 14 of the Table were made with worst and best case estimates of available nutrition. As indicated, wide variations in herd sizes and income levels resulted. Worst/best case populations at 30 years ranged from 3.4 million to 12.3 million animals. These results underline the importance of adequate nutrition to the productivity of the Northern Nigerian beef industry. Such sensitivity analysis is but a beginning and will continue as the research proceeds.

The complete output for one 30 year computer run (data printed at five year intervals) appears in Table II. This run is the so called "standard' run of Table I which is based upon nominal values of all parameters and the assumption of no modernization programs. Some interesting trends can be noted from these data: A steady decline in range condition due to overgrazing and a decline in grazing land area due to growth of the crop sector. Traditional herd population remains relatively constant in spite of these trends due to an increase in nutrition from crop residues.

Work to date has included a limited number of computer runs to explore alternative modernization programs for the beef industry of Northern Nigeria.

TABLE II

THIRTY YEARS OF

MACHO MOD II

STATE VARIABLES, A-E

	A	B	C	D	E
TIME					
	PET	PEM	SUP		
	PMT	PMM	DMT	RGCM	LCT
	SOT	SOM	ERT	ERM	LCM
	TDMAT	TDMAM	LGT	LGM	LG
5	5.51+003*	5.555+001	1.163+003	9.495-001	9.495+003
	1.903+003	3.29[illegible]	9.29[illegible]	3.945-001	1.606+003
	3.507+001	8.[illegible]	6.237+002	1.000+013	3.611+004
	1.5[illegible]	4.[illegible]	3.511+004		
10	5.[illegible]	[illegible]	1.13[illegible]	8.5[illegible]4-001	1.[illegible]
	1.964+003	[illegible]	1.[illegible]+003	4.511-001	1.620+003
	3.5[illegible]-001	[illegible]	7.974+002	1.000+013	3.512+004
	1.907+003	4.15[illegible]+003	3.412+004		
15	5.503+003	4.111+001	1.1[illegible]+003	8.46[illegible]-001	1.148+004
	1.970+003	[illegible]	1.23[illegible]+003	4.617-001	1.[illegible]+003
	3.596-001	[illegible]	8.354+002	1.000+013	3.402+004
	1.925+003	4.09[illegible]+003	3.3[illegible]+004		
20	5.54[illegible]+003	4.127+001	1.16[illegible]+003	7.915-001	1.2[illegible]+004
	2.00[illegible]+003	[illegible]	1.429+003	4.632-001	1.600+003
	3.6[illegible]+001	[illegible]	[illegible]	1.000+013	3.2[illegible]+004
	1.93[illegible]+003	[illegible]	3.1[illegible]+004		
25	5.619+003	[illegible]	1.161+003	7.331-001	1.4[illegible]+004
	2.02[illegible]+003	[illegible]	1.6[illegible]+003	4.642-001	1.6[illegible]
	3.611+001	[illegible]	8.717-002	1.000+013	3.1[illegible]+004
	1.95[illegible]+003	[illegible]	3.[illegible]+004		
30	5.7[illegible]	[illegible]	1.2[illegible]	6.705-001	1.5[illegible]+004
	2.0[illegible]	[illegible]	1.[illegible]	4.643-001	1.6[illegible]+003
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]		

* NOTE THAT ALL NUMBERS ARE PRINTED IN EXPONENTIAL NOTATION. i.e.

$5.515 + 003 = 5.515 \times 10^3$

SIMULATED PLAYOFF - STATISTICS

ROW NUMBER 2

POLICY VARIABLES,F,G,H			CRITERION VARIABLES,I,J,K		
F	G	H	I	J	K
			CF	YE	
RLC2	BFL	EXGT	YA	ICGEX	FABM1
RLC5	SFT	SFM	FCC	ICGEX	EXPBIA
RLT1	SM1	SM2	CMGT	ALEPGT	CFCFCT
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

These results are summarized in Table III where the influence of a number of alternative modernization programs upon a series of criterion variables is tabulated. While conclusions regarding policies for Northern Nigeria should not and cannot be drawn from these preliminary results, they are presented to illustrate how the model might be used at a later date. The criterion variables are those of Table I plus the following:

PFM, PMM = Modern herd population sizes after 30 years - thousands

YA = Producer income from sale of animals at T = 30 years - millions of pounds per year

YM = Producer income from milk production - millions of pounds per year

Run 1 of the table is the standard run of Table I. Since this run assumes no modernization programs, it provides a base for comparison with runs for more modern systems (see 2 through 10 of Table III).

Runs 2 and 3 explore the impact of improved herd management practices through reduction of male/female ratio. Run 3 indicates that a reduction of this ratio from .36 (approximately the ratio at the present time) to .27 increases all model criterion variables, some by as much as 10 percent.

Run 4 provides for the development of grazing reserves by an annual capital investment of 100,000 pounds. At the end of 30 simulated years, some one million animals are on modern grazing reserves and the various model measures of performance are substantially improved.

Runs 5 and 6 explore reduction of the male/female ratio in the modern sector. These changes did not produce significant changes in criterion variables due to assumptions which prevented the female herd size from changing as the male herd size varied. Run 7 introduces an allocation of 100,000 pounds per year to tsetse fly eradication programs, resulting in modest increases in traditional herd size and criterion variables (see Table III).

SOME SAMPLE POLICY RUNS

PARAMETER VALUES

Run	C17	C18	C19	C20	C21	C22	C23	C24	C25	RLTT	C26	C35
1	0	0	0	.023	.29	.05	.3	.6	.05	0	.7	0
2	"	"	"	"	"	"	"	"	"	"	"	.1
3	"	"	"	"	"	.02	"	"	"	"	"	.1
4	"	"	100	"	"	.05	"	"	"	"	"	0
5	"	"	100	"	"	"	"	"	.02	"	"	"
6	"	"	100	"	"	"	"	"	.2	"	"	"
7	"	100	0	"	"	"	"	"	.05	"	"	"
8	"	0	"	"	"	"	"	"	"	370	"	"
9	370	"	"	"	"	"	"	"	"	370	"	"
10	185	"	"	"	"	"	"	"	"	370	"	"

TABLE III

USING MACRO MODEL II

PFT	PMT	PFM	PMM	RCON	FARMI	CF	FOREX	YA	YM	REMARKS
5715	2067	61.30	3.07	.671	84.5	1.15	21.8	21.5	35.8	Standard run
6042	1746	61.30	3.07	.676	87.8	1.18	24.0	23.0	37.8	Trad.herd.mgt.
6126	1663	61.30	3.07	.678	88.9	1.19	24.6	23.4	38.3	" " "
4931	1809	1025	72.4	.606	93.7	1.18	31.7	28.1	38.4	Intro. of modern graz. reserves
4931	1809	1025	43.4	.606	93.8	1.18	31.7	28.1	38.4	Intro.graz.res. & sex ratio mgt.
4931	1809	1025	217.2	.606	93.6	1.18	31.4	27.9	38.4	" " " "
6146	2138	61.3	3.07	.720	88.6	1.16	24.0	23.0	38.4	Intro. Fly Erad.
0.	0.	9608	738.8	2.07	197.0	1.67	132.1	95.0	74.7	New land in animal feed crop
5701	2065	61.3	3.07	.606	273.0	2.09	304.7	21.4	35.7	New land in cash crops
4320	1713	4872	345.2	.669	249.8	1.91	226.4	63.5	64.7	New land in cash & animal feed crops

In run 8, animal feed crop land is allowed to increase by 370,000 acres per year with the feed produced going to animals in the modern sector. After 30 years have elapsed, the additional feed produced is sufficient to support all animals at modern levels of nutrition and traditional herd sizes are zero. Substantial increases in all criterion variables result from this policy. Run 9 shifts this same crop land increase to cash crops in order to weigh the relative benefits of cash versus animal feed crop expansion. The simulation results indicate that expansion of cash crops is much more productive than an equivalent expansion of animal feed crops. In run 10, both cash and animal feed crops are allowed to increase at the rate of 185,000 acres per year. The results are seen to be less favorable than those of run 9 and more so than those of run 8.

While at this time no policy implications should be drawn from the simulation results, experiments and computations such as those described above serve to illustrate the use of the model and provide deeper understanding of the complex and interrelated consequences of various modernization programs. Further refinement of the information base (by applying results of sensitivity analyses) and model assumptions will lead to further improvements in this model.

In conclusion, it is felt, as a result of experience to date with Macro Model II, that the general level of detail developed in this model is appropriate for analyzing many important policy questions for beef production. More detailed models, while capable of answering more specific questions, quickly compound data problems and are much more expensive to construct and test. The next section plans to extend and refine Macro Model II.

Part IV

FUTURE RESEARCH

The description of future research possibilities which follows is ordered according to the probable sequence in which this research will be undertaken: (1) further development of Macro Model II (emphasizing the beef industry); (2) modeling those elements of the Nigerian agricultural model which have the greatest interaction with the beef sector; (3) development of the remaining elements of the model of the entire Nigerian agricultural economy. The importance of each major research alternative is briefly discussed, and the research and modeling priorities are initially determined utilizing as criteria: (1) the potential importance of the economic subsector or development possibility to Nigerian development; (2) the interdependence of the sector with the beef sector (3) the desirability of a more detailed, more complete model of the beef sector of the economy.

Macro Model II - Further Developments

Within the currently funded fiscal year (ending September 30, 1968), top research and modeling priority will be given to further tests and refinements of Macro Model II and a more detailed development of selected crop production and processing sectors which have significant direct interactions with the beef sector. Since these sectors provide a supplemental source of nutrients (in addition to traditional grazing lands) to the livestock population, substantial technological improvements in these crop production enterprises (which appear imminent) can have a substantial impact on the livestock sector of the economy. In addition, there are potential efficiencies in crop by-products (groundnuts, soybeans, cotton, etc) utilization which could substantially improve the nutritional levels of the livestock population.

Substantial increases in total market supply of some food crops (through technological change) could cause the acreage normally allocated to those crops to be diverted into crops more suitable for other purposes, such as animal feed crops. If market supplies would substantially increase and diversion did not take place, one would expect a substantial reduction in consumer prices for foods of plant origin, resulting in a substantial increase in real income for the consumer population. If this would occur or if the levels of consumer income substantially increased for other reasons, the relative and the total demands for plant versus animal protein sources could greatly shift. The consequent changes in the demand for beef could have a substantial impact on the entire beef industry. Thus the grafting of selected detailed crop sectors into our current model seems to have high priority because of the potential impact of changes in these sectors on the beef sector, our current emphasis.

