This is to certify that the

thesis entitled

A Systems Approach to Pastoral Production
In Senegal

presented by

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has been accepted towards fulfillment
of the requirements for

MS degree in Animal Science

Major professor

Date March 24, 1986

A SYSTEMS APPROACH TO PASTORAL PRODUCTION IN SENEGAL

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A THESIS

submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Animal Science

1986

ABSTRACT

A SYSTEMS APPROACH TO PASTOTAL PRODUCTION IN SENEGAL

by

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Pastoral production is the major livestock production system in Senegal. However, with the complexity of this type of system, the use of systems modeling and simulation can be great help in designing and choosing a policy option.

The systems approach methodology is used in this paper to analyze different hypothetical management strategies to improve the productive capacity of the system. In this process, a feasibility evaluation is conducted for the determination of the goals of the system and the needs to be satisfied in order to meet these objectives. The feasibility evaluation has led to the conception of an abstract model for the simulation of the system's performances.

The model comprises a forage and an animal components.

The model is used to test the combination of three management options: increasing the forage availability and accessibility, increasing the offtake rate of the males and provision of feed supplement. The results of 10 years runs show that only a combination of the three options together will yield an outcome acceptable with the defined objectives for the system which were the maximization of the milk and liveweight offtake and the minimization of the deterioration of the rangeland.

To the memory of my mother

Fatou Fall

AKNOWLEDGEMENTS

We are very appreciative and grateful to Dr. Deans for his guidance as my academic advisor and particularly in this study. Special thanks is expressed to Dr. Manetsch for his critical suggestions and to Dr. Campbell for his availability and the helpful discussions we had through the course of this study.

We extend our thanks to the US Agency for International Development (USAID) and to the Institut Senegalais de Recherches Agricoles (ISRA) for giving us the opprtunity to pursue a Master's Degree.

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GLOSSARY: VARIABLES DEFINITION

ADDRT = net rate of addition to the cohorts

ADMY (kg) = actual daily milk yield

AFPM (t DM/ha) = actual forage production month

AGE = average age of a cohort

AGEM = age multiplier

AGER = average age of the animals in a stage of a delay

AMY = age related adjustment factor for milk production

AWT (kg) = actual liveweight

CI = condition index

CR = actual conception rate

CRM = conception rate multiplier

DEL = lenght of a delay

DGMAX (kg) = maximum daily weight gain

DIGF = digestibility of the forage

DIGS = digestibility of the feed supplement

DLMAX (kg) = maximum daily weight loss

DM = dry matter

DR = death rate

DRST = death rate due to starvation

DT = time increment

DW (kms) = distance walked

DWC (kg) = daily weight change

DWM = distance walked multiplier

DWG (kg) = daily weight gain

DWL (kg) = daily weight loss

ERL (MJ) = energy requirement for lactation

ERM (MJ) = energy requirement for maintenance

ERMP (MJ) = energy requirement for maintenance and pregnancy

EVG (MJ)= energy value of liveweight gain

FAM (t DM/ha) = forage availability month

FAMM = forage availability multiplier

FDM = forage digestibility multiplier

FIC = forage intake coefficient

FIME (MJ) = metabolic energy from forage intake

FINT (kg) = daily forage intake

FLR = forage loss rate

FPCR = forage production change rate

FPCT = forage production change time

FPPAY (t DM/ha) = forage production potential on average year

FPPDY (t DM/ha) = forage production potential on dry year

FPPWY (t DM/ha) = forage production potential on wet year

FRI = forage removal intensity

FSI (kg) = feed supplement intake

FSME (MJ) = metabolic energy from feed supplement

K = order of a delay

KB = coefficient of utilization of energy released from body reserves

KG = coefficient of conversion of metabolic energy into net energy for weight gain

KK = coefficient of utilization of energy from milk consumption

KL = coefficient of conversion of metabolic energy into net energy for lactation

KM = coefficient of conversion of metabolic energy into net energy for maintenance

KP = coefficient of conversion of metabolic energy into net energy for pregnancy

LACC (ha) = land accessible for grazing

LACL (days) = lactation lenght

LAND (ha) = total land area

LWG (kg) = liweight gain

MEC (MJ/kg) = milk energy content

MEE (MJ) = metabolic energy in excess

MEG (MJ) = metabolic energy required for liveweight gain

MEMC (MJ) = metabolic energy from milk consumption

MJ = megajoule

MOFT = milk offtake rate

OFT = liveweight offtake rate

PDMY (kg) = potential daily milk yield

PLACC = proportion of land accessible for grazing

PLR = proportional loss rate

PM = physiological status multiplier

PMIDY = proportion of animals that migrate during a dry year

PMIG = proportion of animals that migrate during an average year or a wet year

PMY (kg) = potential milk yield

POP = population

PREG = number of animals that conceive

PUR = number of animals purchased or received as gifts

RPOP = rate of passage of animals into a stage of a delay

SM = sex multiplier

STP (days) = average number of days since the beginning of the pregnancy for the cohort

TCR = conception rate

TDR = total death rate

TDW = therehold distance walked

TFA (t DM) = total forage available

TFFR = therehold fraction of forage removable

THFA (t DM/ha) = therehold forage availability

TLWOFT (tons) = total liveweight offtake

TMEI (MJ) = total metabolic energy intake

TMOFT (tons) = total milk offtake

TPMY (kg) = average potential milk yield for the breed

TQFC (t DM) = total quantity of forage consumed by one species during a month

TQFI (t DM) = total quantity of forage consumed by the livestock during a month

TQFRA (t DM) = total quantity of forage consumed by the livestock during a year

TWT (kg) = expected liveweight

QFC (t DM) = quantity of forage consumed by a cohort during a month

QFR (t DM) = total quantity of forage removed during the year

INTRODUCTION

Livestock plays an important role in the agriculture of Senegal (22 percent of the agricultural GDP). With the increase in the deficit of the meat production and the reduction in the volume of exports from the neighboring countries, interest in the development of this sub-sector has emerged during the last 10 years.

In the livestock industry, production from the pastoral area represents a major contribution. This pastoral production system has many inter-related components: soil, plant and animals, which are subject to the variability of the rainfall and the economic and social environment within which they operate.

The complexity of the system makes it difficult to study and particularly when it comes to making projections on future production. However the use of systems modeling and simulation may be of significant help for planning and research purposes. That is what we attempt to apply in this work, to study pastoral production in Senegal.

The communal nature of the use of the rangeland and the heavy reliance of animals on the natural pastures for their feed suggest a macro approach focusing on a regional or a communal system. It is at these levels where we can study the linkages between the forage component and the animal component of the system, how each one affects the performance of the other one.

The general methodology used is drawn from Manetsch and

Park (1982) for the analysis and conceptualization of the system; and the modeling work refers extensively to the procedures developed by Konandreas and Anderson (1982).

The paper is divided into four chapters:

In chapter 1, is presented a description of the livestock industry in Senegal with an emphasis of the role the pastoral production plays in that sub-sector. The national objectives of the livestock development policy are also discussed along with the place the pastoral system plays in the achievement of those objectives.

Chapter 2 presents the systems approach methodology and its use in the analysis of the pastoral production in Senegal.

Chapter 3 is dedicated to the description of the model. It is divided 4 sections:

Section 1 presents a general description of the model

Section 2 is the forage component of the model

Section 3 is reserved to the animal component

Section 4 is for the modeling of the performance of the overall system.

In chapter 4, is treated the simulation process and the presentation and analysis of the results.

CHAPTER ONE: BACKGROUND ON LIVESTOCK PRODUCTION IN SENEGAL

I.1. THE LIVESTOCK INDUSTRY IN SENEGAL

Senegal is a country covering an area of 196,700 square kilometers with a population in 1982 of 5.6 million people. Agriculture represents 22 percent of the GDP which was estimated in 1982 at US$ 2,510 millions (The World Bank, 1984). Livestock's share in the agricultural production is around 22 percent (Janske, 1982).

Livestock production has increased from 1960 to 1970 at an annual rate of 5 percent for cattle and 10 percent for small stock. During the decade 1971-1980, the national stock has suffered losses from successive droughts particularly in 1972; and the cattle population was in 1980 at 2.235 millions ,its level in 1965. However, for the small stock, after a decline in 1972, the population has recovered and is estimated in 1980 at 3.100 millions, 13 percent higher than its level in 1970. Table 1 presents the livestock population in 1980.

Two main types of livestock production system are found in Senegal:

(1) a transhumant pastoral system in the northern part of the country and associated with low rainfall areas;

(2) a sedentary agropastoral system in the central and southern part of the country where cropping is the main activity.

The livestock breeds raised vary depending on the geographical location; in the north, zebu cattle (GOBRA) and sahelian type sheep (TOUABER and MAURE) and goat (BARIOLE) are kept while in the south, trypanotolerant cattle (NDAMA), sheep and goat (DJALLONKE) constitute the stock.

Table:1 . Livestock population in 1980 ('000)

SPECIES	HEADS	TLU(1)
Cattle	2,235	1565
Sheep	2,065	248
Goats	1,035	124
Camels	6	6
TOTAL TLU		1943

(1) TLU:Tropical Livestock Unit computed with camel= 1 TLU, cattle = 0.7 TLU, sheep and goat = 0.12 TLU, Wilson et al (1983).
Source: FAO (1982)

These systems that used to be oriented towards subsistence, have been influenced recently by the market economy. However, this new orientation concerns mainly the trade of live animals for the urban consumers. Milk offtake still remains an important part of the food supply of the herders. The liveweight offtake rate is estimated at 10 and 30 percent for cattle and small stock respectively.

The meat consumption has fallen during the period 1970 to 1980 from 21.5 to 12.5 kilograms per capita (SODESP, undated). this decline in consumption is explained by differents factors:

(1) The domestic supply of meat has not kept pace with the growth of the population. The animal losses during the

1972 drought are still being felt.

(2)The volume of imports from the neighboring countries (Mali and Mauretania) declined due to better market opportunities in the countries of the gulf of Guinea. The import was 21,200 tons in 1970 (25 percent of the total supply) and dropped to 3,000 tons (4 percent of the supply) in 1980.

The livestock relies almost exclusively on the natural pasture. The use of agricultural by-products (molasses, groundnut cake and cereal brans) is very limited. The forage production depends on the amount of rain an area receives and on the condition of the soil. Figure 1 illustrates the major agricultural zones of the country and table 2 the different rangelands and their carrying capacity.

Table 2 : Carrying Capacity of Senegalese Rangelands (HA/TLU/10 months dry season)

ZONES	RAINFALL (mm)	YEAR WITH LOW RAINFALL	YEAR WITH HIGH RAINFALL
<u>SAHELIAN</u>	<500		
.sandy soil		8 - 30	6 - 15
.soil on lateritic layer		20 -100	6 - 25
<u>SAHELO-SUDANIAN</u>	500-1000		
.shallow soil		6 - 10	4 - 6
.soil on lateritic layer		10 - 15	8 - 10
<u>SUDANO-GUINEAN</u>	1000-1500		
.deep soil		6 - 8	2 - 4
.shallow soil		8 - 10	4 - 6

Source: Anonyme,1982.

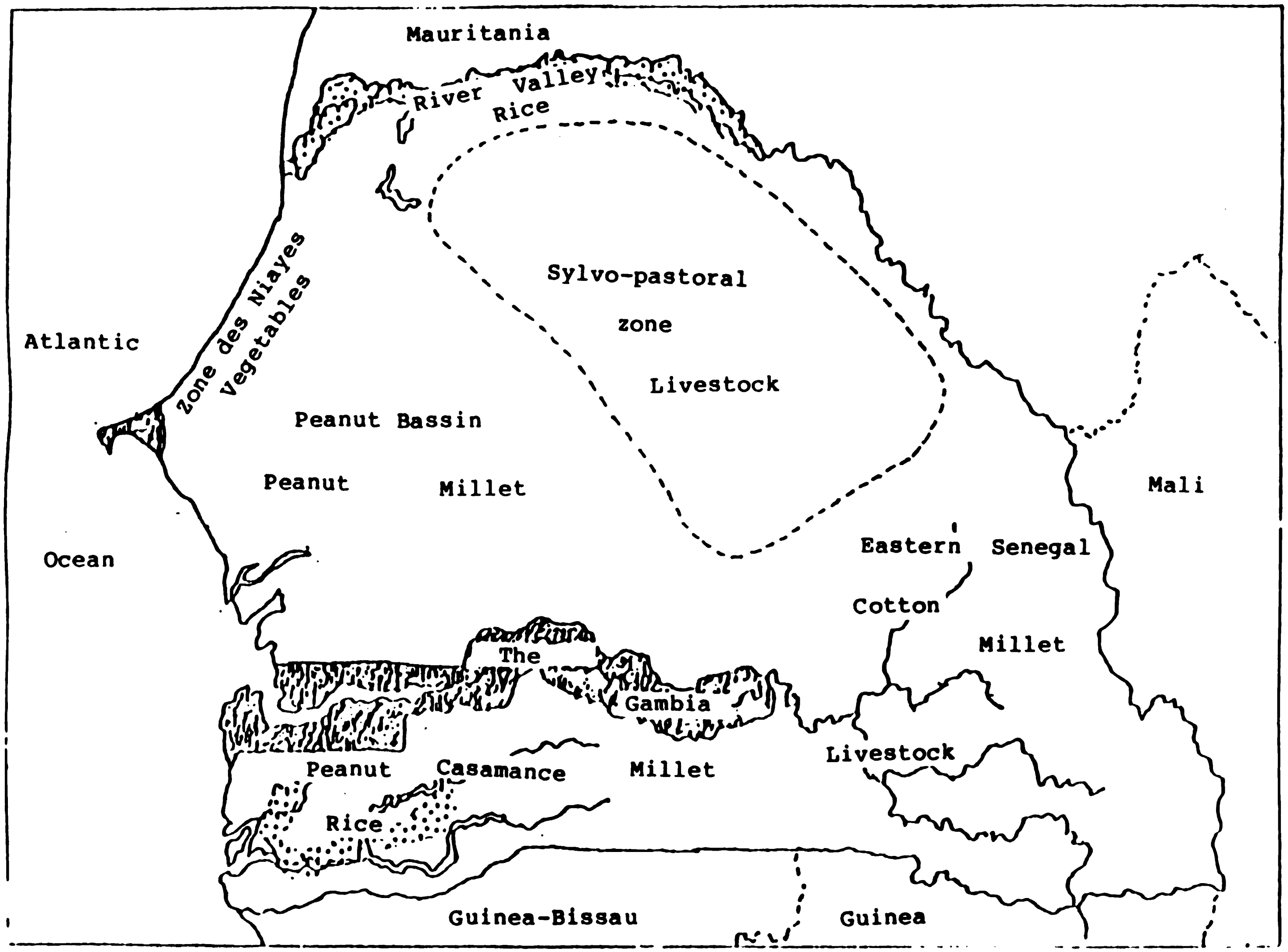


Figure 1: Agricultural zones in Senegal

It is estimated that, on the average, the forage resources were exploited in 1980 at 87 percent of its carrying capacity (Vanpraet, 1983). However, the exploitation is not uniform in all the areas. For example in the peanut basin (central zone) the utilization rate is well over 100 percent; and, even though in the sylvo-pastoral zone the average exploitation rate is below the 100 percent, signs of deterioration are noticeable in some areas, a result of high animal concentration in the dry season.

The development of water supply for the livestock, and the control of the major epizooties (rinderpest, botulism, anthrax and pleuropneumonia) had the priority during the colonial period and have been pursued thereafter. Today immunization against major diseases is regularly undertaken. Effort has also been made in the construction of watering points for the livestock. However, the main problem is getting the boreholes to operate regularly.

After the drought of 1972, livestock began to gain more attention in agricultural policy. Development agencies have given more interest in this subsector leading to the creation of livestock development agencies: SODESP (Societe de Developpement de l'Elevage dans la Zone Sylvo-Pastorale), PDESO (Projet de Developpement de l'Elevage au Senegal Oriental) and the Bakel Project. These institutions have as main goal the improvement of husbandry methods by providing inputs like feed supplement, veterinary supplies, better utilization of the forage resources by ensuring the the availability of water. Attempts to organize the marketing system of livestock have also been undertaken. With such intervention, the VIth development plan 1981-1985 intends to raise the meat consumption to 15.7 kg per capita by 1985 which would mean an increase in the production of 30,000 tons over the 5 year-period.

I.2. PASTORAL PRODUCTION IN SENEGAL

Pastoral production is a livestock production system where people derive most of their income or sustenance from keeping domestic livestock in condition where most of the feed their livestock eat is natural forage rather than cultivated fodder or pastures (Sanford,1983). In Senegal this type of animal production system is operated in the Ferlo region also known as Sylvo-Pastoral zone. It is an area covering some 40,000 square kilometers and receiving an average annual rainfall between 300 and 500 mm, according to the site. This spatial variability is associated with an inter-annual variability which results in heavy losses in the animal population during years of drought. Figure 2 illustrates the distribution of the average annual rainfall with data collected from 5 stations bordering the zone. The data were gathered from 1934 to 1981.

The rain falls from july to september, and the rest of the year is very dry, resulting in a dessication of the forage resources and the lowering of its quality. The long dry season also causes some problems of water availability

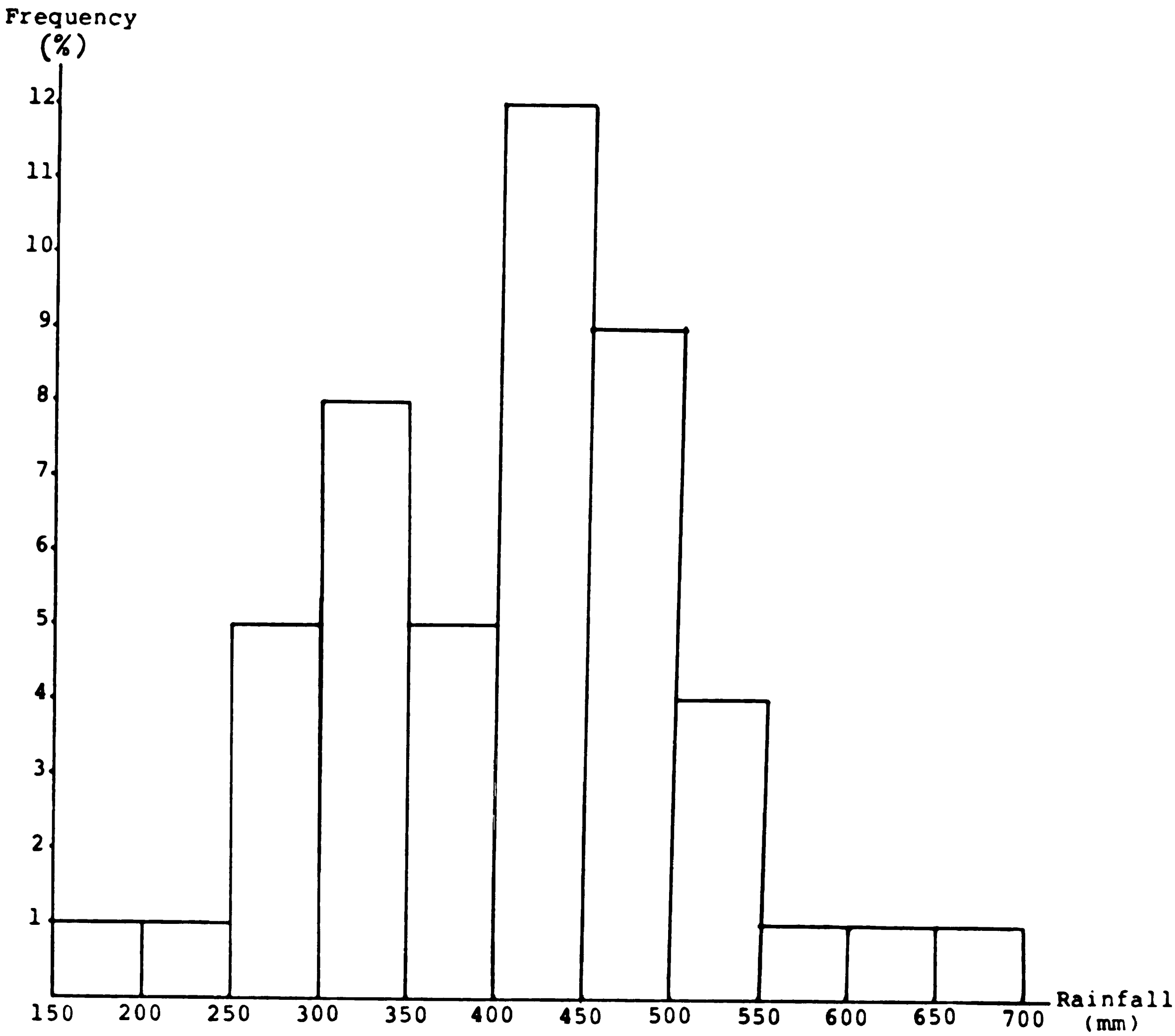


Figure 2: Distribution of the average annual rainfall in the Ferlo region (1934-1981).

for the people and the animals.

The water development program started in the 1950's has resulted in the reduction of the distance travelled by the animals, and also has changed the orientation of the transhumance. Herders and animals who used to migrate in the river valley and the peanut basin during the dry season, now stay in the area year round. It is estimated that only 14 percent of the animals do migrate nowadays versus 60 percent before the creation of the boreholes (ACC-GRIZA,1983).

With the increase in the animal population and the limited exploitable forage resources (43 boreholes in 30,000 km2), more and more pressure is put on the the rangeland. Furthermore, the variability of the forage production and the availability of water from one area to the next have resulted in an increase in the movement of the animals within the sylvopastoral zone.

The animal population is estimated between 450,000 and 550,000 cattle; 350,000 and 450,000 sheep and 200,000 and 300,000 goats (Vanpraet, 1983; SEA, 1978; SODESP, 1984; Anonyme,1982).

Exploitation of the rangeland is done on a communal basis and different species of livestock are raised together: cattle, sheep and goat. During the rainy season and the cool period of the dry season (july to february), people are organized in settlements "rumano" of 3 to 10 households "galle"; and animals exploit pastures up to 5-6 kms around the temporary pounds. With the advance of the dry season, the grazing areas become farther from the settlements and people leave the "rumano" to camp near the dry season pastures while the animals start drinking at the boreholes. The distance walked between the pastures and the watering point increases and reaches in some years 20 kms by the end of the dry season; and the livestock are now obliged to drink once every two days.

Estimation of the human population is difficult to make because of the movement of the herders, but from the ACC-AGRIZA report and given estimates of the human density, a population of 80,000 to 100,000 people could be living in the area.

The food consumption is composed primarily with cereals (58 percent of the energy and 45 percent of the protein intake); milk comes second with 18 percent of the energy and 29 percent of the protein intake (Vanpraet,1983). The cows are milked in the morning and the evening and the milk is usually fermented. Millet is the staple food, but at the end of the dry season, it is often substituted with rice which becomes more available.

The herds and flocks are composed with a majority of females (70 percent) which translates the heavy emphasis on milk production. Production traits are presented in table 3.

The milk offtake is estimated at about 30 percent, value that is commonly considered for pastoral areas (Nicholson, 1984); and most of the milk offtake is auto-consumed. What is left is processed into butter and sold.

Table 3: Production Traits of Cattle, Sheep, Goat.

		Cattle	Sheep	Goat
Age of first parturition (years)		4	1	1
Parturition rate (p.100)		55	110	120
Liveweight (kg)	.birth	20	2.3	2.
	.maturity	325	40	33
Mortality rate (p.100)				
	.pre-weaning	15	25	30
	.post-weaning	6	8	10
	.adult	2	3	3
Milk production (kg)		580	45	60
Lactation length (days)		270	150	150
Offtake rate (p.100)		12	25	30

Source:ACC-GRZA(1983),FAO(1977),ILCA(1978),SODESP(undated).

The monetary income is derived primarily from the sales of animals (80 percent). The ACC-GRIZA report mentions the variation in the prices of livestock and food during the period 1973 and 1980. It states that the price has trippled for cattle and goat, and doubled for sheep; and during the same period, the price of millet was experiencing similar increases. The traditional barter trade between milk and millet has diminished and there is now a specialisation with butter trade. In recent years, the terms of trade have turned to the advantage of butter. In 1957, 1 liter of butter allowed the purchase of 7.3 kg of millet or 2.6 kg of rice or 1.7 kg of sugar or 113 grs of tea; in 1980, the liter of butter purchases 10 kg of millet or 6 kg of rice or 2 kg of sugar or 300 grs of tea.

It is also important to note that there is a negative relationship between the seasonal variation of the price of animals and the price of millet. The price of millet tends to be higher in june-july (end of dry season-beginning of rainy season) when the price of animals is at its lowest level. In june-july the animals have lost weight and are in very bad shape while the supply of millet is very low. In october-november the supply of millet has increased and the animals have regained weight.

To improve the production strategies of the pastoralists and integrate the pastoral economy more and more in the national economy, a development agency (SODESP) has been created in 1975. Its main objectives are:

1.To increase meat production;

2.To increase the well-being of herders;

3.To open the pastoral zone to the national economy;

4.To prepare for the appropriate condition for the herders to take progressively in charge their production system.

The strategy used to carry out these above objectives is the stratification of the production by:

1.Considering the ferlo zone as a breeding area for the production of young males that should be sold at weaning age (8-12 months);

2.Those young animals are then transferred to growing-out zones in the peanut bassin and the river valley;

3.The grown animals are finally moved to finition centers around the cities.

The early removal of young animals from the pastoral area will lessen the pressure on the rangeland. However with the land pressure in the peanut basin, the availability of pasture seems to be very limited if the animals will have to depend on forage resources for their feed. A more intensive use of agricultural by-products may be a solution, but the profitability of such system should be tested.

In Senegal like in other sahelian countries, pastoralism is in a situation of crisis or in other words using the description of Sanford (1979), under pressure. Since the early 1950's pastoralism has undergone many changes; changes in the structural organization of the society, spatial control of the range resources, accessibility to dry season grazing lands, increase in the pastoral and animal populations, shift from a subsistence economy towards a market oriented system. The traditional organization of the pastoral society along clans and the control they had on particular sites in the region have been replaced by a new type of organization where the land has been turned to a public ownership. The increase in animal population and the reduction in the scale of the transhumance have increased the risk of over-grazing.

The productivity of the system has not kept pace with the increase in the herding population and that of the demand of animal products from the other part of the population particularly the urban residents.

Here is briefly presented the situation of the livestock industry in Senegal and the national strategy to improve this sub-sector, with the objective of increasing the meat production of the country. In the next chapters, we will examine, by using a systems approach, the behavior of the system when subject to different policy options that might be used as alternatives for the improvement of the current production system.

CHAPTER TWO: SYSTEMS APPROACH TO PASTORAL PRODUCTION

II.1. SYSTEMS APPROACH METHODOLOGY

II.1.1. DEFINITIONS

A system is a grouping of parts that operate together for a common purpose (Forrester,1968), and capable of reacting as a whole to external stimuli (Speeding,1979). The way of thinking how the differents parts or components of the system are coordinated and work to accomplish a set of goals is a systems approach (Churchman, 1968). This philosophical definition where a system is viewed in a global perspective can be narrowed down in studying the problems the system faces. And systems approach is then defined as a problem solving methodology which begins with a tentatively sets of needs and has as its result an operating system for efficiently satisfying a, perhaps redifined, set of needs which are acceptable or "good" in light of trade-offs among needs and the resource limitations that are accepted as constraints in the given setting (Manetsch and Park,1982).

In this process of problem solving, it is important to define:

1.The system's objectives or goals and more specifically the performance measures of the system. The objectives should not be fuzzy but rather precise, and the performance measures should tell us how the system is doing.

2.The system and its environment; the environment being what is outside the system and influence its behaviour and performance. The resources of the system on the other hand are what are inside the boundries of the system and are used by the system to achieve the defined goals and objectives.

3.The componants of the system, their functions and goals. The componants are defined in terms of the kind of activities they perform. The performance measure of a componant should be related to the performance of the overall system.

4.The management of the system which will set the goals and allocates the resources and controls the performance of the system.

II.1.2. METHODOLOGY

The process of problem solving take five different phases:

1.Feasibility evaluation: for the generation of sets of alternative solutions in order to satisfy the identified needs. The objectives of the system being defined to satisfy those needs.

2.Abstract modeling: for the development of abstract representation of the system explaining the inter-connections between the different componants of the system and their functional relations.

3.Implementation design: to completly specify the details of the system and/or the management strategy designed in the abstract modeling phase.

4. Implementation: to give physical existence to the desired system.

5. System operation: to provide a validity test of system adequacy.

These different steps are operated in an iterative manner.

In this work, we will focus on the first two steps: feasibility evaluation and abstract modeling.

II.1.2.1. FEASIBILITY EVALUATION

II.1.2.1.1. Needs analysis:

The purpose of this step is to identify the needs the system has to satisfy and from there define the objectives and performance measures of the system.

II.1.2.1.2. System identification:

In this phase, the system is defined with its boundaries, different componants, input and output variables and with the parameters which define the system's structure. The input/output relationships between the different components should also be clearly stated. The environment of the system is also defined in terms of its elements that influence the behavior of the system and its performance.

II.1.2.1.3. Problem formulation:

Here, an explicit statement of what the system must do in order to satisfy the determined needs, the specific outputs and the performance sought, is developed.

II.1.2.1.4. Generation of system alternatives:

The different management strategies that should be used in order to achieve the goals set (satisfy the needs defined) are conceptualized in this phase.

II.1.2.1.5. Determination of physical, social and political realizability:

The different management strategies defined above are analyzed here in terms of their physical, social and political implications of the application of those strategies.

II.1.2.1.6. Determination of economic and financial realizability:

The profitability and the ability of the system to support the financial cost of the new alternatives are tested here.

II.1.2.2. ABSTRACT MODELING

The information generated in the feability evaluation is used to develop the model representation of the system. The following methodology is used for this modeling process.

1.Construction of causual maps: to represent the interconnections between the components of the system.

2.Building blocks construction: to provide

-an explicit representation of the model components in terms of there inputs/outputs relations;

-an explicit definition of the interactions between the components of the model;

-a definition of the exogeneous variables and their points of impact upon the system;

-a definition of the policy variables and their points of impact upon the system;

-an explicit definition of the performance variables to be used to measure the performance of the system.

3.Provision of mathematical equations that translate the functional relations between the variables and parameters within and between the components of the system.

4.Computer programming to translate the the mathematical model into a computer language to solve the equations defined above.

5.Testing by assigning values to variables and parameters to see the behavior of the model and bring further necessary refinements in the model.

II.2. ANALYSIS OF THE PASTORAL PRODUCTION

II.2.1. FEASIBILITY EVALUATION

II.2.1.1. NEEDS ANALYSIS

We have seen in chapter 1 that the objectives defined in the national policy was to increase the meat production in the pastoral zone of the country by increasing the offtake rate through an acceleration of the growth of the animals especially the young males. A need for a conservation and improvement of the range resources is also felt. In addition the economic condition of the herders has also to be improved through the increase of their income.