Other research and modeling possibilities which will be considered include the development of a more detailed beef animal population demography subroutine. For an evaluation of some herd management policies, it might be desirable to be able to trace specific impacts of the policy on the age distribution of the beef population. Since the productivity/input ratios vary substantially according to the age of the animal, greater precision in policy comparisons might be achieved by detailing the age composition and sex ratio within each age group to the entire Nigerian herd. Further, the incidence of disease is often highly selective on specific age groups with the herd. Thus, the consequences of various levels and combinations of disease and parasite control programs might be more accurately predicted. The effect of alternative marketing policies or market incentive systems (differential tax rates, differential prices on younger or older animals, male or female) also could be more easily estimated. A more detailed demographic subroutine

has been modeled and is described in Appendix I. While it has not been specifically tested and incorporated into the current Macro Model II, the framework could easily be adapted into the current beef sector model if there was sufficient demand for it. Further, it could be useful in modeling other perennial crop and livestock sectors where productivity and, possibly, management policies would vary according to the population age composition. At this juncture, this level of disaggregation does not appear to be required in the beef industry model.

Another modernization alternative for the beef industry is the introduction of feedlots. A feedlot subroutine has tentatively been modeled, but not included in the current beef industry macro model or this report. The feedlot subroutine can be viewed as one example of a modernization alternative which could be inserted into the current model if investments in this particular development were being contemplated. Feedlots themselves conceivably could have a substantial impact on the efficiency of the Nigerian beef industry, in that they could be used to improve animal quality immediately prior to slaughter. Feedlots could alleviate much of the weight loss currently incurred while trekking cattle to market. More rapid weight gains for the older, less efficient animals (especially males) also could speed sales and improve herd productivity and efficiency. Further, feedlots can provide a more manageable environment than many of the current production techniques. Not only would a more efficient production process be the likely result, but improved harvesting and storage methods, utilization of processing by-products and supplemental feed could provide a more efficient use of available nutrient resources.

Other modeling possibilities which could beutilized in making the current macro model more realistic and more sensitive to special development problems in the beef industry are model disaggregation to represent several regions or seasons. Conceivably, the current model could be multiplied several time in size and slightly modified to provide a more realistic view of the different resources available, size of the animal population, and environmental conditions in several regions of Northern Nigeria (or in other underdeveloped areas). However, regional disaggregation would require a detailed breakdown of resources available by regions, the animal population in each region, and the relative regional beef demand functions, cattle population movement, and productivity differences among regions. The model could be further complicated by disaggregating the year into six-month intervals to account for the wet season and dry season in Nigeria. Substantial weight gains are noted in the wet season and significant weight losses often occur in the dry season. Thus development programs which are intended to alleviate these weight losses could be more accurately evaluated by separately considering the wet and dry seasons and the resources available in each season. Then the effects of policies instigating irrigation, storing feed resources for the dry season, production and use of supplemental animal feed, and stringent herd management policies in the dry season could be directly evaluated. Since other modeling alternatives currently appear to have a higher benefit/cost ratio, these disaggregations will probably not be attempted in the near future.

Tanstitional Modeling Extension - Macro Model II

While the aforementioned developments are expansions of the model which apply primarily to the beef industry, there are several modeling

possibilities which can significantly add to the beef industry while providing pilot studies of important elements of the general agricultural model which will be developed during 1969-70. Some of the aforementioned further developments of Macro Model II fit into this framework. Further key elements in the transitional modeling phase (approximately from mid-1968 through March, 1969) is researching and modeling some remaining important parts of the crop production and processing sector. Initially, the research team would concentrate on those crops and forages which can provide substantial inputs into the livestock industry, then broaden its inquiry into other important crop production and processing areas. Further, a significant addition to the current Macro Model II would be the marketing, transportation, and processing system for beef. Since the current beef marketing system appears primitive, substantial payoff might result if modernization alternatives would be introduced into the sector. Further the beef marketing system model can be viewed as a pilot model for other agricultural marketing systems, adding to its contribution to our long range objectives.

Current systems science control theories are available which might prove useful in optimizing some subsystems within the current macro model. If these control and maximization techniques can be effectively applied to elements within the current model, some development or management policies which are not comprised of multiple objective functions may be automatically determined within the model using feasible optimization techniques. To the extent that these techniques do prove feasible in the beef model, they should prove applicable to similar management or policy resource allocation problems in other sectors of the general model which are to be developed.

Several other extensions of the current model are possible during the transitional modeling phase. The derived demand for the products of the education extension, research and credit institutions to implement selective modernization alternatives will be considered. Modern production alternatives which might be appropriate for the beef industry (other than the modern grazing reserves and feedlots) will be considered, and the consequences of introducing these alternatives into the current production system will be estimated. Since each of these transitional models are elements of the general Nigerian agricultural model which is being planned, their importance and role in the modeling process will be more clear after the key elements of the general model are brought into view.

Development of the Nigerian Agricultural Model -- 1969-1970

A general model of the Nigerian agricultural economy will be developed emphasizing the major sectors of the agricultural economy, the interaction among these sectors, and the further interaction between the agricultural economy and the industrial sector of Nigeria. The crucial issues which need to be effectively considered or evaluated through the global simulation model are (1) the impact of various potential genetic and other technological and managerial developments in the agricultural sector; (2) the means of implementing these developments, and (3) other policies to implement and increase growth in the economic activity and social welfare in Nigeria. The major elements of the general agricultural model of Nigeria will be the following: (1) the livestock and crop production and processing sectors (the beef industry model has already been described in substantial detail), (2) the global marketing, transportation, and processing sectors for all major agricultural products and by-products, (3) the changes

in population, total income, income distribution, cost and price levels, marketing technology and consequent efficiency in the transformation from raw products to consumer products resulting from alternative policies, and the effect of these changes on the effective demand for each major agricultural product; (4) the effect of governmental institution -- education, extension, research, credit--and various governmental marketing production, and investment policies; and (5) the interaction between the industrial and agricultural sectors, especially the allocation of labor and capital between these two broad economic sectors in Nigeria; (6) international trade and foreign exchange balances; (7) governmental revenues and expenditures; and (8) regional trade specializations. All of these areas are quite important and interdependent in the development process. While the research process will initially emphasize the crop production and processing sectors and the agricultural marketing system in Nigeria, all of the above factors currently appear to be basic building blocks which need to be given balanced consideration in the long run development of a realistic model of Nigerian agriculture. As these basic elements of the global model are initially studied and developed, and interaction with Nigerian and USAID researchers and policy makers continues, the tentative research priorities can be re-evaluated and modified to better serve the purposes of this project and the potential users of this planning tool.

SUMMARY

A model of the Nigerian beef industry has been constructed and preliminary model tests have been conducted. The technical and economic behavior simulated by this model appears credible. Simulation experiments made with it lead to greater insight into the complex biological and economic interactions affecting the results of alternative modernization policies. Work to date has identified key information gaps and has raised many relevant questions, some pertaining to agricultural research goals.

Further improvement of the data base and further refinement of the model will lead to more effective modernization plans and more informed policy selections for the Nigerian beef industry. During the remainder of this year, the model will be broadened in a number of areas such as meat processing, marketing, transportation, and in crops relevant to animal nutrition. These efforts are planned to provide an orderly transition to the larger problem of modeling the entire agricultural economy of Nigeria. Due to the need to move on to these broader phases, the beef industry model will probably not be the final form for application to policy making, though large strides will have been made toward an operational planning model.

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GLOSSARY

A1 = Total live births/year (kilo animals/year).
(Eqs. 4, 5, 6, 10 in SUB. DEMOG)

A2 = Live births (kilo animals/year).
(Eqs. 10, 11 in SUB. DEMOG)

A1P = An exponential average of A1.
(Eq. 5 in SUB. DEMOG)

AL1 = The rate of increase of demand for animals.
(Eq. 200)

AL2 = The rate of increase of crop land.
(Eq. 201)

AL3 = The discount rate for cash flow in the criterion function.
(Eq. 226)

AUX1 = The unlagged rate at which land is being freed of fly (K acres/year).
(Eqs. 198, 199)

AUX2 = Actual rate at which fly freed land becomes available for grazing.
(Eqs. 199, 202)

AUX3 = Unlagged (ex-ante) rate of land modernization (K acres/year).
(Eqs. 196, 197)

AUX4 = Actual (lagged) rate at which land becomes operational as grazing reserve (K acres/year).
(Eqs. 197, 1971, 203)

BF = Female births per year.
(Eqs. 11, 12, 18, 19 in SUB. DEMOG)

BR = Live birth rate - proportion of all females calving per year.
(Eqs. 1, 3, 4, in SUB. DEMOG)

C1 = Acres freed of fly/pound.
(Eq. 198)

C2 = Acres of grazing land developed per pound.
(Eq. 196)

C3 = #TDN/ acre year on fly free grazing.
(Eq. 207)

C4 = Yields about 1% deterioration in range condition.
(Eq. 206)

C5 = #TDN/acre - year from crop residues.
(Eq. 208)

C6 = #TDN/acre - year from crop residues.
(Eq. 208)

C7 = #TDN/acre - year - fly region.
(Eq. 209)

C8 = Proportion of fly infested grassland grazed during the dry season.
(Eq. 209)

C9 = #TDN/acre on grazing reserves.
(Eq. 211)

C10 = #TDN/acre of feed crop land.
(Eq. 212)

C11 = Factor to account for heavier weight (and value) of animals marketed from modern grazing reserves.
(Eq. 217)

C12, C13 = Proportion of natural deaths which are marketed.
(Eq. 217)

C14 = Cost of operating grazing reserves (pound/acre-year).
(Eq. 220)

C15 = Value of operating grazing reserves (pound/acre).
(Eq. 223)

C16 = Animal years per pound of TDN at "modern" nutritional level (on grazing reserves).
(Eq. 1972)

C17 = A policy variable (K acres/year) added in cash crops.
(Eq. 181)

C18 = A policy variable (K pounds/year) invested in fly eradication.
(Eq. 183)

C19 = A policy variable (K pounds/year capital expenditure) on grazing reserves.
(Eq. 184)

C20 = A policy variable - proportion of females sold in the traditional sector.
(Eq. 185)

C21 = A policy variable that exerts control over the traditional male herd.
(Eq. 186)

C22 = A policy variable - the "target" ratio of males to females in traditional sector.
(Eq. 186)

C23 = A policy variable - determines the sales rate of females in the modern sector.
(Eq. 190)

C24 = A policy variable that exerts control over the modern male herd.
(Eq. 191)

C25 = A policy variable - the "target" ratio of males to females in modern sector.
(Eq. 191)

C26 = A policy variable - proportion of females in the modern herd.
(Eq. 190)

C27 = Ratio of foreign exchange price to producer price.
(Eq. 231)

C28 = Ratio of foreign exchange price to producer price.
(Eq. 231)

C29 = Pounds of protein per pound of meat.
(Eq. 233)

C30 = Pounds of protein per pound of milk.
(Eq. 233)

C31 = Pounds of cere[illegible] protein per acre of food crops.
(Eq. 234)

C32 = Not used.