Since the production system is still dominated by subsistence, milk production takes an important place in the strategies developed by herders to satisfy their subsistence needs. The milk extracted for human consumption may in some cases affects the growth of the young animals and therefore the total meat output of the system. The national objective of increasing the meat production may be hampered by the needs of the herders to guarantee their food supply.

II.2.1.2. SYSTEMS IDENTIFICATION

The pastoral system is characterized by a communal use of the rangeland with the animals being privately owned by different households. Since the rangeland and the animals are inseparable components in the production system, the area over which the production takes place has been chosen to define the physical boundaries of the system. The scale of the movements of people and animals suggests a regional approach for the study of the pastoral system. In such approach, the animals are considered being evenly distributed in the whole area; there is no restriction in their movements within the boundaries of the system. The migrations of the animals outside the pastoral area are treated as an expansion of the boundaries of the system during the periods of the year those migrations take place.

II.2.1.2.1. SYSTEMS STRUCTURE

The different components of the system are difined according to the role they perform in the overall system.

(1) The animal component: it is composed by cattle,

sheep and goat which are exploited for their meat, milk and hides. They transform the forage energy in useful products for the human consumption.

(2)The rangeland component: its surface area, forage productivity and the accessibility of the forage determines the availability of the forage resource to the animals.

(3) The management component: it is defined by the communal use of the rangeland and the husbandry method practiced: milk offtake, breeding policy.

II.2.1.2.2. SYSTEMS INPUTS

The inputs to the system can be identified as:

(1) Rainfall: it is an exogeneous, stochastic variable that is determinant in the forage production.

(2) Prices: they are exogeneous, policy variables that influence the offtake rates (liveweight and milk) used by the herders.

(3) Expenditures on drinking water supply: the number and location of the boreholes determine the accessibility to the pastures.

(4)Expenditures on fire control: affect the availability of forage for animal utilization.

(5) Expenditures on animal health: affect the mortality rate of the animals.

(6) Quantity of feed supplement.

(7) Expenditures on marketing infrastructure: the organization of the market and the facilities provided will

influence the diffusion of the information and enhance the desire of the herders to sell, therefore resulting in an impact in the offtake rate used.

II.2.1.2.3. SYSTEMS OUPUTS

The outputs measured for the model are the total liveweight offtake and the total milk offtake from the different animal species. These performance measures are considered along with the forage production change rate which measures the influence of the animal pressure of the rangeland.

II.2.1.3. PROBLEM FORMULATION

In this present work, we are seeking an understanding of the long term behavior of the pastoral production system with respect to changes in the availability of forage, changes in the animal population and changes in the husbandry method used. The performance measures of the overall system are defined as the total liveweight offtake and the total milk offtake. However, the need for a conservation of the range resource base, suggests that a measure of the range condition be also used along with the performance measures defined above. The measure of range condition is taken as the forage change rate.

However, the increase of these outputs (milk and liveweight) should be regarded with respect to their economic value. There should be an effective demand for these products to justify their production. The relative prices of the animal products and that of the traded goods used by the herding community is also important in order to assess a real value for the systems outputs.

II.2.1.4. GENERATION OF SYSTEMS ALTERNATIVES

The behavior of the system will be tested with different combinations of the following alternatives.

1. Increasing the liveweight offtake rate of the males.

2. Increasing the accessibility and availability of the forage to the animals by improving the water availability and reducing the forage losses through wild fires.

3. Provision of feed supplement during the the period of low forage availability.

The different options will be used under a regional setting where the whole pastoral area is considered as one system and under a communal setting considered as a system centered around a borehole.

II.2.1.5. DETERMINATION OF PHYSICAL AND SOCIAL REALIZABILITY

Since this work focuses on the understanding of the behavior of the pastoral production system, the different management alternatives tested are assumed to be feasible.

II.2.1.6. DETERMINATION OF ECONOMIC AND FINANCIAL REALIZABILITY

The observations defined above will apply here too.

II.2.2. ABSTRACT MODELING

II.2.2.1. PRINCIPLE AND DEFINITIONS

A model can be defined as a representation of an object, system or idea in some form other than that of the entity itself (Shannon,1975); and modeling as the process of developing a mathematical representation of the inter-relations between the inputs and the outputs variables (Jaske, 1976). In this process, knowledge about the inputs and its transformation are essential in measuring the output.

In a livestock production system a simple representation of the system can described as the forage being the input, the animal being the structure of the system where the input is transformed and the outputs constitued by milk, meat, hides. However this basic representation does not tell us how the forage is made available to the animals, nor it gives a description of the activities that take place in the transformation of the input into output, nor it describes the relationships between the animals and the forage. Incorporation of these processes and relationships make the representation of the more realistic but more complex too.

Study of the behavior of such complex organisation when subject to environmental and managerial changes is almost impossible without recourse to modeling and simulation, simulation being the process of conducting experiment with a model for the purpose of either understanding the behavior of the system or evaluating various strategies for the operation of the system (Shannon,1975).

Our purpose in this study is to develop from the feasibility evaluation, a model that describes the pastoral production system in Senegal, drawing from works that have been done in the modelisation of livestock production.

II.2.2.2. LITERATURE REVIEW ON LIVESTOCK SIMULATION MODELS

During the past 25 years, interest in livestock development in Africa has increased and so has been the body of knowledge gathered in the field of animal nutrition, reproduction, genetics and health, and rangeland productivity. Evaluation and projection of the livestock production system in Africa has been a major problem for planners because of the difficult accessibility to the areas where livestock is produced and also because of the nature of the production system which depends on a perpetual movement of people and animals.

Even though some knowledge has been gained in animal related disciplines, most of that work has been undertaken in research stations where the conditions of experimentation are very different from the real world. Knowledge about the production in the pastoral area has been scare and the collection of data in such system of production is likely to be expensive. Recourse to modeling and simulation could be a useful tool for planning purposes and also in research.

Some of the models developed to study African livestock production or with of acertain interest in the principle they use are presented below.

Manetsch et al.(1971) developed a model for the cattle industry in northen Nigeria. The model disaggregates the cattle industry into two sectors: a traditional which uses traditional methods of husbandry and a modern one which is managed using pasture improvement. Projections are made by testing different policy alternatives with variables like marketing, expenditures in tse-tse fly eradication, grazing reserves, land allocated to crop and animal feed crop production. The amount of total digestible nutrients (TDN) available per animal determines the biological performance of the animals. The performance measures of the system are considered as discounted returns, foreign exchange earnings, farm income, nutrient output and income from beef and milk.

Picardi (1974) studied the problem of the "commons" in the sahelian region. He developed a model to show how the communal exploitation of the land leads to overstocking, overgrazing and finally the destruction of the resource base (the rangeland) of the livestock industry in the sahel. He includes in his model some elements that contribute to the tragedy of the commons, for example the growth of the herding population leads to an increase in the animal population, which associated with the reduction in the scale of the transhumance, result of the water development policy and the expansion of cropping northwards has increased the pressure to the rangelands.

Dahl and Hjort (1976), construct a model to study the rationale for a household to keep large herds. With different calving and mortality rates they project the long term evolution of cattle, sheep, goat and camel herds with respect to the nutritional needs of the household. Their model tests also the effect of drought to the herd dynamics.

Shuette (1976) developed a model to simulate the growth in body weight of beef cattle and the reproductive performance of the females as affected by age and body weight. The model is composed of three components: herd demography, nutrition dynamics and reproduction dynamics. The demographic component simulates the aging and weight changes of the different population groups of animals and move animals from one group to another. The nutrition component determines the feed intake and utilization of the energy for maintenance, growth and lactation. The reproduction component simulates the occurence of puberty based on age and weight, post-calving interval to first oestrus, pregnancy rates and the calving rate and time according to body condition.

Jaske (1976) constructed a beef cattle entreprise model that allows investigation of alternative management decision making strategies. The model comprises five components: demography, forage growth, feed stock accounting, nutrient impact on growth and reproduction and management decision making. The management component provides the manager to make decisions on on-going operations as well as investment planning. Forage is modeled as a function of rainfall, solar radiation and temperature. The nutrient impact component determines expected weight gains and reproductive performance in relation to forage intake.

Graham et al. (1976) developed a computer program to estimate daily energy and nitrogen utilization for sheep. Inputs information for the model include: intake, protein content and digestibility of the diet, age, empty body weight, fat content and feeding activity of the sheep. Environmental factors like ambiant temperature and wind speed and management factors like time of shearing and mating are also included in the inputs information.

Sanders and Cartwright (1979a,b) developed a deterministic model for simulating beef cattle under a wide range of management schemes and environements. The genetics of the animals are specified as production potentials which are reached only if past and present nutritions are adequate. Intake of feed is simulated as function of the weight and physiological status of the animals and the availability, digestibility and crude protein content of the feed. The model comprises a main program that is primarily a herd dynamics submodel and three main subroutines for the simulation of the growth, reproduction and death rates.

Sullivan et al. (1981) used an interfaced forage and beef cattle model to study the catlle production system in East Africa. The model was designed to study the physical linkages between the scarce forage resource and the outputs of cattle: meat and milk. Stochastic weather variables were introduced in the forage submodel to simulate the effects of weather variability in the production pattern. The cattle model used was developed by Sanders and Cartwright (1979a,b).

Konandreas and Anderson (1982) constructed a general cattle herd simulation model in which animals are treated as individual entities. The model is divided into five components: forage intake, energy requirements, milk production and growth, mortality and reproduction. The model introduces great details the the factors that affect forage intake in the context of pastoral production systems. The quantity and quality of forage on offer are specified as input to the model. Policy options for weaning, breeding, milking, buying and selling of stock and supplemental feeding are provided by the user to test alternative management strategies. The model was design to study african pastoral production systems characterized by herds of small size.

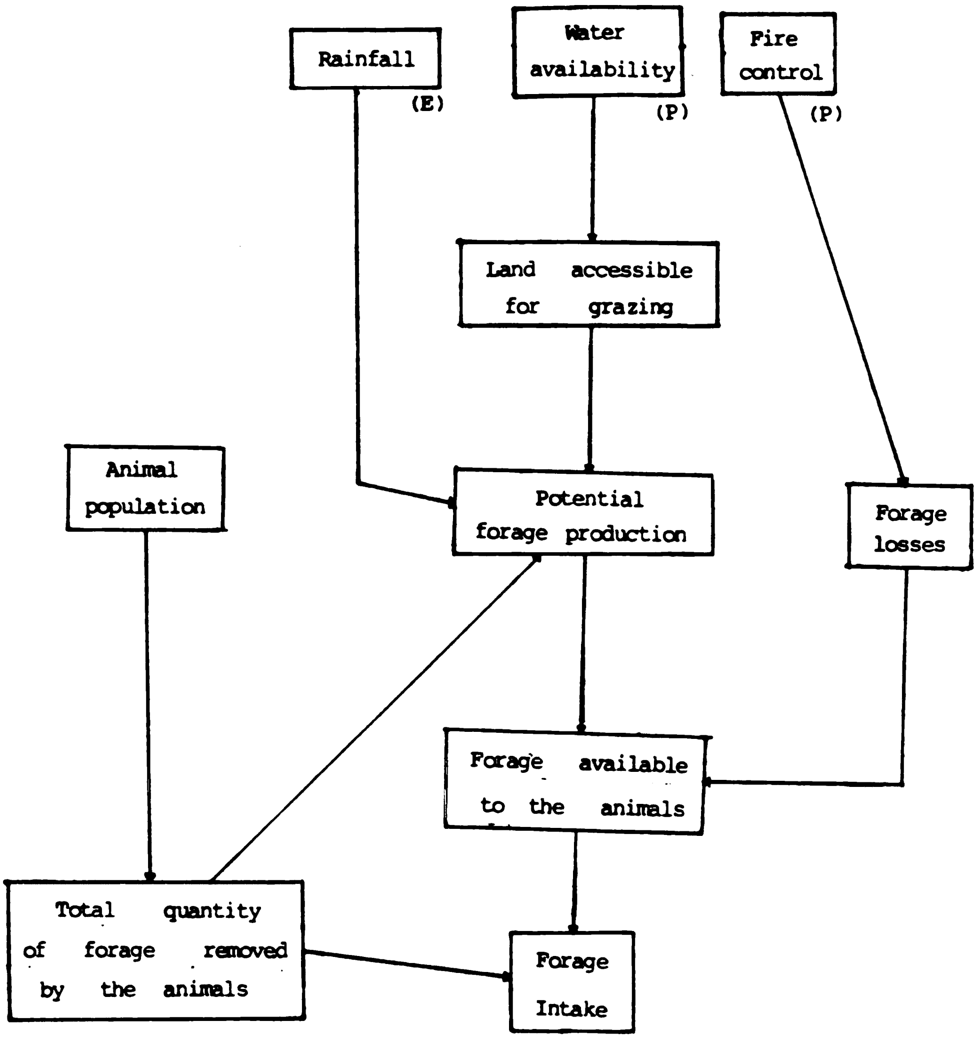
CHAPTER THREE: MODEL DEVELOPMENT

III.1. GENERAL DESCRIPTION OF THE MODEL

The model is divided into two components: a forage component and an animal component. These two parts interact in terms of forage availability which is an input to the animal component, and in terms of forage production change rate which measures the effect of grazing pressure on the rangeland.

The forage component is representd with a causual map in figure 3. The forage production is affected by the rainfall the region receives and the condition of the soil. The rain is an exogenous factor that is that is considered in the model as a stochastic variable and the soil condition is affected by the intensity of forage utilisation which is the ratio of quantity of forage removed by the livestock and through other processes (fire, wind, other animals) over the quantity of forage produced at the end of the growing season. The quantity of forage available to the animals is determined by the standing biomass at the beginning of the previous month minus the total quantity removed by the livestock and lost through other processes.

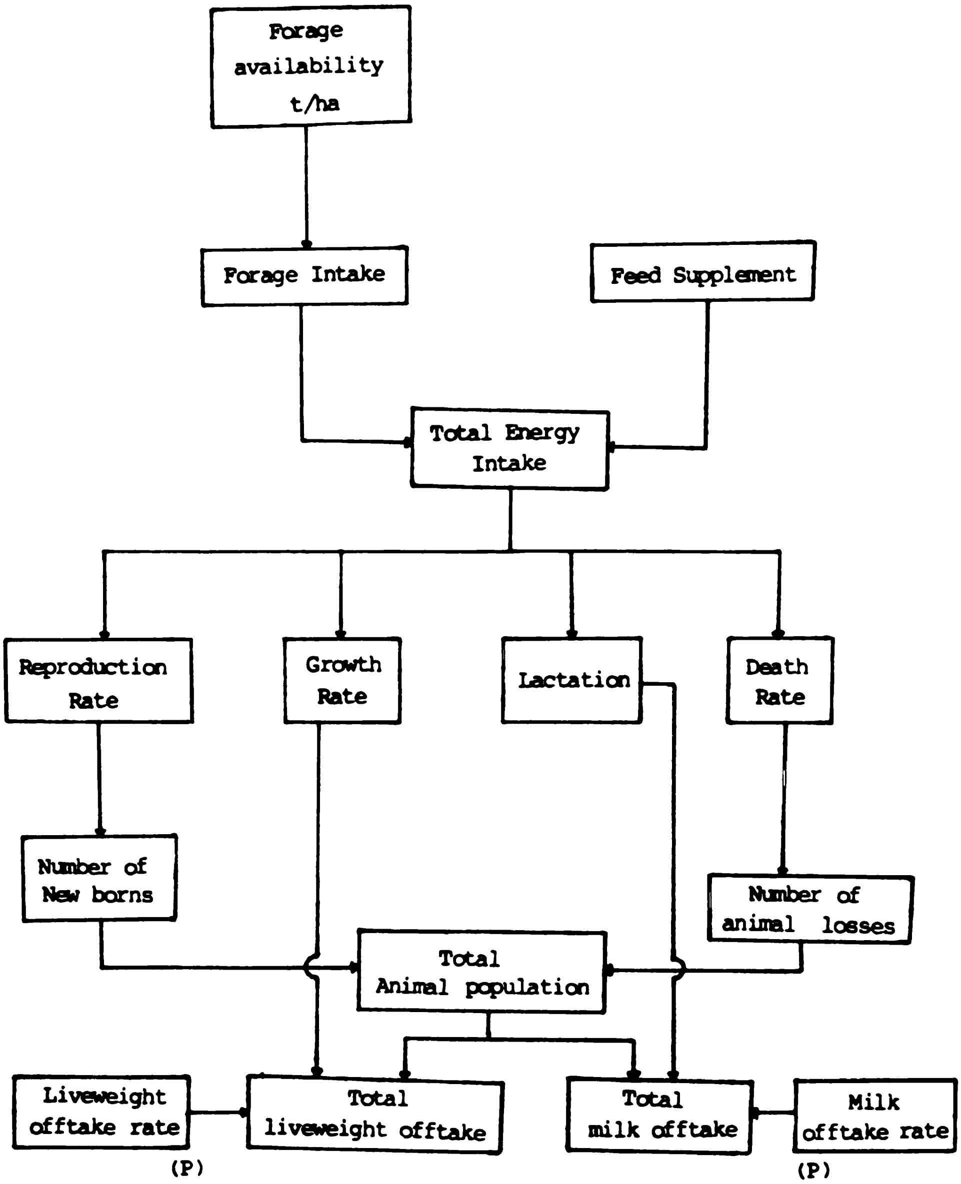
Figure 4 presents a causual map that describe the animal performance. The forage availability determines the amount of forage intake which added to the quantity of feed supplement provided gives the total energy intake. The energy is then utilized for the different functions: maintenance, reproduction, lactation and growth.



(E) = Exogeneous variable

(P) = Policy variable

Figure 3: Causual map explaining the forage production component



(P) = Policy variable

Figure 4: Causual map explaining the animal performance

The performance of these functions determines the population dynamics and associated with the management strategy (offtake rate, milk offtake) determines the quantity of outputs produced (meat, milk). The output performances are then used with the condition of the rangeland to assess the overall performance of the system.

III.2. THE FORAGE COMPONENT

This part is handled stochastichally in order to incorporate in the model the yearly variation of rainfall. The spatial variation has not been taken into account here; the whole area is considered as receiving the same amount of rain. It is assumed that the animals are evenly distributed over the land area accessible for grazing. The total pastoral zone is defined in the model as variable LAND and the area accessible for grazing each month as LACC which is:

LACC = LAND for the 5 first months of the year beginning in july.

= (LAND*PLACC)+(LAND*PMIG) for the remaining months of the year during which a certain percent of the animals do migrate out of the pastoral area.

PLACC is the percent of land accessible for grazing during the dry season and PIMG is the percent of animals that migrate in period of wet or normal year. In period of dry year that variable is called PMIDY.

The percent of land accessible PLACC is related to the availability of water during the dry season.

The forage production is determined stochastically using three levels of productivity for dry, average and wet year. With a series of rainfall data for 48 years (1934 - 1981) from 5 stations bordering the pastoral zone we have computed the distribution of the rainfall using with the occurence of dry year being when the amount of rain is less than 0.8*MEAN RAINFALL and a wet year the amount of rain is greater than 1.2*MEAN RAINFALL (Penning de Vries and Djieteye, 1982). With a mean annual rainfall of 400 mm, a dry year is considered dry when the rain is less than 320 mm and wet when there is greater than 480 mm with a respective occurence of 0.3 and 0.15. Therefore a random variable between 0 and 1 is generated each year and when it is less than 0.3 we have a dry year, when it is greater than 0.85 it is a wet year and between 0.3 and 0.85, we have an average year. Each type of year corresponds to a potential forage production (FPPDY, FPPAY AND FPPWY).

The actual forage production (AFPM) is determined for the three months of the growing season (july, august and september) by:

AFPM (tons DM) = (FPP * (1+FPCR)) for august and september
= (FPP * (1+FPCR))*JFFPP for july.

JFFPP is the fraction of forage production potential for the month of july; the production potential being the standing biomass in august and september.

The total quantity of forage available (TFA) each month is given by:

$$TFA_t \text{ (tons DM)} = AFPM * LACC \qquad \text{for month 1, 2 and 3}$$

$$= TFA_{t-1} * (1 - (FLR/9)) \qquad \text{for month 4}$$

$$= TFA_{t-1} * (1 - (FLR/9)) - TQFI_{t-1} \qquad \text{for month 5}$$

$$= (TFA_{t-1} * (1 - (FLR/9)) - TQFI_{t-1}) * (1+PMIG) \qquad \text{for month 6.}$$

$$= TFA_{t-1} * (1 - (FLR/9)) - TQFI_{t-1} \qquad \text{for month 7, 8, 9, 10, 11 and 12.}$$

where: t is the current month

FLR is the forage loss rate (through fire or other factors)

and TQFI the quantity of forage consumed by the animals each month.

The forage availability month (FAM) is defined as:

$$FAM \text{ (t DM/ha)} = TFA/LACC$$

The forage production change rate (FPCR) is incorporated in the model in order to account for the effect of forage removal intensity in upon future productions. Following LeHouerou (1978) and Toutain and Lhoste (1978) who estimate that one third of the biomass produced can be removed by the animals and one third lost through other factors (fire, rodents). Therefore one third should be left to protect the soil. However, Penning de Vries and Djieteye (1982) argue that the amount of forage required to protect the soil is not a percent of the biomass but rather an absolute value; furthermore, they state that the former authors based their estimates on observations rather than on theoretical basis. Using the nitrogen balance in the soil as an indicator of the equilibrium of the soil-plant system, Penning de Vries and Djieteye argue that 45 percent of the nitrogen can be removed without disturbing the equilibrium. In the model, we have settled at a middle ground between the two estimates and fix the allowable forage removal intensity (TFFR) at 50 percent of the production at the end of the growing season.

The forage production change rate (FPCR) is given by:

$$\begin{aligned} FPCR &= (TFFR - FRI)/3 && \text{if } FRI > TFFR \\ &= (TFFR - FRI)/20 && \text{if } FRI > TFFR \end{aligned}$$

The 3 and 20 are the forage production change time (FPCT) which is the time necessary for an overstocked area to deteriorate and to restore a deteriorated area to its potential respectively (Penning de Vries and Djieteye, 1982; Picardi, 1974). The forage removal intensity (FRI) is the ratio of the total quantity of forage removed (QFR) over the total forage available (TFA) at the end of the growing season. The total quantity of forage removed (QFR) is:

$$QFR\ (t\ DM) = TQFRA + (TFA_3 * FLR)$$

where TQFRA is the amount of forage consumed by the animals during the whole year

$$TQFRA_i \text{ (t DM)} = \sum_{i=1}^{12} TQFI \qquad i= 1,..., 12 \text{ months}$$

where TQFI is the monthly animal consumption

$$TQFI \text{ (t DM)} = \sum_{j=1}^{3} TQFC_j$$

where j represents the 3 species.

The forage consumption for each species (TQFC) is the sum of the consumption of the different cohorts (QFC):

$$TQFC \text{ (t DM)} = \sum_{k=1}^{14} QFC_k \qquad k = 1,....,14 \text{ cohorts}$$

and

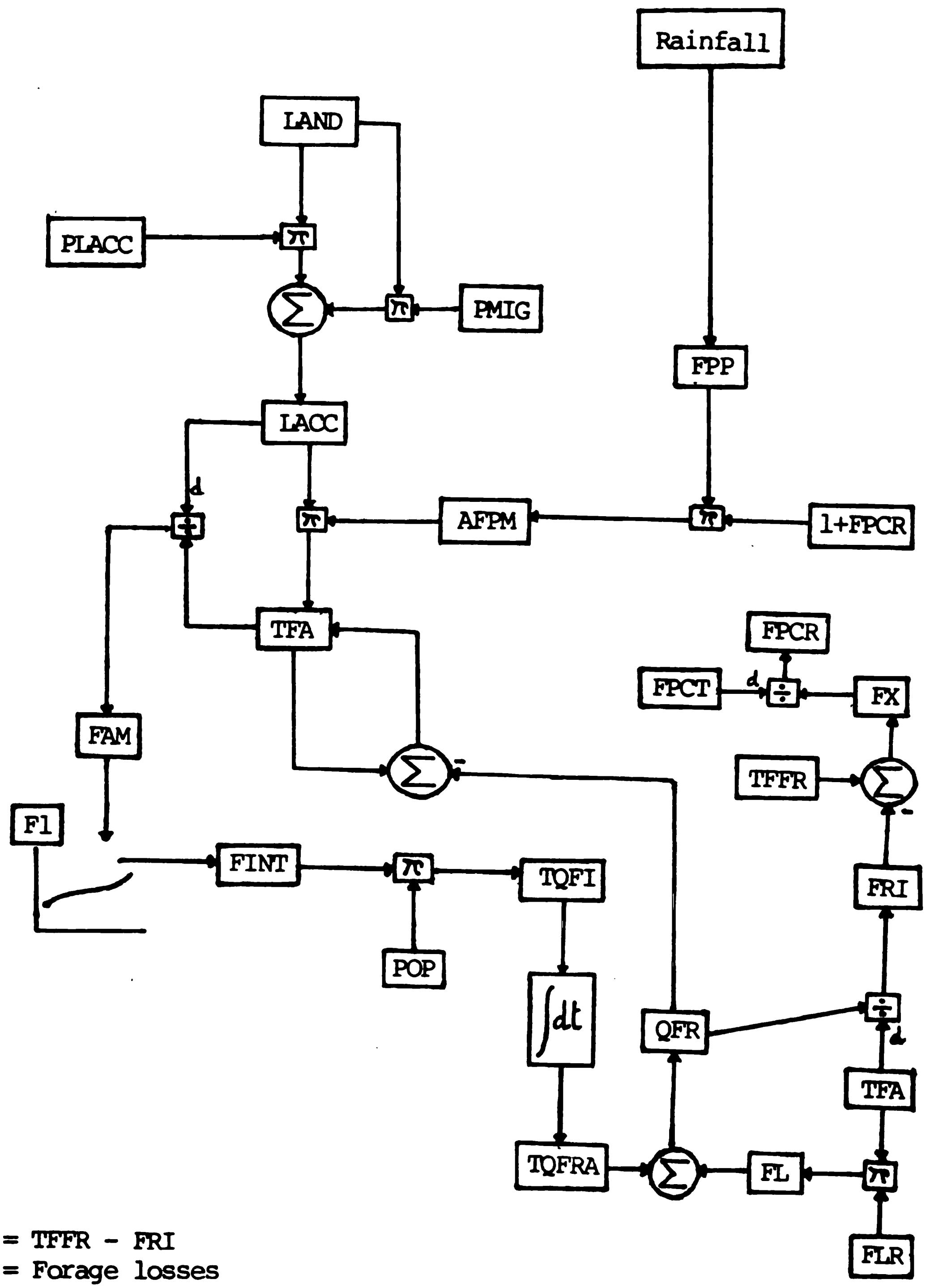
$$QFC_k \text{ (t DM)} = FINT_k * POP_k * 30 * CFKT$$

where FINT is the daily forage intake, POP the population of the cohort and CFKT is the convertion factor from kilograms to tons (CFKT = 0.001).

Figure 5 represents a flow diagram for the computation of these variables.

III.3. THE ANIMAL COMPONENT

This component is divided into two parts: a main program that simulates the performance variables of the animals: reproduction, lactation, weight changes, mortality and a subroutine that computes the animal population and moves the animals from one cohort to the next one. The animal performance variables are modeled using the principle



FX = TFFR - FRI
FL = Forage losses
FPCT = Forage production change time
F1 = Function estimate of forage intake

Figure 5: Schematic block diagram flow for the forage production component

described by Konandreas and Anderson (1982) with a cattle herd.

The model is developed with a monthly time step but since the feed intake and nutritional requirements are given on a daily basis, the daily behavior of the animal is considered to be constant for all the days of the month. Each month, the quantity of forage available and its digestibility is determined and given as input to the animal component for the computation of the daily forage intake. The forage intake is determined by the forage available, the animal activity (distance walked) and the physical and physiological condition of the animal under consideration. Here, unlike the model developed by Konandreas and Anderson which uses a microprocess approach where each single animal of the herd is treated as an entire entity, we use an aggregated approach where each cohort of the herd is represented by an average animal and it is assumed the cohort population is normally distributed around that average animal.

The simulation of the animal performances starts by computing the daily forage intake, and in addition to the feed supplement provided, the total metabolic energy intake. Then, the energy requirements and the partitionning of the energy intake into maintenance, pregnancy, lactation and growth, are determined. The equations defined in Konandreas and Anderson's model are kept for cattle and modified as appropriate for the use in sheep and goat.

III.3.1. ENERGY INTAKE AND UTILIZATION

III.3.1.1. ENERGY INTAKE

The total energy intake is the sum of the energy from forage intake plus the energy from feed supplement and the energy from milk consumption for the young animals. The energy unit used in the model is the megajoule (MJ).

III.3.1.1.1. FORAGE INTAKE

The forage intake depends on the quality of the forage (crude protein) which is defined as its digestibility, the quantity of forage available, the distance walked, the age, the sex, the physiological status, the expected liveweight and the forage intake coefficient of the animal. These factors define different multipliers that adjust the forage intake.

The different equations used to estimate forage intake are drawn from Konandreas and Anderson (1982) for cattle and have been extended to the smallstock with some modifications relative to the age and physiological status.

Forage digestibility multiplier: (FDM)

It adjusts for the effects of low quality forage (digestibility < 0.4) on forage intake.

$$FDM = ((DIGF/0.4)^{0.6})/(1-DIGF) \qquad \text{if } DIGF \leq 0.4$$

$$= 1/(1-DIGF) \qquad \text{if } 0.4 < DIGF \leq 0.65$$

$$= 1/(1-DIGF) \qquad \text{if age} < 1.5 \text{ for cattle}, < 0.75 \text{ for sheep and goat} \quad \} DIGF > 0.65$$

= 1.86/DIGF   if age > 1.5 for cattle }
                > 0.75 for sheep }DIGF>0.65
                and goat }

where DIGF is the digestibility of the forage.

<u>Forage availability month multiplier</u>: (FAMM)

This factor corrects for the effect of forage density on forage intake.

FAMM = FAM/THFA   if FAM < THFA

= 1   if FAM >/ THFA

where THFA is the forage availability under which forage intake is affected. THFA is set at 0.8 t/ha for cattle, 0.75 t/ha for sheep and 0.7 t/ha for goat based on the fact that sheep graze closer to the ground than cattle and goat relie more on browse than cattle and sheep.

<u>Distance walked multiplier</u>: DWM

It corrects for the effect of animal activity on the forage intake, activity related to time spent walking to the watering point or searching for pasture.

DWM = 1   if DW \< TDW

= 1-0.05*(DW-TDW)   if DW > TDW

where DW is the distance walked each day of the month and TDW is the distance walked over which the forage intake is affected. TDW is set at 14 kms a day.