C33 = Controls secular increases in animal prices.
(Eq. 194)

C34 = Controls seasonal changes in animal prices.
(Eq. 194)

C35 = Parameter affecting male sales policies in the traditional sector.
(Eq. 186)

CF = Criterion function.
(Eq. 226)

CIMP = Computed imports (K animals/year).
(Eq. 218)

COGR = Operating costs of grazing reserves (K pounds/year).

CROUT1 (1)
CROUT1 (2) = Essentially state that there are no funds in the "pipeline" for fly eradication programs.
CROUT1 (3) (Eq. 199)

CROUT2 (1)
CROUT2 (2) = Essentially state that there are no funds in the "pipeline" for grazing reserve programs.
CROUT2 (3) (Eq. 197)

CROUT3 (1)
CROUT3 (2) = Determine initial values of grazing reserve capital.
CROUT3 (3) (Eq. 2231)

D1, D2, D3, D4, and D5 = (Years) Time delays in determining birth rates, death rates, etc. (Eqs. 7, 8, 9, 14, 16, 17 of SUB. DEMOG)

DELAY = A Fordyn subroutine which introduces distrubuted delays with various properties.

DEM = Total Nigerian demand for beef (K animals/year). (Eqs. 200, 218)

DF = Female deaths (K animals/year). (Eqs. 14, 18 in SUB. DEMOG)

DFM = Natural death of females in modern sector. (Eq. 217)

DFT = Natural death of females in traditional sector. (Eq. 217)

DI = (Thousand animals/year) Initial value of demand. (Eq. 200)

DM = Male deaths (kilo animals/year). (Eqs. 16, 19 in SUB. DEMOG)

DMM = Natural death of males in modern sector. (Eq. 217)

DMT = Natural death of males in traditional sector. (Eq. 217)

DR = Death rate - proportion of total population dying per year. (Eqs. 2, 3, 13, 15, in SUB. DEMOG)

DT = Time Increment. (Eqs. 197, 199, 202, 203, 206, 225, 221, 2231, 226, 230, 232, 235 and Eqs. 5, 10, 14, 16, 17, 18, 19 in SUB. DEMOG)

EFE = Expenditure on fly eradication (K pounds/year). (Eq. 193)

ELAS1 = Price elasticity of animal supply in the traditional sector.
(Eq. 185)

ELAS2 = Price elasticity of animal supply in the modern sector.
(Eq. 190)

ER = Actual extraction ratio.
(Eq. 17 of SUB. DEMOG)

ERM = Extraction ratio in the modern sector (maximum percent offtake possible without changing herd size).
(Eq. 17 in SUB. DEMOG)

ERP = Extraction ratio - proportion of herd that matures annually unlagged.
(Eq. 3 in SUB. DEMOG)

ERT = Extraction ratio in the traditional sector (maximum percent offtake possible without changing herd size).
(Eq. 17 in SUB. DEMOG)

EXGR = Capital expenditure on grazing reserves (K pounds/year).
(Eqs. 2231, 226, 228, 235)

EXP = The exponential function (base, e).
(Eqs. 201, 226)

FARMIA = Farm Income (accumulated) - K pounds.
(Eq. 230)

FEGDEL = (Years) Delay in implementing grazing reserve programs.
(Eq. 199)

FOREXA = Accumulated foreign exchange - K pounds.
(Eq. 232)

GRCAP = Capital investment in grazing reserves - K pounds.
(Eq. 235)

GRDEPD = Useful life of grazing reserve capital - years.
(Eq. 2231)

GRE = (Acres/animal-year) Equilibrium grazing rate.
(Eq. 206)

GRGDEL = (Years) The gestation delay in developing grazing reserves.
(Eq. 197)

GRT = Grazing rate in the traditional sector (acres/animal).
(Eq. 206)

LC1 = Total land in food crops in fly free area of Northern Nigeria (K-acres).
(Eqs. 208, 225)

LC2 = Total land in cash crops in fly free area of Northern Nigeria (k-acres).
(Eqs. 208, 221, 223)

LC3 = Total land in animal feed crops in fly free Northern Nigeria (K-acres).
(Eqs. 195, 212)

LC10 = (K-acres) Initial land in food crop land (fly free).
(Eq. 201)

LG = Fly free grazing area (K-acres).
(Eq. 202)

LGF = Fly infested grazing area (K-acres).
(Eq. 209)

LGM = Land in modern grazing reserves (K-acres).
(Eqs. 203, 204, 211, 220)

LGT = Total fly free grazing area.
(Eq. 204, 205)

NCPP = Number of simulation cycles per unit out of output data.

PA = Pounds/animals. Price per animal (paid to herdsman).
(Eq. 194, 185, 190, 1941)

PAO = Normal animal price (In the absence of seasonal and secular factors) - (pounds/animal).
(Eqs. 185, 190, 194)

PF = Population of females (K animals).
(Eqs. 3, 18 of SUB. DEMOG)

PFCAM = Percent of females lactating in the modern sector.
(Eq. 20 in SUB. DEMOG)

PFCAT = Percent of females in lactation in the traditional sector.
(Eq. 20 in SUB. DEMOG)

PFM = Population of females in the modern sector (K-animals).
(Eqs. 214, 2162, 236 and Eq. 18 of SUB. DEMOG)

PFT = Population of females in the traditional sector (K-animals).
(Eqs. 210, 2161, 236, and Eq. 18 of SUB. DEMOG)

PM = Population of males (K-animals).
(Eqs. 3, 19 of SUB. DEMOG)

PMM = Population of males in the modern sector (K-animals).
(Eqs. 214, 2162, 236 and Eq. 19 of SUB. DEMOG)

PMT = Population of males in the traditional sector (K-animals).
(Eq. 210, 2161, 236 and Eq. 19 of SUB. DEMOG)

PRMM = Price of milk in the modern sector (Ƀ/pound).
(Eq. 21 in SUB. DEMOG)

PRMT = Price of milk in the traditional sector (Ƀ/pound).
(Eq. 21 in SUB. DEMOG)

RAA = Rate animals are added to modern sector (K animals/year).
(Eq. 1972)

RCON = Range condition (ratio of yield per acre to yield in base year).
(Eqs. 206, 2061, 207).

RFT, RMT = Rate of females and males that are transferred from traditional to modern production (K animals/year).
(Eq. 1974)

RFTT = Rate females are transferred out of the traditional sector (K animals/year).
(Eqs. 1974, 1975)

RLC2 = Rate at which land is transferred to cash crops in fly free area (K acres/year).
(Eq. 202)

RLC3 = Rate at which land is transferred to animal feed crops in the fly free area (K acres/year).
(Eq. 202)

RLENTH = Determines the length of a given simulation run - adjust as desired. (Years).

RLTT = Total rate at which land is transferred (from grazing land) to cash and feed crops (K acres/year).
(Eq. 182)

RMTT = Rate males are transferred out of the traditional sector (K animals/year).
(Eq. 1974, 1976

RTDN = Total rate of increase of TDN in the modern sector - K pounds/year^2 (where TDN itself is a flow rate K pounds/year)
(Eq. 71)

SF, SM = Sales of females and males per year respectively (K animals/year).
(Eqs. 18 and 19 of SUB. DEMOG)

SFM = Sales of females in the modern sector (K animals/year)
(Eqs. 190, 1901)

SFT = Sales of females in the traditional sector (K animals/year).
(Eq. 135)

SMM = Sales of males in the modern sector (K animals/year).
(Eqs. 191, 193)

SMT = Sales of males in the traditional sector (K animals/year).
(Eqs. 186, 188)

SUP = Supply - K animals/year (from Northern Nigerian herds).
(Eq. 217)

T = Time.

TABLIE = A simulation sub-program which approximates arbitrary functional relationship by straight line segments.

TDNA = Total digestible nutrients per animal (K pounds/year).

TDNAM = Per-animal TDN in the modern sector (K pounds/animal year).

TDNFC = TDN from (animal) feed crops (K pounds/K acre-year).
(Eqs. 212, 213)

TDNGM = TDN from grass in the modern sector (K pounds/K acre-year).
(Eq. 213)

TDNGT = Total (traditional) TDN from grass in fly free Northern Nigeria (K pounds/year).
(Eq. 209)

TDNM = Total TDN in the modern sector (K pounds).
(Eq. 213)

TDNRES = TDN available to traditional animals from crop residues (K pounds/year).
(Eq. 209)

TDNT = Total TDN available to the traditional sector (K pounds/year).
(Eq . 209)

VAL 1 An array of
VAL 2 numbers which
VAL 3 = defines the dependent
VAL 4 argument of the
VAL 5 function.