<u>Age multiplier</u>: (AGEM)

It adjusts for the effect of aging on forage intake.

AGEM = 1   if AGE \< 8 years for cattle
            \< 5 years for sheep
            and goat

= 1-0.03*(AGE-8)   if AGE > 8 years for cattle

= 1-0.03*(AGE-5)   if AGE > 5 years for sheep and goat.

<u>Sex multiplier</u>: (SM)

This factor adjusts for the higher feed intake of young males over the females.

SM = 1 for cattle older than 1.5 years and 0.75 years for small stock.

= 1.1 for male cattle \< 1.5 years and male sheep and goat \< 0.75 years old.

<u>Physiological status multiplier</u>: (PM)

This allows for the correction of the intake for the different biological classes in the herd (young animals, lactating females, pregnant females).

PM = 1.10 for lactating females

= 0.53 for unweaned animals

= 0.53+0.47*(AGE-0.5) for cattle \< 1.5 years old

= 0.53+0.47*(AGE+0.25) for small stock \< 0.75 years

= 1. for cattle > 1.5 and for small stock > 0.75 years old.

= $e^{(0.00037*STP)}$ for pregnant cattle

= $e^{(0.00067*STP)}$ for pregnant sheep and goat

where

STP = average number of days since the beginning of the pregnancy. It is the adjusted stage of pregnany for the cohort according to the rates the animals are in the different stages of the delay that represents the pregnant cohort.

Forage intake coefficient: (FIC)

It is a parameter specific for species and physiological status of the animal.

FIC = 0.049	for pregnant cattle
= 0.054	for lactating cattle
= 0.046	for other classes of cattle
= 0.028	for pregnant sheep
= 0.033	for lactating sheep
= 0.027	for other classes of sheep
= 0.026	for pregnant goat
= 0.0345	for lactating goat
= 0.0255	for other classes of goat

Expected liveweight: (TWT)

For each cohort, the expected liveweight is determined according to the average age of the animals (see section III.3.2.2.).

The forage intake is then computed using the formula:

$$FINT\ (kg\ DM) = FDM*FAMM*DWM*AGEM*SM*PM*FIC*(TWT^{0.73})$$

III.3.1.1.2. TOTAL METABOLIC ENERGY INTAKE

The total metabolic energy intake (TMEI)is defined as the sum of the energy from forage intake (FIME) plus the energy from feed supplementation (FSME) plus the energy from milk consumption for young animals (MEMC). The metabolic energy from these differents sources of nutrients is given by:

FIME (MJ)= 14.6*FINT*DIGF

FSME (MJ)= 14.6*FSI*DIGS

MEMC (MJ)= 0.93*MEC*QMAC

where

FINT = forage intake (kg/day)

FSI = quantity of feed supplement (kg/day)

QMAC = quantity of milk available for each young (kg/day)

MEC = energy content of milk (MJ/kg)

DIGF = digestibility of the forage

DIGS = digestibility of the feed supplement

The 14.6 factor comes from the fact that gross energy content of tropical forage is at about 18 MJ/kg DM (Minson, 1981) and that of most feed is at about 18 MJ/kg DM since the dominant constituents are carbohydrates with an energy value of 17.5 MJ/kg DM (MAFF, 1975); and the metabolizable proportion of the gross energy is 0.81 (19 percent of the digestible energy is lost through the urines and methane); thus 18*0.81=14.6 .

The 0.93 is the digestibility of milk.

The energy content of milk set at 0.35 MJ/kg for cattle, 0.40 MJ/kg for sheep and 0.375 MJ/kg for goat (Dahl and Horjt, 1976; Nicholson, 1984).

The quantity of milk available for consumption is given by:

QMAC = ADMY * (1 - MOFT)

where

ADMY = actual daily milk yield (kg)

MOFT = milk offtake rate.

III.3.1.2. ENERGY UTILIZATION

The metabolic energy intake is allocated to the different biological functions according to the following hierarchy: maintenance and pregnancy satisfied first, in second position comes lactation and growth is satisfied the last. Maintenance and pregnancy are treated as inseparable functions. Functions like reproduction and mortality are also influenced by the nutritional plan through the condition index defined in section III.3.2.2.

The metabolic energy intake is converted into net energy with different coefficients of efficiency:

-for maintenance, KM = 0.55+0.3*Q (Konandreas and Anderson, 1982; MAFF, 1975)

where Q is the metabolizability of the feed offered.

Q = 0.81* DIG (Konandreas and Anderson, 1982)

where DIG is the digestibility of the feed.

-for pregnancy KP = 0.72 (MAFF, 1975)

-for lactation KL = 0.60 (Konandreas and Anderson, 1982)

-for weight gain KG = 0.03+0.81*Q

-for energy released from body reserves KB = 0.82

-for energy from milk consumption KK = 0.75

III.3.1.3. ENERGY REQUIREMENTS

III.3.1.3.1. MAINTENANCE

Maintenance requirement is estimated using the formulas given in Konandreas and Anderson (1982) and King (1983) who draw their work from Blaxter (1969) and Webster (1978). The metabolic energy requirement for maintenance is defined as:

$$ERM = ((0.376*AWT^{0.73})/KM)+(0.0021*AWT*DW) \quad \text{for cattle}$$

$$= ((0.243*AWT^{0.73})/KM)+(0.0024*AWT*DW) \quad \text{for sheep and goat}$$

where AWT= actual liveweight

KM = coefficient of conversion of metabolic energy into net energy;

DW =the distance walked daily during the month (km/day)

The second part of the equation allows for animal activity. The coefficient 0.0021 in the Konandreas and Anderson's model was maintained here for cattle; and for sheep and goat, we refer to the value given by Clapperton (1964) for sheep.

III.3.1.3.2. PREGNANCY

For pregnant females, the energy required for pregnancy and the energy required for maintenance are combined into one requirement (ERMP).

$$ERMP = ERM+1.13*e^{0.0106*t} \quad \text{for cattle (MAFF, 1975)}$$

$$= (1.2+0.05*AWT)*e^{0.0072*t} + 0.0024*AWT*DW$$ for small stock (MAFF, 1975)

III.3.1.3.3. <u>LACTATION</u>

The net energy requirement for lactation depends on the potential daily milk yield (PDMY in kg) and its energy value (MEC in MJ/kg). With an efficiency of conversion of 0.60, the metabolic energy requirement for lactation is:

ERL = 1.67*MEC*PDMY

III.3.1.3.4. <u>LIVEWEIGHT GAIN</u>

The energy in excess from maintenance, pregnancy and lactation is used for weight gain (LWG). The energy value of gain (EVG) is related to the liveweight and the energy in excess (MEE).

EVG (MJ/kg) = 6.28+0.3*(MEE*KG)+0.0188*AWT (MAFF, 1975)

Since the MEE is equal to (LWG*EVG)/KG , therefore the metabolic energy required for gain (MEG) can be defined as

MEG (MJ) = (LWG*(6.28+0.0188*AWT))/((1-0.3*LWG)*KG)

For lactating animals the energy in excess of lactation requirement is used with an efficiency equal to that of lactation (KL).

III.3.1.3.5. <u>MOBILIZATION OF BODY RESERVES</u>

Body reserves can be mobilized to satisfy the energy deficit for maintenance or lactation. The efficiency of utilization of body reserves for lactation is at about 0.82 (MAFF, 1975) and the same value is used for maintenance and pregnancy. With an energy value of 20 MJ/kg, the net energy available from the mobilization of body reserves (E) is:

$$E\ (MJ) = 0.82*20*DWL$$

where DWL is the daily weight loss (kg).

III.3.2.HERD/FLOCK DYNAMICS

The amount of energy received will determine the level of performance of the production traits of the animal: reproduction, growth, lactation and mortality. These traits combined together will determine the dynamics of the herd/flock.

II.3.2.1. DEMOGRAPHY

The population in each species is disaggregated into 14 cohorts according to sex, age and physiological status. The cohorts have been indexed as follows:

POP(1) = mature breeding females

POP(2) = replacement females 3

POP(3) = replacement females 2

POP(4) = replacement females 1

POP(5) = weaned females

POP(6) = female calves

POP(7) = mature males

POP(8) = male-class 3

POP(9) = male-class 2

POP(10)= male class 1

POP(11)= weaned males

POP(12)= male calves

POP(13)= pregnant females

POP(14)= lactating females

A cohort is considered as a delay process with flows interconnecting different delays to represent the overall process of maturation (Jaske, 1976). A distributed delay subroutine (DELAY) (Llewellyn, 1965) with proportional loss rate is used. The delay is defined by a linear differential equation:

$$a_k \frac{d^k y(t)}{dt^k} + a_{k-1} \frac{d^{k-1} y(t)}{dt^{k-1}} + \ldots + a_1 y(t) = x(t)$$

where x(t) = the unlagged variable

y(t) = the lagged variable

The order of the differential equation k defines the order of the delay which is the number of stages the individual entities in the delay go through to accomplish the maturation process. The delay is also characterized by the time the maturation process takes (DEL).

A proportional loss rate is applied to the delay to account for the mortalities, offtake, transfer and addition to the cohort. The transfers concern the animals that conceive and are moved to the pregnant cohort.

The subroutine DELAY simulates the movement of animals from one cohort to the next one and also updates the rate of passage of the animals to each stage of the delay. This rate of passage is defined as RPOP. Since the delay does not conserve flow because of the losses, the population of the cohort is computed with the formula:

$$POP_i = \sum_{j=1}^{K_i} (RPOP_{ij} * (K_i / DEL_i))$$

The proportional loss rate (PLR) is defined as:

$$PLR_i = TDR_i + ADDRT_i + ((PREG_i / POP_i) * DT)$$

where:

TDR = total death rate

ADDRT = net rate of addition to the herd or flock.

$$TDR_i = DR_i + DRST_i$$

with DR = the natural death rate

DRST = death rate due to starvation (to be defined later)

$$ADDRT_i = OFT_i - (PUR_i / POP_i)$$

where

OFT = offtake rate

PUR = number of animals added to the cohort through purchases or gifts

PERG = number of animals that get pregnant

DT = the time increment (=0.0833)

Figure 6 presents a flow diagram of the movement of the animals from cohort to cohort.

Each cohort is characterized by an average age which is adjusted to the rates of passage of the animals in the different stages in the delay. Since the maturation process is here function of age, each stage in the delay can be described by an average age and the age of the cohort-delay is given by:

$$AGE_i = \sum_{j=1}^{K} (RPOP_{ij} * AGER_{ij}) / \sum_{j=1}^{K} RPOP_{ij}$$

where

$AGER$ = the average age of the animals in the stage j.

For the pregnant cohort, the age is the adjusted average of the ages of the animals entering the cohort.

$$AGE_{13} = \sum_{i=1}^{n} (PREG_i * AGE_i) / \sum_{i=1}^{n} PREG_i$$

For the lactating cohort, the average age is taken as

$$AGE_{14} = AGE_{13} + 0.75$$

III.3.2.2. <u>GROWTH</u>

The animals in each cohort are described by an average age and an expected average weight (TWT). The expected weight is defined as a function of age and the weight curve can be divided into 2 sections: one with an accelerating slope and one with a decreasing slope (figure 7). The equation that describes the weight is in the general form:

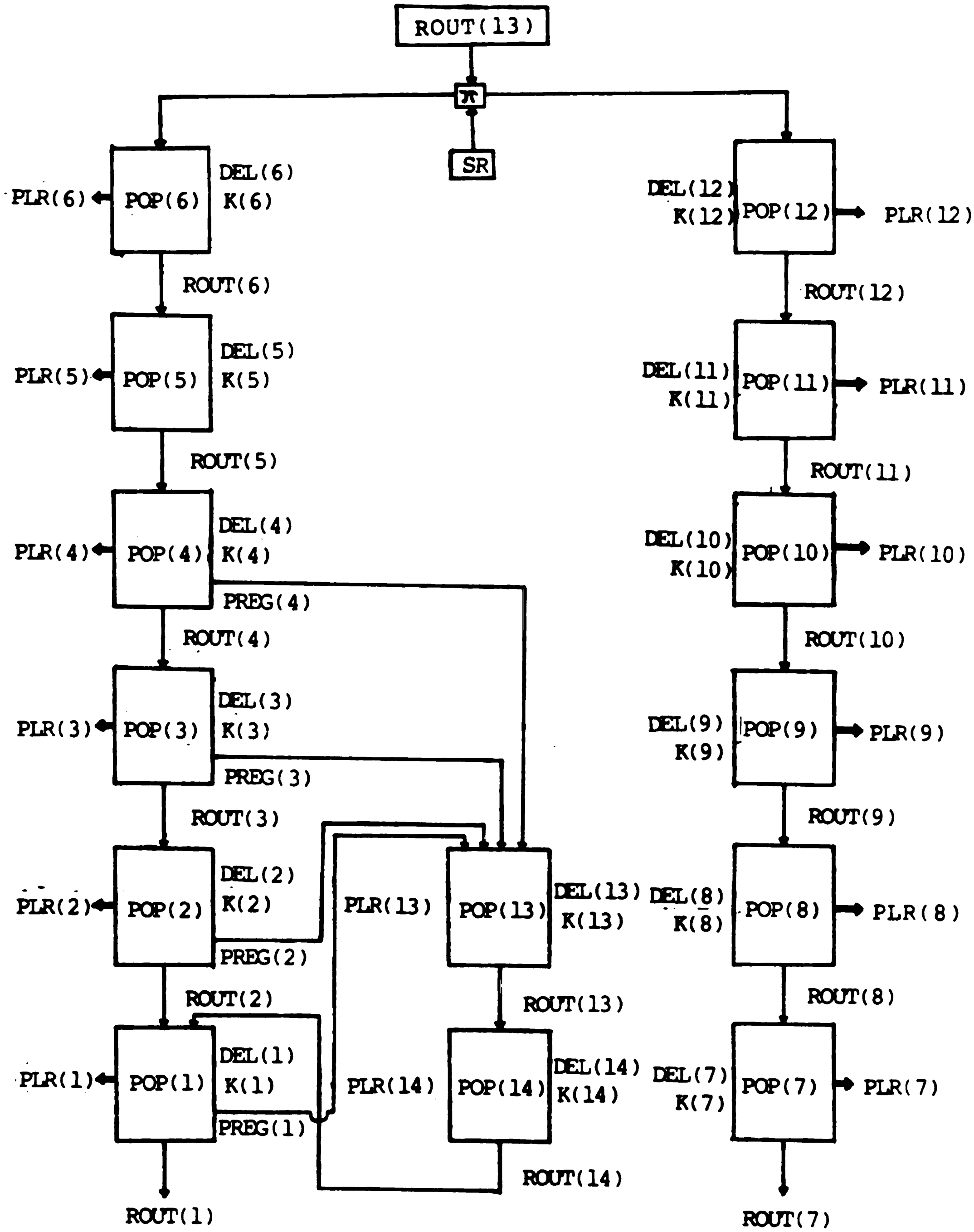


Figure 6: Flow diagram for the animal demography

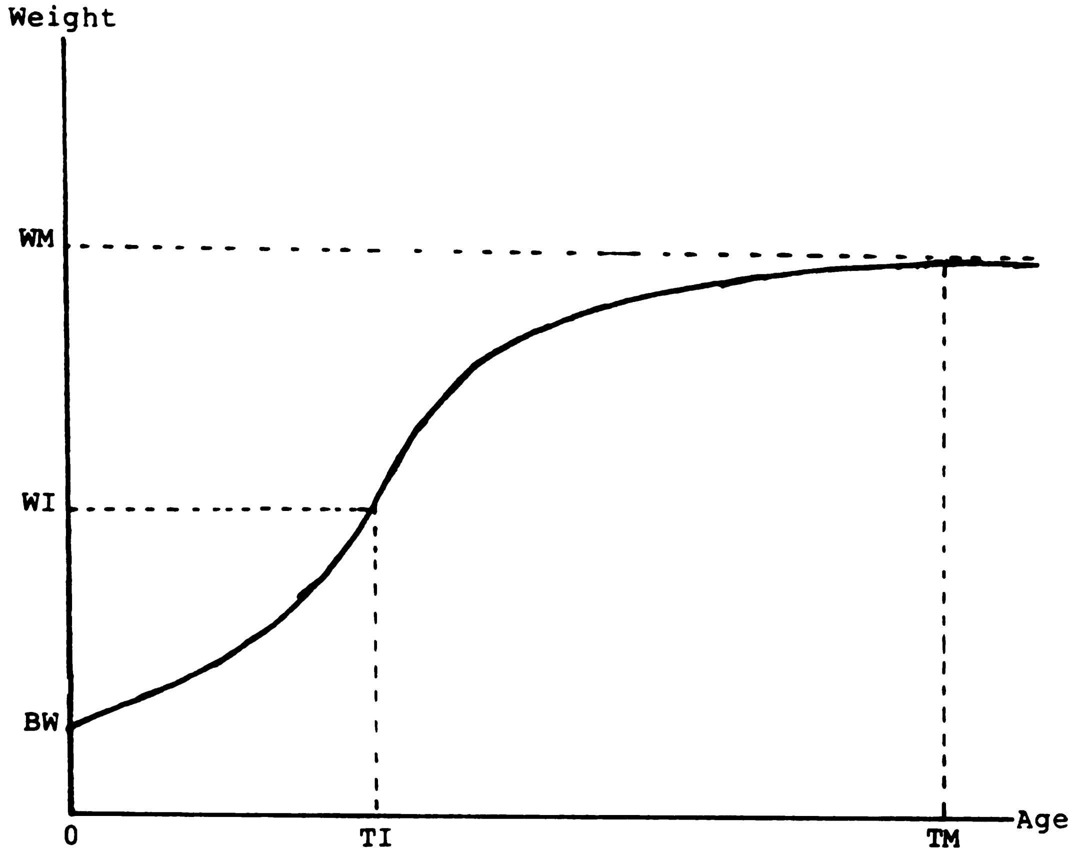


Figure 7: Expected liveweight curve

$$TWT = a_1 + b_1 * t + c_1 * t^2 \quad \text{for the section AB where } t \leq TI;$$

$$= a_2 + b_2 * t + c_2 * t^2 \quad \text{for the section BC where } TI < t \leq TM$$

where t = age in months

TI= the age corresponding to the point of inflection where the curve changes slope

TM= the age at maturity in months

The coefficients a_1, b_1, c_1, a_2, b_2 and c_2 are estimated using birth weight (BW), the age corresponding to the point of inflection (TI), the weight at the point of inflection (WI), the age at maturity (TM) and the weight at maturity (WM).

$$a_1 = BW$$

$$b_1 = 2*(TM*(WI-BW)-TI*(WM-BW))/(TI*(TM-TI))$$

$$c_1 = (TI*(WM-WI)+TI*(WM-BW)-TM*(WI-BW))/(TI^2*(TM-TI))$$

$$a_2 = (TI^2*WM+TM^2*WI-2*TM*TI*WM)/(TM-TI)^2$$

$$b_2 = (2*TM*(WM-WI))/(TM-TI)^2$$

$$c_2 = -(WM-WI)/(TM-TI)^2$$

For t greater than TM, the TWT is WM.

Using this procedure with data provided for BW, TI, WI, TM and WM (table 4), the equations that describe the expected liveweight as function of age have been constructed for the sex groups of each species considered.

Table 4 :Data points for expected growth curve.

		BW(kg)	TI(months)	WI(kg)	TM(months)	WM(kg)
Cattle:	male	21	18	180	60	350
	female	19	18	150	60	300
Sheep:	male	2.5	12	25	36	45
	female	2.2	12	20	36	35
Goat:	male	2.2	12	20	36	35
	female	2.0	12	18	36	30

For cattle:

Males TWT (kg)= $21+9.57*t-0.041*t^2$ t \< 18 months

= $3.06+11.57*t-0.096*t^2$ 18<t\<60 months

= 350 t>60 months

Females TWT (kg)= $19+7.41*t-0.008*t^2$ t \< 18 months

= $-6.12+10.2*t-0.09*t^2$ 18<t\<60 months

= 300 t>60 months

For sheep:

Males TWT (kg)= $2.5+2.08*t-0.02*t^2$ t\<12 months

= $2.5*t-0.035*t^2$ 12<t\<36 months

= 45 t>36 months

Females TWT (kg)= $2.2+1.72*t-0.02*t^2$ t\<12 months

= $1.25+1.9*t-0.03*t^2$ 12<t\<36 months

= 35

For goat:

Males TWT (kg)= $2.2+1.72*t-0.02*t^2$ t\<12 months

= $1.25+1.9*t-0.03*t^2$ 12<t\<36 months

= 35

Females TWT (kg)= $2.0+1.7*t-0.02*t^2$ t\<12 months

= $3.0+1.5*t-0.02*t^2$ 12<t\<36 months

= 30

where

t = average age of the cohort.

Assuming a normal distribution for the weight, an upper (WMAX) and a lower (WMIN) weight boundaries are defined using the coefficient of variation of the weight (WCV) and a 95 percent confidence.

WMAX = TWT*(1+1.96*WCV)

WMIN = TWT*(1-1.96*WCV)

The upper and lower boundaries are used with the actual weight (AWT) to compute the condition index (CI) of the animal and the maximum allwable weight gain (DGMAX) or loss (DLMAX).

CI = (AWT-WMIN)/(WMAX-WMIN)

$$DGMAX = (WMAX_{t+1} - AWT_t)/30$$

$$DLMAX = (AWT_t - WMIN_{t+1})/30$$

where t is the current simulation month.

The condition is used to adjust the potential daily milk yield, the conception rate and to compute the death rate due to starvation.

III.3.2.3. MILK PRODUCTION

The different classes of reproducing females have different milk production potentials according to their age. Cows reach their peak production level between 6 and 9 years and small stock between 2.5 and 5.5 years. The earliest age at which cattle lactate is set in the model at 3 years and for small stock at 1.25 years. The milk production potential as function of age is described by 2 curvilinear segments AB and CD and a horizontal segment BC. An adjustment factor for age (AMY) following the same shape as the milk production curve (figure 8) is used to correct the milk production potential which value is known as an average for the breed under consideration. The value of AMY varies from 0 to 1. Four age points are needed to estimate the adjustment factor:

T1= the earliest age of parturition;

T2 and T3 = the ages between which the milk production reaches the peak level;

T4= age for the oldest animal that can produce milk.

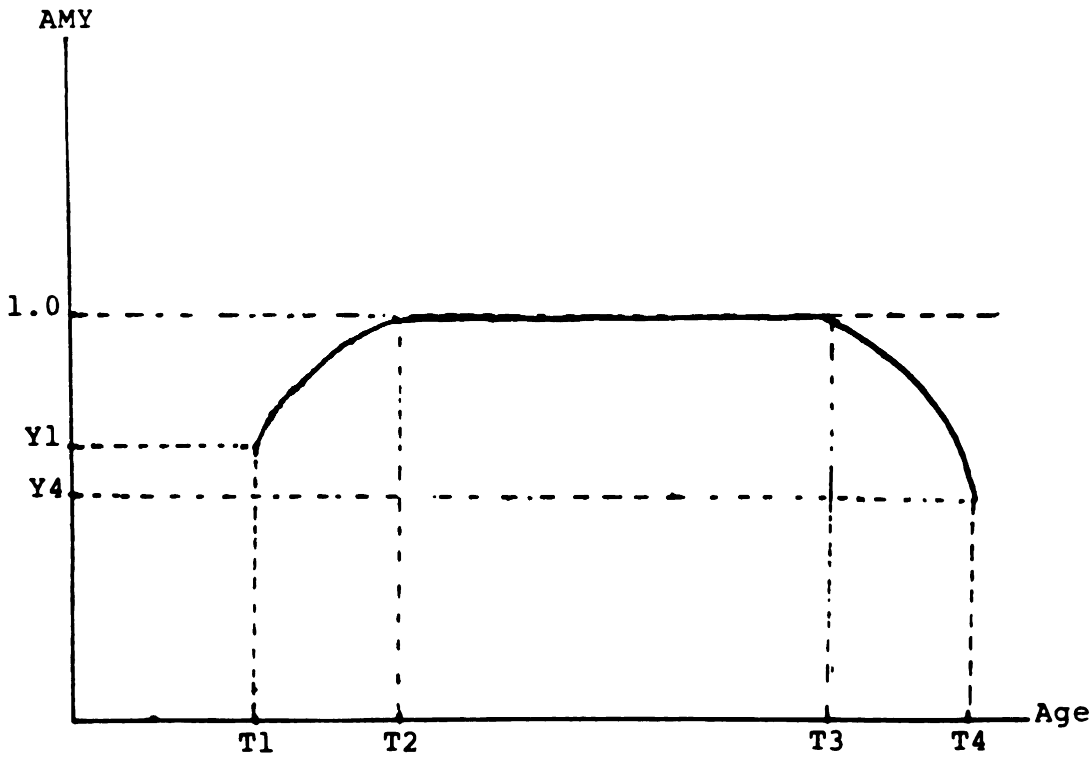


Figure 8: Adjustment factor (AMY) curve for milk production

The proportions of the potential production at T1 (Y1) and T4 (Y4) are also required for the setting of the equations that describe the adjustment factor as function of age. The equations are in the general form:

$$AMY = a_1 + b_1 * t + c_1 * t^2 \qquad \text{for } T1 \le t \le T2$$

$$= 1 \qquad \text{for } T2 < t < T3$$

$$= a_2 + b_2 * t + c_2 * t^2 \qquad \text{for } T3 \le t \le T4$$

where t is the age of the animal;

a_1, b_1, c_1, a_2, b_2 and c_2 are coefficients to be determined.

$$a_1 = (T1*(T1-2*T2)+T2^2*Y1)/(T2-T1)^2$$

$$b_1 = (2*T2*(1-Y1))/(T2-T1)^2$$

$$c_1 = (Y1-1)/(T2-T1)^2$$

$$a_2 = (T4*(T4-2*T3)+T3^2*Y4)/(T4-T3)^2$$

$$b_2 = (2*T3*(1-Y4))/(T4-T3)^2$$

$$c_2 = (Y4-1)/(T4-T3)^2$$

Using this procedure with the following values set for Y1 and Y4 :

$Y1 = 0.80$

$Y4 = 0.60$

the equations that describe AMY are:

For cattle

$$AMY = -0.15+0.38*t-0.03*t^2 \qquad t \leq 6 \text{ years}$$

$$= 1 \qquad 6 < t \leq 9 \text{ years}$$

$$= -2.6+0.8*t-0.04*t^2 \qquad t > 9 \text{years}$$

For sheep and goat

$$AMY = 0.2+0.53*t-0.09*t^2 \qquad t \leq 2.5 \text{ years}$$

$$= 1 \qquad 2.5 < t \leq 5.5 \text{ years}$$

$$= -13.4+4.8*t-0.4*t^2 \qquad t > 5.5 \text{ years}$$

Once the milk production potential is defined according to the age of the lactating cohort, the lactation curve is used in order to take into account the different stages the animals in the cohort. Assuming that for cattle, 35 percent of the milk is produced during the first two months of lactation, the proportion of the production during the following months are estimated by the formula:

$$H(n) = ((N^2+N+2)*H(1,2)-8)/(2*(N^2-3*N+2)$$

$$-(n*(N*H(1,2)-2))/(N^2-3*N-2)$$

where n is the month of lactation;

N is the lactation length;

H(1,2) is the proportion of milk produced during the first two months of lactation.

This formula is valid if the following relationship between H(1,2) and N holds:

$$2/N \leq H(1,2) \leq (4*N-8)/(N^2-N-2)$$

or N between 6 and 9 months; therefore applying only for catlle.

Thus for the three stages defined in the lactating cohort, the proportion of milk produced during each stage is 0.504, 0.340 and 0.16 respectively. For sheep and goat, assuming a more stable lactation, we have set the proportion of milk production for the three stages of the lactation period to be 0.45, 0.35 and 0.20 respectively.

The potential milk production at each stage is given by:

PMY1 = 0.504*TPMY*AMY }
PMY2 = 0.340*TPMY*AMY } for cattle
PMY3 = 0.160*TPMY*AMY }

PMY1 = 0.450*TPMY*AMY }
PMY2 = 0.350*TPMY*AMY } for sheep and goat
PMY3 = 0.200*TPMY*AMY }

where TPMY = average potential milk yield for the breed under consideration:

TPMY = 580 kg/lactation for cattle
45 kg/lactation for sheep
60 kg/lactation for goat

The potential milk yield (PMY) for the cohort is calculated using the rates at which the animals are in the three stages of lactating cohort:

$$PMY = (3*(RPOP1*PMY1+RPOP2*PMY2+RPOP3*PMY3))/(RPOP1+RPOP2+RPOP3)$$

where RPOP1, RPOP2 and RPOP3 are the rates.

The potential daily milk yield (PDMY) is adjusted with the condition index (CI) of the animals at the end of the previous month.

$$PDMY = (PMY/LACL)*(CI/0.3) \quad \text{if } CI < 0.3$$
$$= PMY/LACL$$

where LACL = lactation length.

III.3.2.4. REPRODUCTION

Since information on parturition rate are more available in the litterature than that of conception rate, in the model, we consider conception rate as parturition rate; therefore assuming that there is no abortion and each conception will result in the birth of a new animal.

Four cohorts of cattle and five of smallstock are considered as being able to conceive. These are for cattle cohort 1, 2, 3 and 14; and for smallstock, cohort 1, 2, 3, 4 and 14. In the cohort 14 only animal in the third stage of lactation can conceive. This assumption is made according to the fact that an interval between parturition and next conception of 180 days for cattle and 100 days for smallsock can be considered an upper limit for the animals raised in the system under study. These limits correspond to a calving rate of 0.8 and a kidding or lambing rate of 1.44 .

Conception rate depends on age and condition index. The conception rate can be described as function of age by two curvilinear segments AB and CD and a horizontal one BC (figure 9).