VAL1 (1)
VAL1 (2)
VAL1 (3) = Determines the function that relates calving rate (proportion of entire female herd per year) to TDN per animal in traditional sector. (Eq. 1 of SUB. DEMOG)
VAL1 (4)

VAL2 (1)
VAL2 (2)
VAL2 (3) = Determines the function that relates calving rate (proportion of entire female herd per year) to TDN per animal in modern sector. (Eq. 1 of SUB. DEMOG)
VAL2 (4)

VAL3 (1)
VAL3 (2)
VAL3 (3)
VAL3 (4) = Determines the function that relates death rate (proportion to entire herd per year) to TDN per year in traditional sector. (Eq. 2 of SUB. DEMOG)
VAL3 (5)
VAL3 (6)
VAL3 (7)

VAL4 (1)
VAL4 (2)
VAL4 (3)
VAL4 (4) = Determines the function that relates death rate (proportion of entire herd per year) to TDN per year in modern sector. (Eq. 2 of SUB. DEMOG)
VAL4 (5)
VAL4 (6)
VAL4 (7)

VAL5 (1)
VAL5 (2) = Determines the function that relates milk production to TDN per animals per year. (Eq. 20 of SUB. DEMOG)

YA = Income derived from the beef industry (K pounds/year). (Eq. 226)

YCC = Income derived from cash crops (K pounds/year). (Eq. 226)

YMAM = Output of milk per animal in the modern sector (pounds/animal-year). (Eq. 20 in SUB. DEMOG)

YMAT = Output of milk per animal in the traditional sector (pounds/animal-year). (Eq. 20 in SUB. DEMOG)

APPENDIX I

DETAILED DEMOGRAPHIC SUBROUTINE

This subroutine illustrates the usefulness of simulation in dynamic demographic analyses of population productivity. It allows the researcher to apply different parameters such as costs, death rates, nutritional requirements, acquisition and salvage values, and marketing policies to different age and sex groups. Where policies affect specific demographic segments within the population, the ability to disaggregate according to these demographic characteristics allows the decision maker to analyze in more detail the resulting changes in efficiency of resource use and total productivity over time. If different demographic groups exhibit substantial productivity and efficiency differences, it may be worthwhile to acquire a more detailed demographic description of the population, acquire the different input-output relationships for each demographic segment, and proceed with more detailed analyses of policies having selective effects within these demographic groups.

Specifically, this subroutine allows one to follow the beef population of Northern Nigeria through time, keeping account of the number in each age and sex group and the additions and subtractions that take place through time, i.e., births, sales, deaths, and transfers to the modern grazing sector. All of these variables can be made functions of different variables as they apply to each age group. For example, the death rate functions and sales functions may involve different variables and parameters for different age groups. Therefore, if the age groups are identified, the results can be more realistic.

In addition to calculating the additions and subtractions for each age group, this subroutine calculates productivity of each age group relative

to the feed resources consumed. Therefore, total productivity -- pounds of gain -- can be calculated and that figure and the gain per unit of feed can both be used. By use of various programming techniques, the numbers and weights of the various categories are calculated each year and transferred through time. Thus, the net effect of sales and deaths on the future herd productivity and efficiency as well as the nutritional contribution to the Nigerian population can be more accurately estimated.

Adaptations of this general type of models should prove useful in analyzing the effects of various marketing policies, taxation policies, price changes, disease control programs and other phenomenon that affect differently each age group in the population. If each age group is followed through time, one can specify the reactions of the total population from these changes more precisely. For example, by identifying the number and age of breeding stock within a given population, the elasticity of supply for given price changes can be analyzed more accurately because the relevant portion of the herd is clearly identified and the gains and losses from expanding or contracting can be more clearly specified. This general idea can be applied to many other changes that might occur.

This subroutine is specifically directed to beef herds, but this general demographic cohort analysis is applicable to many populations. One particular area in which it might prove very useful is in tree crop production. In this activity, productivity varies greatly according to the age of the tree. The identification of age groups of trees is crucial to any analysis of supply response changes through time, resulting from diseases, price changes and cost changes, and management practices which vary according to the demographic groupings in the population being studied.

Certain variables used in this subroutine will be taken from the main program. Others will have to be assigned initial values. Each variable will be defined and sources indicated throughout. The initial values assumed are listed in the last pages of this appendix.

The first calculations involve the allocation of the total digestible nutrients to the various age groups.

(1) TLBS210 = (PFT(2) + PMT(2)) * AVW(2) + (PFT(3) + PMT(3)) * AVW(3) +
(PFT(4) + PMT(4)) * AVW(4) + (PFT(5) + PMT(5)) * AVW(5) +
(PFT(6) + PMT(6)) * AVW(6) + (PFT(7) + PMT(7)) * AVW(7) +
(PFT(8) + PMT(8)) * AVW(8) + (PFT(9) + PMT(9)) * AVW(9) +
(PFT(10) + PMT(10)) * AVW(10)

Where:

TLBS210 = Total weight of all cattle over one year old

PFT(I) = The number of females I years old. PFT(2) = number of 2 year old females

PMT(I) = The number of males I years old

These values are given as initial conditions for first year values. However, they are calculated for I = 1, . . . 10 for each annual iteration and the new value is used in each succeeding iteration.

AVW(I) = The average weight for each age category. I = 1,. . . 10.

This array is assigned initial values for the first year, but calculated within the subroutine for the succeeding years.

(2) TDNT1 = (PFT(1) + PMT(1)) * 1,642.5

This is the total TDN required by the mothers of 1 to 9 month old calves for nursing. It is assumed that the cows nursing calves consume this amount regardless of the total available. The additional TDN requirements they have are calculated with their age group.

(3) TDNT20 = TDNT - TDNT1

Where:

TDNT = Total TDN from the traditional sector. This number is calculated in the main program.

TDNT20 = Total TDN available to animals 2 years and over.

(4) TDNT21 = ((PFT(2) + PMT(2)) * AVW(2) * TDNT20) / TLBS210 + ((PFT(1) + PMT(1)) * .19 * AVW(2) * TDNT20 / TLBS210

(5) TDNT2 = TDNT21 / (PFT(2) + PMT(2)+ (PFT(1) + PMT(1)) * .75)

Where:

TDNT2 = The total TDN available to animals 9-24 months old.

The .19 is a result of ¼ of the 0-1 year olds being 9-12 months old. They will weigh 75% as much as 2 year olds; therefore, .19 = .25 * .75

This is the first equation that illustrates the allocation mechanism used to ration the available TDN. In general, it works as follows:

$$\frac{\text{number of animals X average weight}}{\text{total weight of all animals}} = \text{fraction of the total weight accounted for by this group}$$

This fraction is multiplied times the TDN available to determine the pounds of TDN available to this particular group per year.

(6) TDNT3 = (((PFT(3) + PMT(3)) * AVW(3) +(PFT(4) + PMT(4)) * AVW(4)) * TDNT20) / TLBS210

(7) TDNT34 = TDNT3 / (PFT(3) + PMT(3) + PFT(4) + PMT(4))

Where:

TDNT34 = Number of pounds of TDN available per animal to animals 3 and 4 years old for the year

(8) TDNT51 = ((PFT(5) + PMT(5)) * AVW(5) * TDNT20 / TLBS210

(9) TDNT5 = TDNT51 / (PFT(5) + PMT(5))

Where:

TDNT5 = Pounds of TDN available per animal to 5 year old animals for the year.

(10) TDNT6 = (((PFT(6) + PMT(6) * AVW(6) + PFT(7) + PMT(7)) * AVW(7) +

(PFT(8) + PMT(8)) * AVW(8) + (PFT(9) + PMT(9)) * AVW(9) +

(PFT(10) + PMT(10)) * AVW(10)) * TDNT20) / TLBS210

(11) TDNT60 = TDNT6 /(PFT(6) + PMT(6) + PFT(7) + PMT(7) + PFT(8) +

PMT(8) + PFT(9) + PMT(9) + PFT(10) + PMT(10))

Where:

TDNT60 = Number of pounds of TDN available per animal to animals 6-10 years old for one year

The next set of relationships calculate the pounds gained by the various groups as a function of the TDN available.

(12) LBSG12 = TABEXE (VAL13, 365., 365., 2, TDNT2)

Where:

TABEXE = A simulation sub-program which approximates functional relationships by straight line segments

VAL13 = An array of numbers which defines the dependent argument of the function

TDNT2 = The number calculated by equation number 5

(13) LBSG34 = TABEXE (VAL14, 912., 912., TDNT34)

Where:

LBSG34 = Pounds gained for the year by the animals in age groups 3 and 4

TDNT34 = Value taken from equation 7

(14) LBSG5 = TABEXE (VAL15, 1004., 1004., 2, TDNT5)

Where:

LBSG5 = Pounds gained per animal for the year by animals in age group 5

TDNT5 = Value taken from equation 9

(15) LBSG610 = TABEXE (VAL16, 1004., 1004.2, TDNT60)

Where:

SBSG610 = Pounds gained per animal for the year by animals in the 6-10 age groups

Dr. Deans of the M.S.U. Department of Animal Husbandry developed these gain functions, which are illustrated by Figure (1).

The pounds gained are added to the average weight to give the new average weights for each age group.

(16) AVW(10) = LBSG610 + AVW(9)

AVW(9) = LBSG610 + AVW(8)

AVW(8) = LBSG610 + AVW(7)

AVW(7) = LBSG610 + AVW(6)

AVW(6) = LBSG5 + AVW(5)

AVW(5) = LBSG34 + AVW(4)

AVW(4) = LBSG34 + AVW(3)

AVW(3) = LBSG12 + AVW(2)

AVW(2) = LBSG12 + AVW(1)

AVW(1) = 40.

(17) TWT = AVW(1) * (PFT(1) + PMT(1)) + AVW(2) * (PFT(2) + PMT(2)) +
AVW(3) * (PFT(3) + PMT(3)) + AVW(4) * (PFT(4) + PMT(4)) +
AVW(5) * (PFT(5) + PMT(5)) + AVW(6) * (PFT(6) + PMT(6)) +
AVW(7) * (PFT(7) + PMT(7)) + AVW(8) * (PFT(8) + PMT(8)) +
AVW(9) * (PFT(9) + PMT(9)) + AVW(10) * (PFT(10) + PMT (10))

This array of average weights is calculated every year. TWT is the total weight of the herd.