The earliest age for conception (T1) is set at 2.25 years for cattle and 0.83 years for goat and sheep. Reproduction performances are at the maximum between age T2 and age T3 which are set at 4 and 8 years for cattle and 2 and 5 years for smallstock. Conception rate is lower at age (T4) 11 years for cattle and 6.5 years for sheep and goat. The equations that describe the curvilinear segments are:

$$TCR = a_1 + b_1 * t + c_1 * t^2 \qquad \text{for } T1 \leq t \leq T2$$

$$= a_2 + b_2 * t + c_2 * t^2 \qquad \text{for } T3 < t \leq T4$$

and for the horizontal section

$$TCR = CR23 \qquad \text{for } T2 < t \leq T3$$

where:

t = age in years;

CR23 = the conception rate for the species between T2 and T3

a_1, b_1, c_1, a_2, b_2 and c_2 are coefficients to be determined.

$$a_1 = (T1*(T1-2*T2)*CR23+T2^2*CR1)/(T2-T1)^2$$

$$b_1 = (2*T2*(CR23-CR1))/(T2-T1)^2$$

$$c_1 = (CR1-CR23)/(T2-T1)^2$$

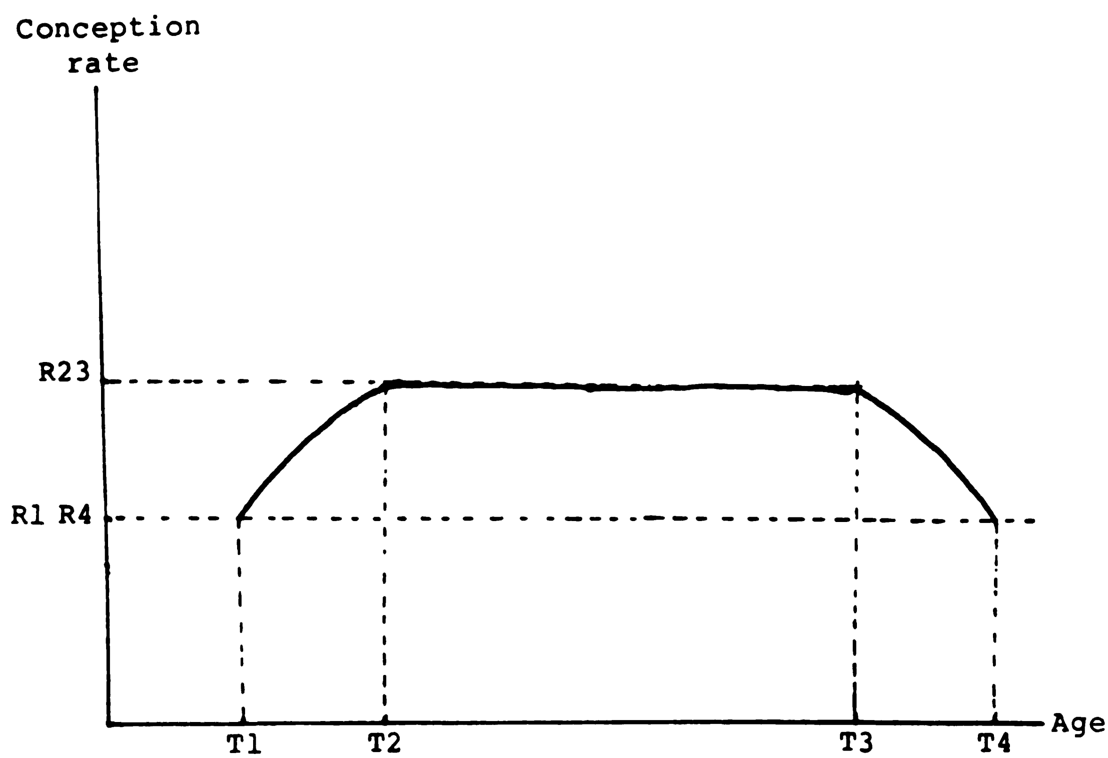


Figure 9: Conception rate curve as function of age

$$a_2 = (T4*(T4-2*T3)*CR23+T3^2*CR4)/(T4-T3)^2$$

$$b_2 = (2*T3*(CR23-CR4))/(T4-T3)^2$$

$$c_2 = (CR4-CR23)/(T4-T3)^2$$

where CR1, CR23 and CR4 are the conception rate for the breed at age T1, between T2 and T3 and at age T4 respectively.

With data provided for CR1, CR23 and CR4 (table 5),the following conception rate equation curves have been obtained:

Cattle:	$TCR = -2.17+1.4*t-0.18*t^2$	$t \leq 4$ years
	$= 0.70$	$4<t \leq 8$ years
	$= -3.21+0.98*t-0.06*t^2$	$t>8$ years
Sheep:	$TCR = -1.10+2.20*t-0.55*t^2$	$t \leq 2$ years
	$= 1.10$	$2<t \leq 5$ years
	$= -7.23+3.33*t-0.33*t^2$	$t>5$ years
Goat:	$TCR = -1.34+2.64*t-0.66*t^2$	$t \leq 2$ years
	$= 1.30$	$2<t \leq 5$ years
	$= -8.70+4.0*t-0.40*t^2$	$t>5$ years

Table 5 : Average conception rates

	CR1	CR23	CR4
Cattle	0.15	0.70	0.15
Sheep	0.35	1.10	0.35
Goat	0.40	1.30	0.40

The conception rate is then adjusted using the condition index (CI) of the previous month to give the actual conception rate. The adjustment factor (CRM) is defined as:

CRM = 0.6+1.5*CI   if CI \< 0.2

 = 0.833+0.333*CI   if 0.2 < CI \< 0.9

 = 3.233-2.333*CI   if CI > 0.9

and the actual conception rate (CR) becomes:

CR = TCR*CRM

III.3.2.5. <u>DEATH</u> <u>RATE</u> <u>DUE</u> <u>TO</u> <u>STARVATION</u>

We introduce here the effect of nutrition on mortality rate to peak up the increase in death rate during period of starvation. Since we do not have data to estimate this increase in mortality, we consider that death occurs if the condition index decreases below 0.5 with the assumption that the animals are normally distributed in each cohort. The annual death rate increases exponentially as the condition index decreases and at CI equal zero the death rate due to starvation reaches 0.5 . Since we are dealing with an aggregated system, a maximum of 50 percent of the animals die when the condition of the cohort is equal 0. The equation that describes that death rate is:

$$DRST = e^{A*CI} - 0.5$$

where A = -1.38643 .

III.3.3. ANIMAL PERFORMANCE

For the different classes of animal, the energy is used to satisfy maintenance requirements (maintenance + pregnancy for pregnant females) first and if there is an excess, it is used for lactation (lactating females), and there still is some energy left, it will be used for growth.

III.3.3.1. LIVEWEIGHT CHANGE FOR PREGNANT FEMALES

Maintenance and pregnancy requirements (ERMP) are compared with the total energy intake (TMEI). If TMEI is greater than ERMP, then the excess energy is used for liveweight gain and the weight gain will process up to the maximum allowable daily weight gain (DGMAX). If TMEI cannot satisfy the ERMP, then the animal will loss weight up the maximum allowable daily weight loss (DLMAX).

Figure 10 represents the algorithm for the computation of liveweight change for pregnant females.

III.3.3.2. MILK PRODUCTION AND LIVEWEIGHT CHANGE FOR LACTATING FEMALES

If the energy requirement for maintenance (ERM) is less than

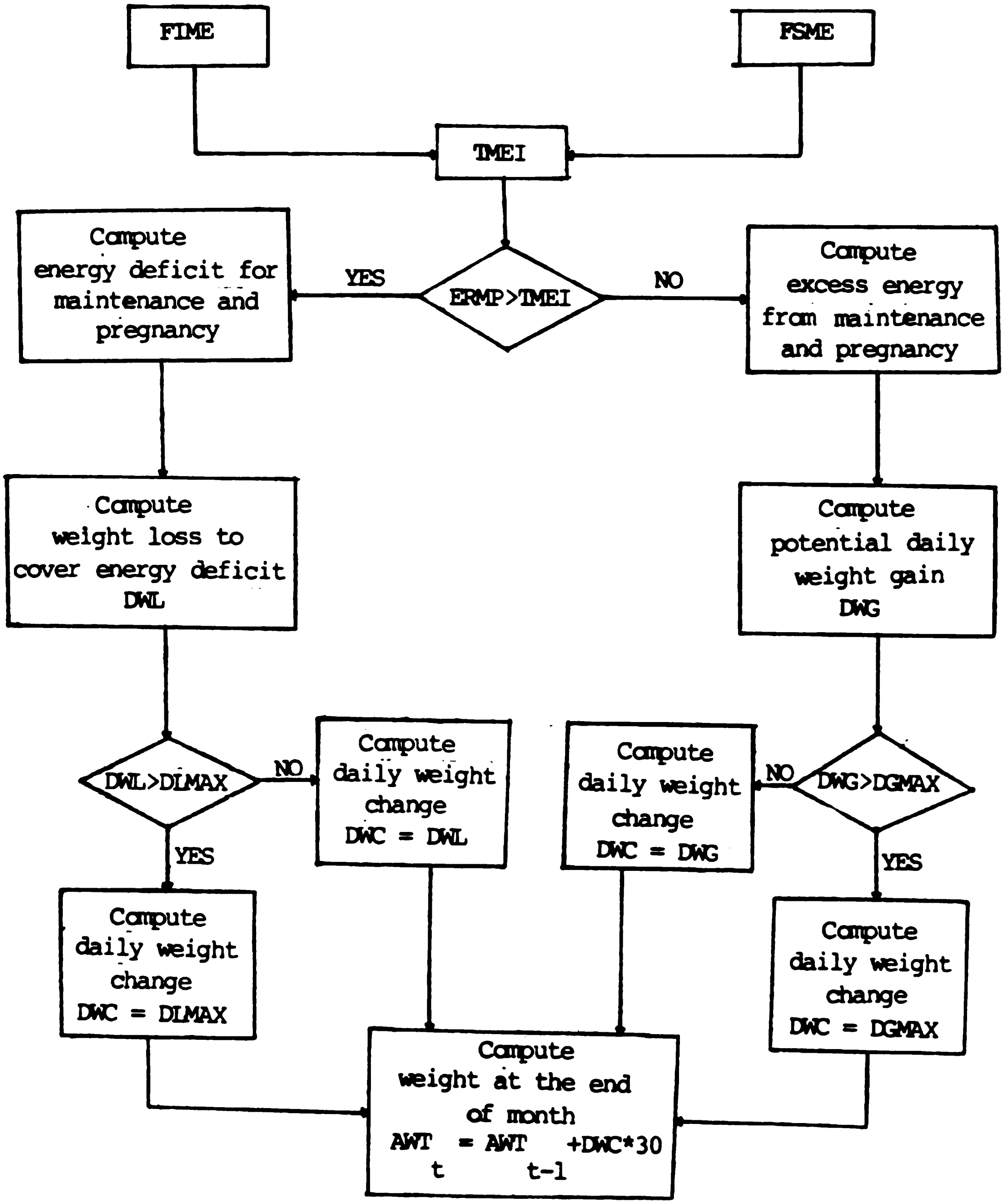


Figure 10: Algorithm for weight changes for pregnant females

the TMEI, then the excess energy is used for lactation up to the potential milk production. If there is an excess energy after production potential is met, then, the energy is used for weight gain up to the DGMAX. If after maintenance, the excess energy cannot meet lactation needs, then there will be weight loss up to the DLMAX.

If the TMEI is less than the ERM, then there will be weight loss to satisfy maintenance first and then lactation needs. If the energy released up to the DLMAX cannot satisfy maintenace, then the lactation will stop.

Figure 11 presents the algorithm used to compute milk production and weight change for lactating females.

III.3.3.3. LIVEWEIGHT CHANGE FOR MALES AND FOR NON-LACTATING AND NON- PREGNANT FEMALES

If the maintenance requirements are satisfied, then the excess energy is used for weight gain up to the DGMAX. Otherwise, there will be weight loss up to the DLMAX.

Figure 12 represents the algorithm used to compute the weight change for these animals.

III.4. PERFORMANCE OF THE SYSTEM

The performance measures of the system are defined as the total liveweight offtake (TLWOFT), the total quantity of milk offtake (TMOFT) and the forage production change rate (FPCR).

$$TLWOFT = \sum_{i=1}^{3} \sum_{j=1}^{12} \sum_{k=1}^{14} (POP_k * OFT_k * DT * AWT_k)$$

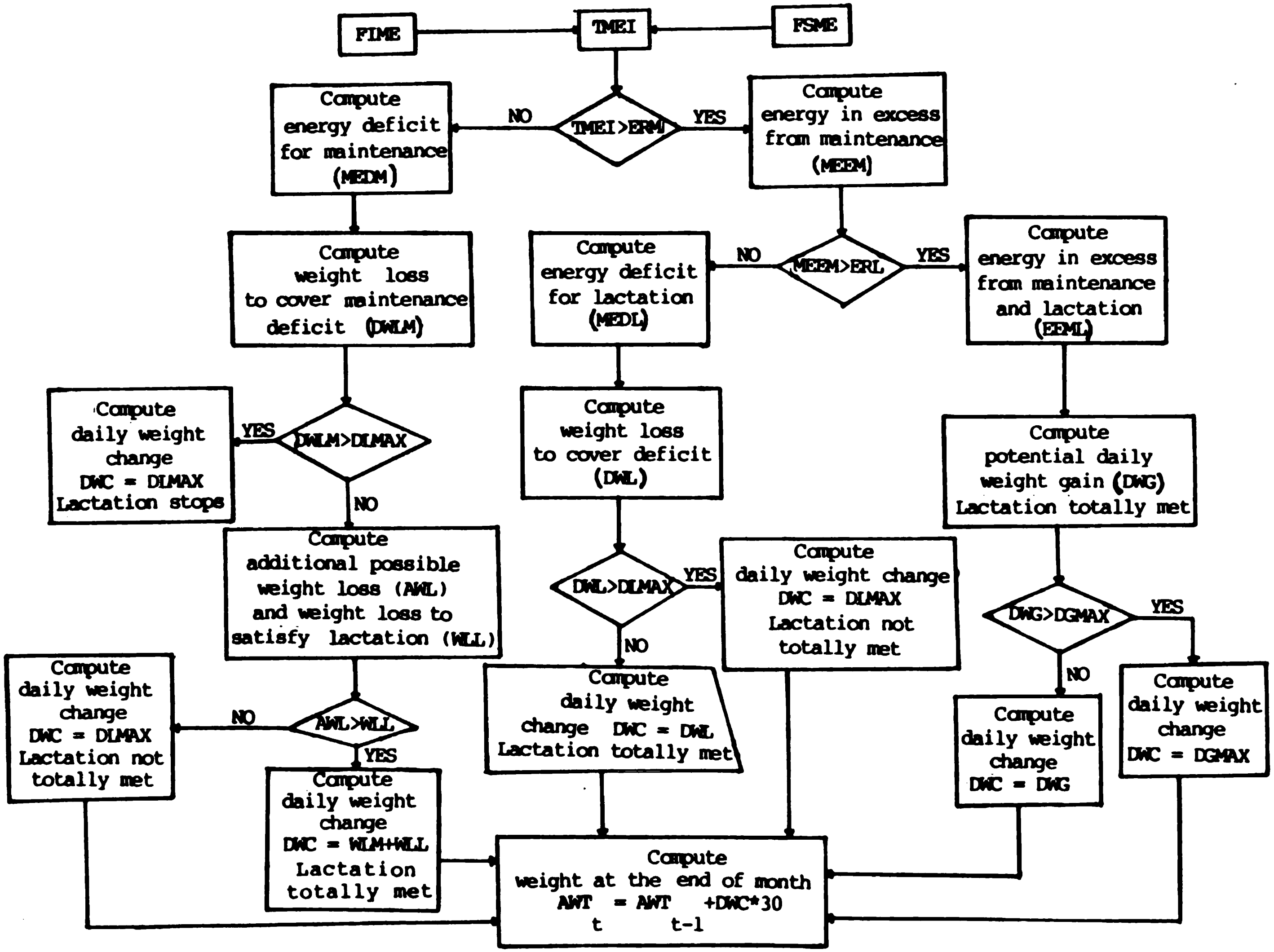


Figure 11: Algorithm for weight changes and milk production for lactating females