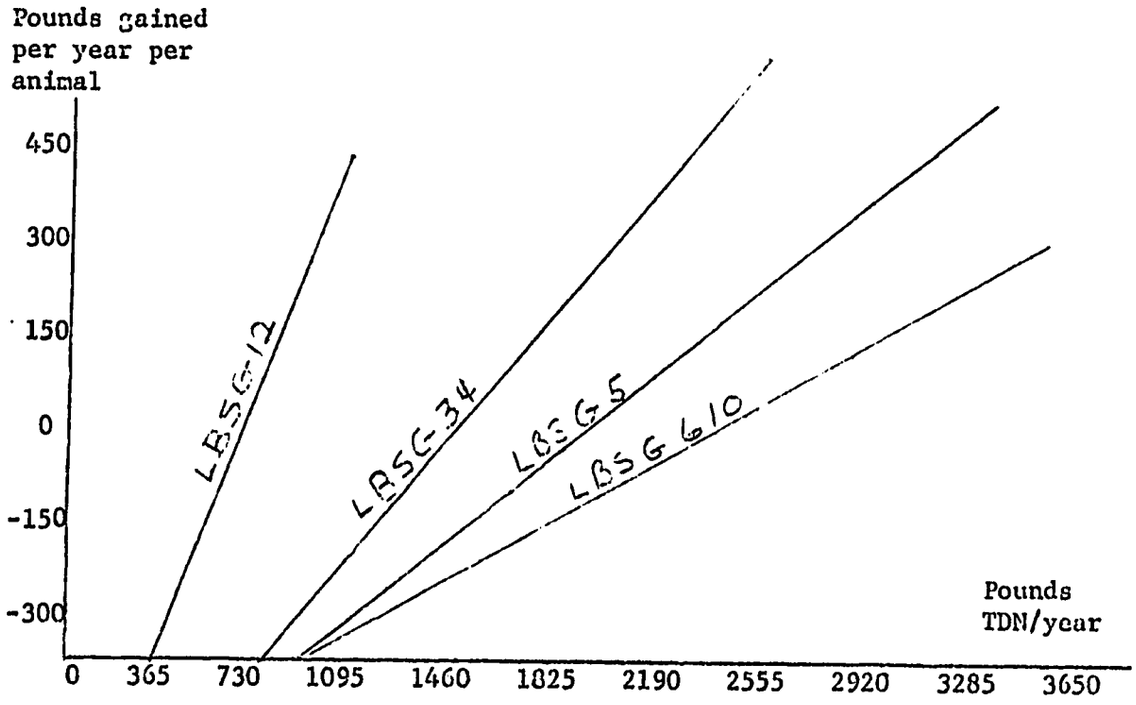
Pounds gained per year per animal
450
300
150
0
-150
-300
LBSG12
LBSG34
LBSG5
LBSG610
Pounds TDN/year
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650

Figure (1)

(18) TDNTB = (TDNT5 + TDNT60) / 2.

(19) BR = TABLIE (VAL10, 785., 785., 3, TDNTB)

Where:

BR = Birth rate

TABLIE = A simulation sub-program which approximates functional relationships by straight line segments

The birth rate is a function of the TDN received by the 4-10 year old females. This function is drawn in Figure (2).

(20) TDNTD = (TDNT2 + TDN34) / 2.

(21) DR24 = TABLIE (VAL11, 0., 228., 8, TDNTD)

(22) DR510 = TABLIE (VAL12, 0., 785., 4, TDNTB)

Dr. Deans of the M.S.U. Department of Animal Husbandry developed these birth and death rate functions. These functions are illustrated in Figures (3) and (4).

In the Nigerian situation, some animals are transferred from traditional grazing herds to modern reserves. The following do loop models this process.

(23) DØ1I = 1, 10

RFTT(I) = PFT(I) / TNFT * RFTT

1 RMTT(I) = PMT(I) / TNMT * RMTT

Where:

RFTT, RMTT = Rates that females and males are transferred to the modern herd

TNMT, TNFT = Total number of males and females in the traditional herd

This particular form transfers whole herds to the modern sector with the same age groupings that exist in the traditional herd. However, alternative policies could be formulated such as taking higher proportions from various age or sex groups.

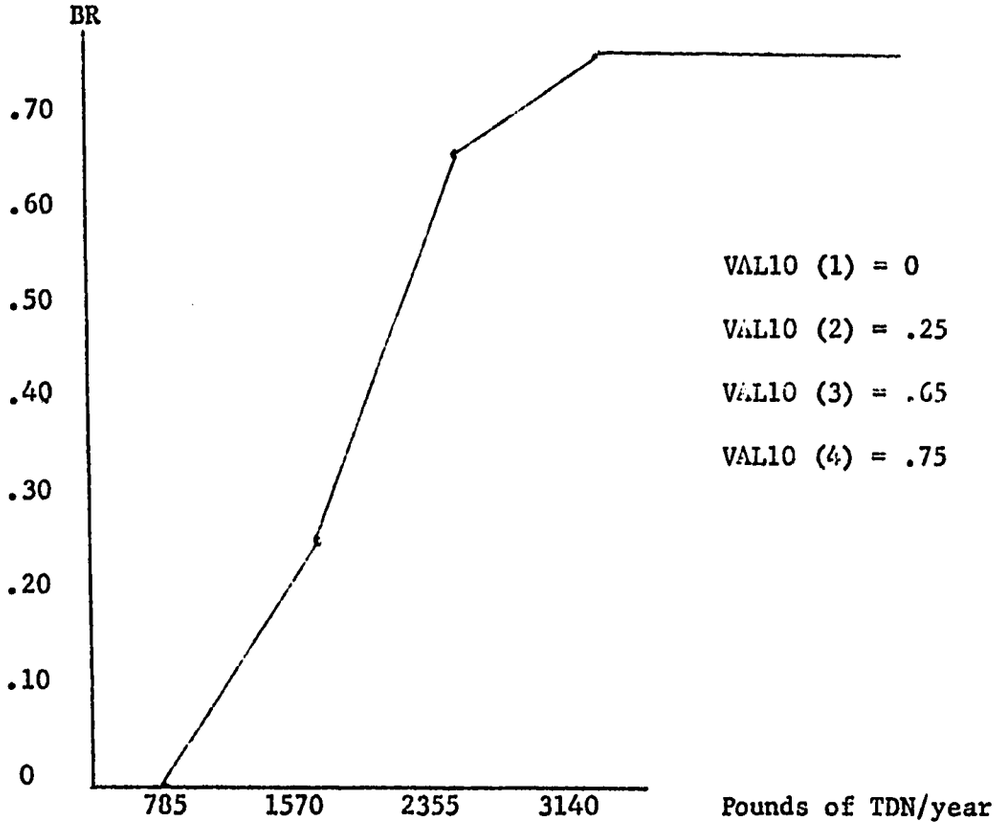
BR
.70
.60
.50
.40
.30
.20
.10
0
785
1570
2355
3140
Pounds of TDN/year
VAL10 (1) = 0
VAL10 (2) = .25
VAL10 (3) = .65
VAL10 (4) = .75

Figure (2)

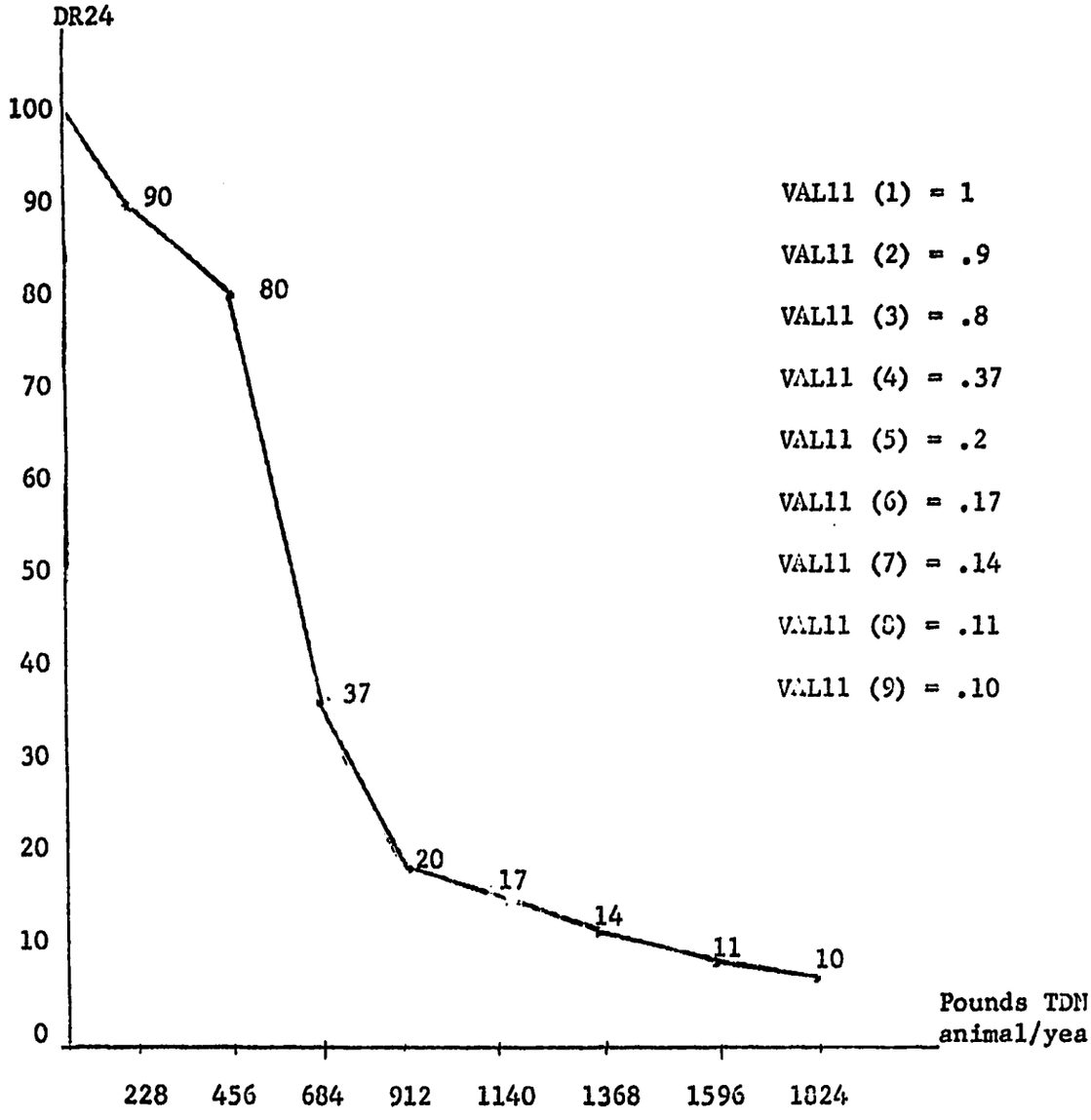
DR24
100
90
80
70
60
50
40
30
20
10
0
90
80
37
20
17
14
11
10
VAL11 (1) = 1
VAL11 (2) = .9
VAL11 (3) = .8
VAL11 (4) = .37
VAL11 (5) = .2
VAL11 (6) = .17
VAL11 (7) = .14
VAL11 (8) = .11
VAL11 (9) = .10
Pounds TDN
animal/yea
228
456
684
912
1140
1368
1596
1824

Figure (3)

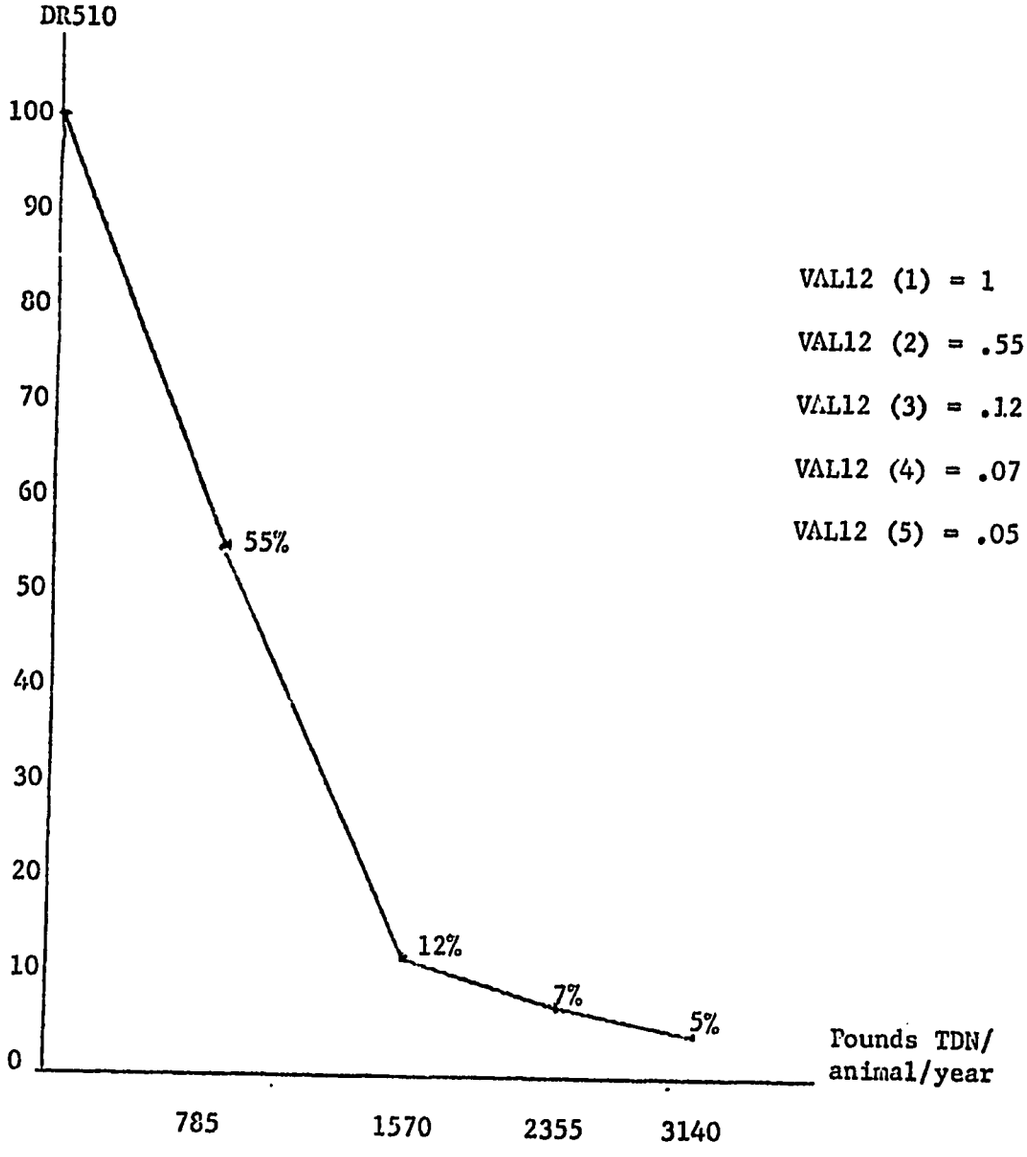
DR510
100
90
80
70
60
50
40
30
20
10
0
55%
12%
7%
5%
785
1570
2355
3140
Pounds TDN/
animal/year
VAL12 (1) = 1
VAL12 (2) = .55
VAL12 (3) = .12
VAL12 (4) = .07
VAL12 (5) = .05

Figure (4)

The sales functions for each age group can be specified in many alternative ways. The form chosen here is to specify a desired population in the category and allow sales to increase or decrease as this desired population is less or greater than the actual population.

First, the desired population must be specified.

(24) DPFT(4) = .12 * TNFT

DPFT(5) = .11 * TNFT

DPFT(6) = .095 * TNFT

DPFT(7) = .08 * TNFT

DPFT(8) = .065 * TNFT

DPFT(9) = .05 * TNFT

DPFT(10) = .045 * TNFT

DPMT(4) = .12 * TNMT

DPMT(5) = .065 * TNMT

DPMT(6) = .023 * TNMT

DPMT(7) = .007 * TNMT

DPMT(8) = .002 * TNMT

DPMT(9) = .001 * TNMT

DPMT(10) = .0007 * TNMT

(25) SFT(1) = 0.

SFT(2) = 0.

SFT(3) = 0.

SFT(4) = (PFT(4) -DPFT(4)) + .04SFT

SFT(5) = (PFT(5) - DPFT(5)) + .08SFT

SFT(6) = (PFT(6) - DPFT(6)) + .12SFT

```
      SFT(7) = (PFT(7) - DPFT(7)) + .15SFT
      SFT(8) = (PFT(8) - DPFT(8)) + .21SFT
      SFT(9) = (PFT(9) - DPFT(9)) + .23SFT
      SFT(10) = (PFT(10) - DPFT(10)) + .17SFT
(26)  SMT(1) = 0.
      SMT(2) = 0.
      SMT(3) = 0.
      SMT(4) = (PMT(4) - DPMT(4)) + .04SMT
      SMT(5) = (PMT(5) - DPMT(5)) + .05SMT
      SMT(6) = (PMT(6) - DPMT(6)) + .09SMT
      SMT(7) = (PMT(7) - DPMT(7)) + .13SMT
      SMT(8) = (PMT(8) - DPMT(8)) + .22SMT
      SMT(9) = (PMT(9) - DPMT(9)) + .26SMT
      SMT(10) = (PMT(10) - DPMT(10)) + .21SMT
(27)  DØ 5 I = 1, 10
      IF (SFT(I).LT.0) SFT(I) = 0
    5 IF (SMT(I).LT.0) SMT(I) = 0
```

The sales of males and females in each age group is determined by the deviation of the actual population from the desired. The functions could include economic variables such as prices and costs if data were available. This general formulation allows one to see the results on herd age and sex composition of various marketing policies that might be followed. If the sale of younger animals is to be encouraged, heavy marketings in the younger groups could be incorporated easily in these equations. Taxes on older cattle, different prices for young stock and price differentials for sex are all realistic situations that can easily be injected into these marketing equations.

The mechanism to transfer the cattle from one group to another as time passes is presented below.

```
(28)  PFT(1) = 0.5 * BR * (PFT(5) + PFT(6) + PFT(7) + PFT(8) + PFT(9) +
                PFT(10))

(29)  PMT(1) = PFT(1)

(30)  PNFT(2) = PFT(1) - (DR1 * PFT(1)) - RFTT(1) - SFT(1)

(31)  PNMT(2) = PMT(2) - (DR1 * PMT(1)) - RMTT(1) - SMT(1)

(32)  DØ 2 I = 3, 5

      PNFT(I) = PFT(I - 1) - DR24 * PFT(I - 1) - SFT(I - 1) - RFTT(I - 1)

     2PNMT(I) = PMT(I - 1) - DR24 * PMT(I - 1) - SMT(I - 1) - RFTT(I - 1)

(33)  DØ 3 I = 6, 10

      PNFT(I) = PFT(I - 1) - DR510 * PFT(I - 1) - SFT(I - 1) - RFTT(I - 1)

     3PNMT(I) = PMT(I - 1) - DR510 * PMT(I - 1) - SMT(I - 1) - RMTT(I - 1)

(34)  DØ 4 I = 2, 10

      PFT(I) = PNFT(I)

     4PMT(I) = PNMT(I)

(35)  TNFT = PFT(1) + PFT(2) + PFT(3) + PFT(4) + PFT(5) + PFT(6) + PFT(7) +
             PFT(8) + PFT(9) + PFT(10)

(36) TNMT = PMT(1) + PMT(2) + PMT(3) + PMT(4) + PMT(5) + PMT(6) + PMT(7) +
            PMT(8) + PMT(9) + PMT(10)

(37)  TNC = TNFT + TNMT
```

These FORTRAN statements model the populations in each group as they are transferred to new age groups each year. The deaths, sales and transfers are subtracted from each group as it moves on through time. The new array of PFT(I) and PMT(I) for I = 1, . . . 10 will be used in succeeding operations.

Initial Conditions

The initial arrays for the average weight and population in age group are:

	0-1	1-2	2-3	3-4	4-5
AVW =	40.	475	645	795	840
PFT =	1,000,000	820,000	760,000	680,000	620,000
PMT =	750,000	540,000	400,000	260,000	140,000

	5-6	6-7	7-8	8-9	9-10
AVW =	800	775	775	775	760
PFT =	540,000	460,000	380,000	310,000	270,000
PMT =	50,000	14,000	3,000	2,000	1,000

TNFT = 5,840,000 = 73%

TNMT = 2,160,000 = 27%

TNC = 8,000,000

These are the starting points for the program. New values for population and weights will be calculated in each annual iteration.

APPENDIX II

```
      PROGRAM MACRO
      REAL LGF,LG,LC1,LC2,LC3,LGM,LGT
    1 FORMAT(1H1,30X*MACRO MOD II*,
     1 20X*RUN NUMBER*,I3///16X*STATE VARIABLES,A-E*,
     2        35X*POLICY VARIABLES,F,G,H*,12X*CRITERION VARIABLES,I,J,K
     3*///9X*A*,11X*B*,11X
     4  ,*C*,11X,*D*,11X,*E*,11X,*F*,11X,*G*,11X,*H*,11X,*I*,11X,*J*,11X
     5  ,*K*// 1X,*TIME*////7X,*PET*,9X,*PEM*,9X,*SUP*,6X,*CE*,10X,*YY*,
     610X*FARMI*)
 1000 FORMAT   (7X,*P T*,9X,*PD*,9X,*DE*,
     1                 9X,*RCUN*,9X,*LC1*, 9X*LC2*,9X,*EFE*,9X,*EXGR
     2  *,6X,*YA*,10X,*FORFX*,7X*FARMIA*/7X,*SPT*,9X,*SD*,9X,*EPT*,9X
     3 *ERM*,9X,*LC2*, 9X*LC3*,8X,*SFT*,9X,*SFM*,9X,*YCC*,9X,*FORFXA*,6
     4  X*CERPRCUT*/7X,*TDNAT*,7X,*TDNAM*,7X,*LGT*,9X,*LGM*,9X,*LGF*, 9X,*
     5  RLTT*,8X,*SLT*,9X,*SLM*,9X,*CDGF*,8X,*ANDPCT*,6X,*VALCAP*)
    2 FORMAT(1H0,F4.1,  F10.3,10(2XF10.3)/
     1                                5X,10(F10.3,2X),F10.3/5X,10(F10.3,2X)
     2  ,F10.3/5X3(F10.3,2X),60XF10.3,2X,F10.3,2XF10.3)
    3 FORMAT(1H1,32X*MACRO MOD II*,16X*RUN NUMBER*,I3///                  1
     1  28X*STATE VARIABLES, COLUMNS L THROUGH R*,22X,                    2
     2  *POLICY VARIABLES, S,T,U,V*///9X*L*,11X*M*,11X,                   3
     3  *N*,11X*O*,11X*P*,11X*Q*,11X*R*,11X*S*,11X*T*,                    4
     4  11X*U*,11X*V*//1X*TIME*///)
    4 FORMAT(7X*RT*,9X*[illegible]*,9X*A1PT*,9X*A1PM*,9X*A4T*,9X*A4M*,    6
     1  9X*SRT*,9X*C17*,9X*C21*,9X*C25*,9X*AUX1*/                        7
     2  7X*DRT*,9X*DRM*,9X*A1T*,9X*A1M*,9X*RDDELT*,9X*HRDELT*,            8
     3  6X*TDNFES*,6X*C18*,9X*C22*,9X*C26*,9X*AUX2*/                      9
     4  7X*DMT*,9X*DMM*,9X*A2T*,9X*A2M*,9X*TDNT*,9X*TDNM*,                10
     5  8X*TDNFC*,7X*C19*,9X*C23*,9X*RLC1*,9X*AUX3*/                      11
     6  7X*ERPT*,8X*ERPM*,8X*A3T*,9X*A3M*,9X*TDNGT*,7X*TDNGM*,            12
     7  7X*CIMP*,8X*C20*,9X*C24*,31X*AUX4*)                               13
    5 FORMAT(1H0,F4.1,  F10.3,10(2XF10.3)/5X10(F10.3,2X),F10.3/
     1  5X,10(F10.3,2X),F10.3/5X,2(F10.3,2X),12X,F10.3)                   15
  197 FORMAT(8F10.3/3F10.3,12,F10.3)
    6 FORMAT(7F10.3)
    7 FORMAT(5(8F10.3)/)
      DIMENSION VAL1(9),VAL2(9),VAL3(9),VAL4(9),CROUT1(3),CROUT(3),CROU
     1T2(3),VAL5(9),CROUT3(3)
      DIMENSION  ZT(30),ZERT(30),ZDRT(30),ZDMT(30)       ,                16
     1  ZERPT(30),ZA1PT(30), ZA1T(30), ZA2T(30), ZA3T(30),               17
     2  ZA4T(30), ZRDELT(30), ZRNV(30), ZDRV(30), ZDMV(30),              18
     3  ZERPM(30), ZA1PM(30), ZA1M(30), ZA2M(30), ZA3M(30),              19
     4  ZA4M(30), ZHRDELM(30), ZCIMP(30)                                 20
      DIMENSION  ZAUX1(30), ZAUX2(30), ZAUX3(30), ZAUX4(30),             21
     1  ZRLC1(30), ZGRT(30), ZTDNGT(30), ZTDNRES(30),                    22
     2  ZTDNT(30), ZTDNGM(30),ZTDNFC(30), ZTDNM(30),                     23
     3  ZC17(30), ZC18(30), ZC19(30), ZC20(30), ZC21(30),                24
     4  ZC22(30), ZC23(30), ZC24(30), ZC25(30), ZC26(30)                 25
```

```
C CONSTANTS
      NR=11
      DT=.1
      RLENTH=30.
      NCPP=50
      RITOL=RLENTH/(NCPP*DT)
      DI=800.
      AL1=.029
      AL2=.02
      AL3=.06
      LC10=6500.
      C1=4.25
      C2=5.75
      C11=1.15
      C14= .036
      C15= 17.
      C16=.000133
      C27=1.5
      C28=1.5
      C29=60.
      C30=.035
      C31=42.
      C32=.0056
      C33=0.
      C34=0.
      ELAS1=1.
      ELAS2=1.
      GRDERD=10.
      DO 22 M=1,NR
      READ (60,107)C17,C18,C19,C20,C21,C22,C23,C24,C25,RLTT,C26,ISPRS
     1,C35
      READ 6,C3,C4,DRF,C5,C6,C7,C8,C9,C10,C12,
     1C13,L3,PVT,PFT
      GRGDEL=3.
      FEGDEL=3.
      PAO=17.9
      PA=17.9
      VAL1(1)=.06
      VAL1(2)=.19
      VAL1(3)=.27
      VAL1(4)=.33
      VAL2(1)=.08
      VAL2(2)=.29
      VAL2(3)=.44
      VAL2(4)=.54
      VAL3(1)=.05
      VAL3(2)=.22
      VAL3(3)=.13
```

```
      VAL3(4)=.11
      VAL3(5)=.1
      VAL3(6)=.09
      VAL3(7)=.08
      VAL4(1)=.5
      VAL4(2)=.17
      VAL4(3)=.1
      VAL4(4)=.08
      VAL4(5)=.07
      VAL4(6)=.06
      VAL4(7)=.05
      VAL5(1)=1.
      VAL5(2)=1.
      CROUT1(1)=0.
      CROUT1(2)=0.
      CROUT1(3)=0.
      CROUT2(1)=0.
      CROUT2(2)=0.
      CROUT2(3)=0.
      CROUT3(1)=0.
      CROUT3(2)=0.
      CROUT3(3)=0.
      LGF=74000.
      D1=1.
      D2=3.
      D3=1.
      D4=1.
      D5=3.
      PFCAT=.65
      PFCAM=.65
      YMAT=950.
      YMAM=1200.
      PRMT=.01
      PRMM=.01
: INITIAL CONDITIONS
      RCON=1.
      CF=0.
      LGM=1000.
      TDNM=C9*LGM
      PFM=36.5
      PNM=19.5
      A2T=.25*PFT
      A1PT=0.
      DFT=.15*PFT
      DMT=.15*PMT
      A2M=.41*PFM
      A1PM=0.
      DFM=.07*PFM
```

```
      DAK=.07*RAK
      ERT=  0.
      ERM=.2
      LC1=8100.
      LC2=1600.
      LC3=0.
      T=0.
      FARVIA=0.
      FORSXA=0.
      SFT=C20*PFT
      SFM=0.
      CRCAP=0.
      PRINT 106, CF,TLA ,PFT,PMT,RT,RP  ,LS,LS ,A2T,A1PT,BFT,BMT,A2M,
     1A1PM, R,DAK,ERT,ERM,LC1,LC2,LC2,T,CRCAP
  106 FORMAT(*1  CF=*,E10.3,5X,*TLA=*,E10.3,5X,* PFT=*,E10.3,5X,* PMT=*
     1,E10.3,5X,* RP=*,E10.3,5X,* R =*,E10.3//* LS=*,E10.3,5X,* LS =*
     2,E10.3,5X,* A2T=*,E10.3,5X,*A1PT=*,E10.3,5X,* BFT=*,E10.3,5X,* BMT
     3=*,E10.3//* A2M=*,E10.3,5X,*A1PM = ,E10.3,5X,* BFM=*,E10.3,5X,* BM
     4=*,E10.3,5X,* DAT=*,E10.3,5X,* DAM =*,E10.3//* LC1=*,E10.3,5X,* LC2
     5=*,E10.3,5X,* LC2 =*,E10.3,5X,*    T=*,E10.3,5X,*CRCAP=*,E10.3)
      READ(18(61,107)C17,C1,C1,C20,C21,C2 ,C2 ,C2 ,C1 ,C1 ,C1 ,C1 ,C1 ,C2 ,
     1,C25
      PRINT 7,C1,C2,C1,C1,C2,C1,C2,C1 ,C1 ,
     1C1 ,LS,A2T,PFT
      DO 224 I=1,NITCL
      DO 236 J=1,NGPP
      T=T+DT
: POLICY VARIABLES
  101 RLC2=C17
  102 RLC1=RLTT-RLC2
  103 ERM=C18
  104 DXS=C17
  105 CFT=PFT*(C20+LS*1*SFT*(PMT-PMT)/(CFT*PM) )
  106 CMT=C21*(PMT-C22*PFT)+C23*PMT
  107 IF (SMT) 108,108,108
  108 CM1=0.
  109 CF=C22*(PMT-TLA-C16*C20)+C23*PMT-C1*LS*C2*(PMT-PMT)/PM
 1000 IF (SFM) 1001,1001,1001
 1001 CFM=0.
  101 CMM=C22*(PMT-C22*PFM)+C23*PMT-C
  102 IF (SFM) 103,103,103
  103 CM2=0.
  104 PM=PMM*(1.+C2*T+C24*SIN( .1*T))
 1041 PMM=.1*PM
      WRITE (7,107)CMM
  110 LC3=LC3+DT*RLC1
  106 LC2=LC2+DT*RLC2
  107 CALL DELAY(DXS,DXM,CRCAP,T,DT,DT,2)
```

```
1971 RTDN=AUX4*C9+RLC3*C10
1972 RAA=RTDN*C16
1973 RFTT=RAA*(PFT/(PFT+PWT))
1974 RWTT=RAA-RFTT
1975 RFTW=-RFTT
1976 RWTY=-RWTT
 198 AUX1=UFE*C1
 199 CALL DELAY(AUX1,AUX2,CFOUT1,FFODEL,DT,3)
 200 DEM=D1*EXP(AL1*T)
 201 RLC1=AL2*LC1D*EXP(AL2*T)
 202 LG=LG+DT*(-RLC1-RLC2-RLC3+AUX2)
 203 LGW=LGW+DT*AUX4
 204 LGT=LG-LGW
 205 GRT=LGT/(PFT+PWT)
 206 RCON=RCON+DT*C4*(GRT-GRL)
2061 IF(RCON.LT..1) RCON=.1
 207 TDNGT=RCON*C3*LGT
 208 TDNRES=C5*LC1+C6*LC2
 209 TDNT=TDNGT+TDNRES+C7*C9*LGF
 210 TDNAT=TDNT/(PFT+PWT)
 211 TDNGW=LGW*C9
 212 TDNFC=LC3*C10
 213 TDNW=TDNGW+TDNFC
 214 TDNAW=TDNW/(PFT+PWT)
 215 CALL DEMCS(SFT,SWT,TDNAT,PFT,PWT,DFT,VAL1,GRC,GRD,D3,VAL3,GRC,D4
    10,G,D1,D2,D3,D4,D5,DWT,DFT,A2T,A1PI,PFTT,RWTT,DT,WRT,PRT,PRFT,AIT
    2,BROELT,A3T,A4T,VALS,G,T,PRCAT,YWAT,PRWT,YWT)
 216 CALL DEMCS(SFW,SWW,TDNAW,PFW,PWW,DFW,VAL2,GRC,GRD,D3,VAL4,GRC,D4
    10,G,D1,D2,D3,D4,D5,DWW,DFW,A2W,A1PW,PFTW,RWTW,DT,WRW,PRW,PRFW,AIW
    2,BROELW,A3W,A4W,VALS,G,W,PRCAW,YWAW,PRWW,YWW)
2161 WRT=PWT/PFT
2162 WRW=PWW/PFW
 217 SUP=SFT+SWT+C11*(DFW+SWW)+C12*(DFT+DWT)+C13*(DFW+DWW)
 218 CUMP=DFW-SUP
 219 YA=CUMP*PA
2191 YW=YWT+YWW
2192 GW=GWT+GWW
 220 COGR=LG*C14
 225 LC1=LC1+DT*RLC1
 221 LC2=LC2+DT*RLC2
 223 YCC=C15*LC2
2231 CALL DELAY(EXGR,GRDEP,CFOUT3,CRDEPD,DT,3)
 226 CF=CF+DT*((YA+YCC+YW-COGR-CRE-GRDLPIEXGR)*EXP(-AL3*T))
 227 CD=PFETCOGR
 228 CAPE=EXGR
 229 FARMT=YA+YW+YCC
 230 FARMIA=FARMIA+DT*(A*I)
 231 FOREX=C27*YCC-C26*CUMP*PA
```

```
232 FORCEXA=FORCEXA+DT*(FORCEX)
233 ASPROT=CL*SUPT*CPOSOX
234 CERPROT=CJ1*LC1
235 GRCAP=GRCAP+DT*(EXGR-GRCAP)
236 VALCAP=(PFTHP*T+LIN(PI*T*T))*DV/TIRCAP
      IF (ISPRS .EQ.1) GO TO 1390
C BUILD ARRAYS FOR PRINTING TABLE 2                                    49
      ZT(I)=T & ZDNT(I)=DNT & ZDRT(I)=DRT & ZPNT(I)=PNT                50
      ZFRPT(I)=FRPT & ZA1PT(I)=A1PT & ZA1T(I)=A1T & ZA2T(I)=A2T        51
      ZA3T(I)=A3T & ZA4T(I)=A4T & ZTNDELT(I)=TNDELT                    52
      ZDRM(I)=DRM & ZDRP(I)=DRP & ZDP(I)=DP & ZTNDP(I)=TNDP            53
      ZA1PM(I)=A1PM & ZA1M(I)=A1M & ZA2(I)=A2 & ZDEL(I)=DEL            54
      ZA4P(I)=A4P & ZDNDELP(I)=DNDELP & ZCLP(I)=CLP                    55
      ZAUX1(I)=AUX1 & ZAUX2(I)=AUX2 & ZAUX3(I)=AUX3                    56
      ZAUX4(I)=AUX4 & ZRLC1(I)=RLC1 & ZDPT(I)=DPT & ZTDNGT(I)=TDNGT    57
      ZTDNRES(I)=TDNRES & ZTDNT(I)=TDNT & ZTDNS(I)=TDNS                58
      ZTDNFC(I)=TDNFC & ZTDNT(I)=TDNT & ZC17(I)=C17 & ZC18(I)=C18      59
      ZC19(I)=C19 & ZC20(I)=C20 & ZC21(I)=C21 & ZC22(I)=C22            60
      ZC23(I)=C23 & ZC24(I)=C24 & ZC25(I)=C25 & ZC26(I)=C26            61
C PRINT FIRST TABLE
 1390 IF (I.NE. 1) GO TO 1400
      PRINT 1,P
      PRINT 1000
 1400 PRINT 2,  T,PFTHP,SUP,CDN,LC1, L C2, [illegible],AUX,DT,A4,PA[illegible],
     1          DNT,PNT,A1,BR,LC2,RLC3,DT,DP,Y4,FORCEX,FORCEYA,
     2          BRT,BRM,BNT,LC4,LC5,RLTT,T,[illegible],XCC,FL[illegible],CL[illegible]T,
     3          TDNAT,TDNA4,LCT,CDDN,[illegible],VALCAP
 224 CONTINUE
      IF(ISPRS .EQ. 1) GO TO 22
C PRINT TABLE 2                                                        29
      DO 8 I=1,NITOL                                                      30
      IF(I.NE.1)GO TO 60                                               31
      PRINT 3,P                                                        32
      PRINT 4                                                          33
   60 PRINT 5, ZT(I),ZDNT(I),ZPNT(I),ZFRPT(I),ZA1PT(I),ZA4T(I),        34
     1  ZA4P(I),ZBNT(I),ZC17(I),ZC21(I),ZCDN(I),ZAUX1(I),ZDRT(I),      35
     2  ZDRM(I),ZA1T(I),ZA1M(I),ZTNDELT(I),ZTNDELP(I),ZTNDRES(I),      36
     3  ZC19(I),ZC20(I),ZC22(I),ZAUX2(I),ZDPT(I),ZDP(I),ZA2T(I),       37
     4  ZAP(I),ZTDNT(I),ZTDNS(I),ZTDNFC(I),ZC18(I),ZC23(I),            38
     5  ZRLC1(I),ZAUX3(I),ZFRPT(I),ZDRP(I),ZA3T(I),ZA3P(I),            39
     6  ZTDNGT(I),ZTDNS(I),ZCLP(I),ZC24(I),ZC25(I),ZAUX4(I)            40
    8 CONTINUE                                                         41
   22 CONTINUE
      END
      SUBROUTINE SCANS(S,T,TO,TF,P,P0,S0,VALL,ALL,DIFFS,S,VALD,S1,
     1LLD,DIFFD,SD,S1,S2,S3,DA,[illegible],TF,[illegible],A1P,VMT,DPT,DT,BR,CS,EN,A1,
     2RDEL,DS,[illegible],VALD,[illegible],[illegible],[illegible],[illegible])
      DIMENSION VALL(9),VALD(9),VALP(9)
```

```
 1 BR=TABLIE(VALB,SMALLB,DIFFB,KB,TDNA)
 2 DR=TABLIE(VALD,SMALLD,DIFFD,KD,TDNA)
 3 DRP=PF*BR/(PF+PM)-DR
 4 A1=BR+PF
 5 A1P=A1P+(DT/.3)*(A1-A1P)
 6 IF (A1-A1P) 7,7,7
 7 BRDEL=D1
 8 GOTO 10
 9 BRDEL=D2
10 A2=A2+(DT/BRDEL)*(A1-A2)
11 BF=.5*A2
12 BM=BF
13 A3=PF*DR
14 DF=DF+(DT/D3)*(A3-DF)
15 A4=PM*DR
16 DM=DM+(DT/D4)*(A4-DM)
17 ER=ER+(DT/D5)*(ERP-ER)
18 PF=PF+DT*(BF-DF-SF-RFT)
19 PM=PY+DT*(BY-DY-SY-RMT)
20 GY=PF*PFC/*YMA*TABLIE(VALG,1.60,.1,1.50,.1,TDNA)
21 YM=GM*PR
   RETURN
   END
   SUBROUTINE DELAY(RINK,ROUTK,CROUTK,DEL,DT,K)
   DIMENSION CROUTK(1)
   DEL1 = DEL/(FLOAT(K)*DT)
   RIN = RINK
   DO 1 I = 1,K
   ABC = CROUTK(I)
   CROUTK(I) = ABC + (RIN-ABC)/DEL1
 1 RIN = ABC
   ROUTK = CROUTK(K)
   RETURN
   END
   FUNCTION TABLIE(VAL,SMALL,DIFF,K,DUMMY)
   DIMENSION VAL(1)
   DUM=AMIN1(AMAX1(DUMMY-SMALL,0.0),FLOAT(K)*DIFF)
   I=1.0+DUM/DIFF
   IF(I.EQ.K+1) I=K
   TABLIE=(VAL(I+1)-VAL(I))*(DUM-FLOAT(I-1)*
  1DIFF)/DIFF+VAL(I)
   RETURN
   END                                    CARD COUNT          331
```