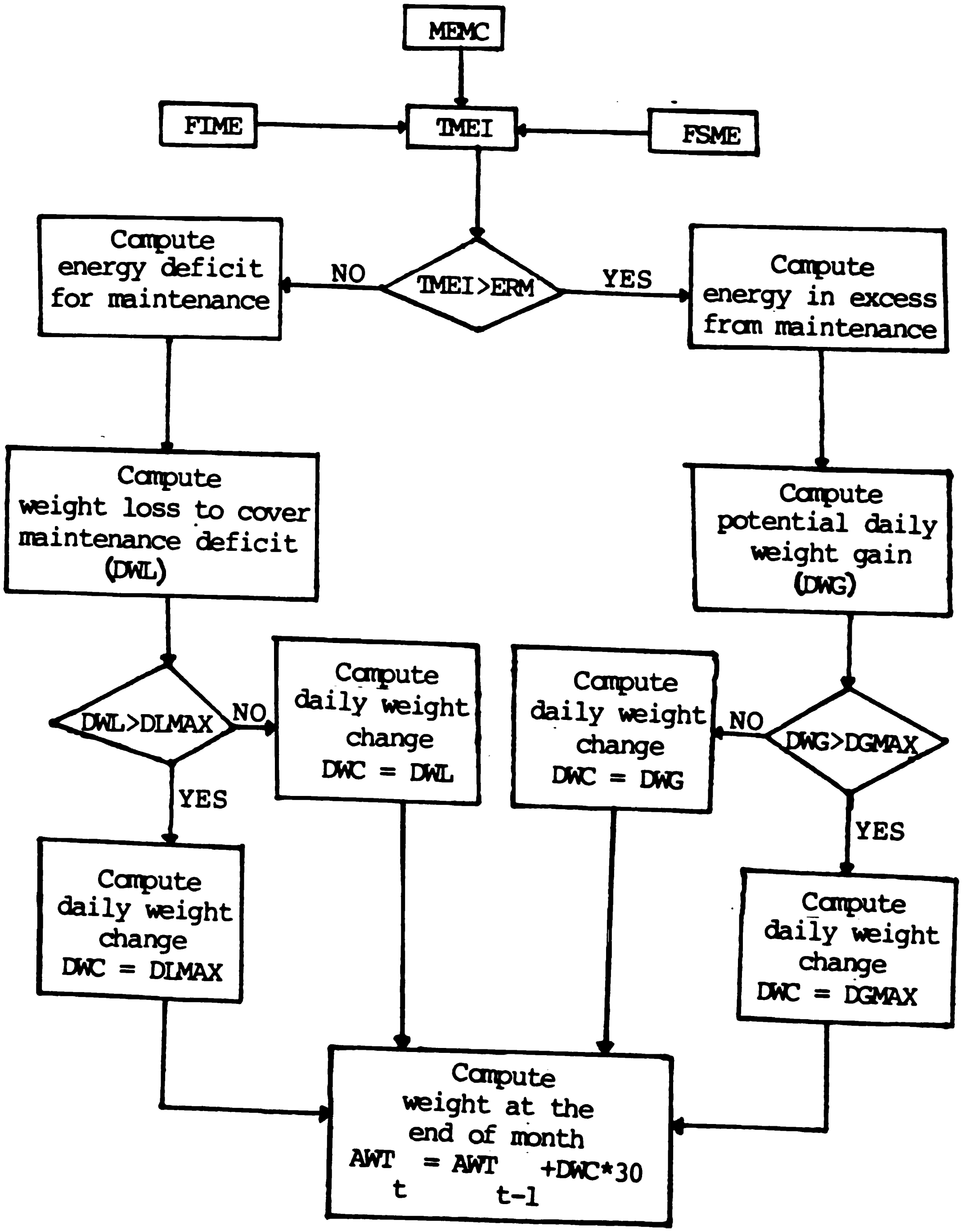


Figure 12: Algorithm for weight changes for males and non-pregnant, non-lactating females

where

i represents the species, j, the 12 months of the year and k, the 14 cohorts of each species.

DT = time increment (= 0.0833)

POP = population

OFT = liveweight offtake rate

AWT = actual liveweight

$$TMOFT = \sum_{i=1}^{3} \sum_{j=1}^{12} (POP_{14} * TAMY * MOFT_{i})$$

where

i = the 3 species

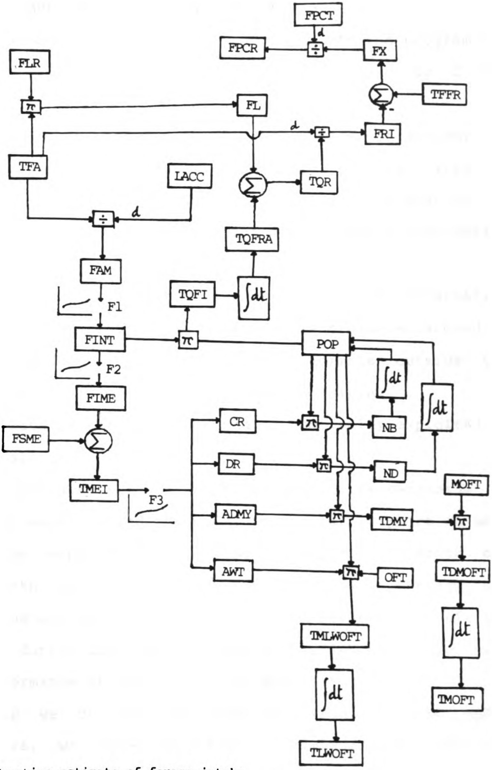
j = the 12 months of the year

POP_{14} = population of the lactating cohort

TAMY = total milk production during the month

MOFT = milk offtake rate

Figure 13 represents a block diagram for the computation of the system's performances.



F1 = Function estimate of forage intake
F2 = Function estimate of metabolic energy of forage
F3 = Function utilization of metabolic energy intake

Figure 13: Block diagram for the whole system

CHAPTER FOUR: SIMULATION AND RESULTS

The model is programmed in FORTRAN V. In the program the variable related to each species are preceded by C for cattle, S for sheep and G for goat (Annexes).

The model is used for two different types of system:

- a regional system where the whole pastoral area is considered as a single system characterized by migration of a portion of the animal population outside the system during the dry season.
- a communal system which is considered as an alternative management strategy where the system is organized around a borehole and the migrations of the animals outside the boundaries of the system is no longer possible.

For both cases, the rangeland is communally exploited by the animals in the system.

The year starts in the model in july, the beginning of the rainy season; and the model is run for 10 years in each simulation experiment. The time increment is 1 month and each month of the year is characterized by an average day held constant during the month and the performances of the animals during that day are then multiplied by 30 to give the performance at the end of the month.

Since we do not have precise values of the model parameters, we have relied on information drawn from the literature on similar systems of production. For the initial values assigned to the state variables, we have used our own judgement on the basis of information available from the particular system under study.

Since there is no information about the performance the system, a validation of the model has not been undertaken. A baseline run is done according to what is believed to be the estimated values of the parameters of the system.

IV.1. ASSIGNMENT OF VALUES FOR PARAMETERS AND INITIAL VALUES FOR STATE VARIABLES

IV.1.1. THE FORAGE COMPONENT

The values assigned to the parameters are presented in table 6 .

Table 6 : Values assigned to forage component parameters

	REGIONAL	COMMUNAL
LAND (ha)	3000000	70000
PMIG	0.14	0.
PMIDY	0.30	0.
FPPWY (t DM/ha)	1.60	1.60
FPPAY (t DM/ha)	1.20	1.20
FPPDY (t DM/ha)	0.80	0.80
JFFPP	0.50	0.50
TFFR	0.50	0.50

For the state variable FPCR, it has been initialized at 0.

IV.1.2. THE ANIMAL COMPONENT

The parameters defined in the model are presented in the following tables: 7, 8, 9 and 10 .

Table 7 : Values assigned to animal population parameters

		Cattle	Sheep and Goat
DEL (years):	(1)	8	4
	(6, 12)	0.75	0.4167
	(5, 11)	0.75	0.3333
	(4, 10)	0.75	0.50
	(3, 9)	0.75	0.75
	(13, 14)	0.75	0.4167
	(2, 8)	1.	1.
	(7)	3.	2.
K	(1)	8	4
	(2 to 4)	3	3
	(5, 7, 11)	3	2
	(6, 12)	4	4
	(8 to 10)	3	3
	(13, 14)	3	3

The figures in parentheses represent the cohorts.

Table 8 : Values assigned to forage digestibility

Month	Cattle	Sheep	Goat
1	0.54	0.56	0.58
2	0.60	0.62	0.60
3	0.60	0.62	0.60
4	0.57	0.58	0.58
5	0.55	0.55	0.56
6	0.53	0.53	0.55
7	0.52	0.53	0.53
8	0.50	0.51	0.53
9	0.50	0.51	0.52
10	0.48	0.50	0.52
11	0.46	0.48	0.50
12	0.46	0.48	0.50

Source: Wilson et al. (1983); Abassa, (1984)

Table 9 : Distance walked (kms/day)

Month	Cohorts		
	(6, 12)	(5, 11)	(1 to 4 and 7 to 10)
1	2	5	8
2	2	5	5
3	2	5	5
4	2	5	6
5	2	6	7
6	2	6	9
7	2	8	10
8	2	8	12
9	2	8	14
10	2	9	14
11	2	10	16
12	2	10	16

Table 10: Values assigned to other parameters used in the model

	Cattle	Sheep	Goat
WCV (6, 12)	0.30	0.30	0.30
(5, 11)	0.27	0.27	0.27
(1 to 5, 7 to 10, 13, 14)	0.25	0.25	0.25
SR	0.50	0.50	0.50
TDW (kms/day)	14	14	14
TFA (t/ha)	0.80	0.75	0.70
FIC (1, 12)	0.046	0.027	0.0255
(13)	0.049	0.028	0.026
(14)	0.054	0.033	0.0345
DR (6, 12)	0.10	0.22	0.27
(5, 11)	0.030	0.12	0.14
(1 to 4, 7 to 10, 13, 14)	0.020	0.06	0.08
TPMY (kg/lactation)	580	40	60
LACL (days)	270	150	150
MEC (MJ/kg)	3.50	4.	3.75

Figures in parentheses represent the cohorts.

Initial values assigned to animal state variable population, age and weights are presented in tables 11, 12, 13. For the variable population, a herd/flock compostion has been used with the proportion of females being around 72 percent for both species.

Table 11 : Initial values for cohort populations

Cohorts	Cattle		Sheep		Goat	
	R(1)	C(1)	R	C	R	C
1	75000	1500	70000	1200	40000	800
2	20000	350	10000	150	5000	100
3	30000	500	25000	400	15000	200
4	40000	750	30000	450	15000	250
5	40000	750	20000	350	12000	250
6	30000	600	25000	500	17000	350
7	15000	350	10000	200	5000	100
8	15000	350	10000	250	8000	125
9	20000	400	20000	350	12000	250
10	30000	600	25000	400	12000	275
11	40000	650	17000	300	10000	200
12	30000	600	25000	500	17000	350
13	65000	1250	60000	1150	45000	800
14	60000	1200	50000	1000	34000	700
TOTAL	510000	9850	397000	7200	250000	4750

(1) R = regional system; C = communal system.

Table 12 : Initial values for average age (years) of the cohorts

Cohorts	Cattle	Sheep and Goat
1	8	5
2, 8	3.5	2.5
3, 9	2.625	1.625
4, 10	1.875	1.
5, 11	1.125	0.583
6, 12	0.375	0.208
7	5.75	4.
13	6.50	3.50
14	7.25	3.917

Table 13 :Initial values for expected weight (TWT) and actual weight (AWT) in kg.

Cohort	Cattle		Sheep		Goat	
	TWT	AWT	TWT	AWT	TWT	AWT
1	300	270	35	32	30	28
2	272	245	34	31	29	27
3	231	208	28	26	24	22.5
4	180	262	20	18	18	17
5	118	107	13	12	12	11
6	52	47	7	6	6	5.5
7	350	315	45	41	35	33
8	319	288	44	40	34	32
9	279	245	36	33	28	26
10	214	193	25	23	20	19
11	143	129	16	15	13	12
12	63	57	8	7.5	7	6.5
13	300	280	35	33	30	29
14	300	270	35	32	30	28

The condition index is set at 0.4 for all the animals in the system.

IV.2. RESULTS OF THE SIMULATION

IV.2.1. THE REGIONAL SYSTEM

A 2 by 2 by 3 factorial experiment is conducted with

- 2 levels of forage availability and accessibility (FAA) defined by the proportion of land accessible for grazing (PLACC) and the forage loss rate (FLR)
- 2 levels of liveweight offtake rate (OFT)
- 3 levels of feed supplementation (FS)

These facors and levels are defined as follows:

FAA: level 1: PLACC = 0.75
FLR =0.25
level 2: PLACC = 1.
FLR = 0.10

OFT: level 1: current offtake rate (table 14)
level 2: increase of the offtake rate of the males (table 14)

FS: level 1: without
level 2: 0.0025 kg/kg liveweight (0.003 kg/kg liveweight for lactating females)
level 3: 0.0050 kg/kg liveweight (0.006 kg/kg liveweight for lactating females)

The feed supplement is considered as having 65 percent digestibility and is provided during the second half of the year from january to june.

Table 14 : liveweight offtake rate

Offtake rate	Cattle	Sheep	Goat
Level 1: (5,6,12,13,14)	0.	0.	0.
(1)	0.08	0.20	0.25
(2 to 4)	0.03	0.10	0.15
(11)	0.08	0.15	0.18
(7 to 10)	0.35	0.50	0.60
Level 2: (5,6,12,13,14)	0.	0.	0.
(1)	0.08	0.20	0.25
(2 to 4)	0.03	0.10	0.15
(11)	<u>0.60</u>	<u>0.40</u>	<u>0.45</u>
(7 to 10)	<u>0.60</u>	<u>0.75</u>	<u>0.80</u>

Figures in parentheses represent the cohorts. The underscored values are the increased liveweight offtake rates.

The 12 combinations are numbered as follows:

1. FAA 1-OFT 1-FS 1
2. FAA 1-OFT 1-FS 2
3. FAA 1-OFT 1-FS 3
4. FAA 1-OFT 2-FS 1
5. FAA 1-OFT 2-FS 2
6. FAA 1-OFT 2-FS 3
7. FAA 2-OFT 1-FS 1
8. FAA 2-OFT 1-FS 2
9. FAA 2-OFT 1-FS 3
10. FAA 2-OFT 2-FS 1
11. FAA 2-OFT 2-FS 2
12. FAA 2-OFT 2-FS 3

The trial 1 is considered as the baseline.

The milk offtake rate (MOFT) is held constant in the model and is equal to:

MOFT = 0.30 for cattle
= 0.20 for goat
= 0. for sheep

The random variables generated during the 10 year simulation runs give:

- 3 dry years (year 4, 6 and 7);
- 1 wet year (year 2) and
- 6 average years (year 1, 3, 5, 8, 9 and 10)

which correspond to probabilities of occurences of 0.30, 0.10 and 0.60 for dry, wet and average year respectively. The values are close to the computed probabilities form the actual data of the distribution of the rainfall in the area which are 0.30, 0.15 and 0.55 respectively for dry, wet and average year.

The results of the 10 years simulation runs have been averaged and presented in table 15 and figures 14, 15 and 16. Figures 17, 18 19 and 20 illustrate the yearly evolution of the total liveweight offtake and the total milk offtake.

The comparisons of the baseline run with the other combinations of alternatives show that for the total liveweight offtake, increasing the offtake rate alone yields an average production of only 5 percent higher than the baseline output (trial 1 versus trial 4). And the improvement in the forage availability and accessibility alone results in an increase in the liveweight output by 4 percent (1 vs 7). The provisions of feed supplement has raised the production by 27 and 53 percent for the two levels of feed supplementation (1 vs 2 and 1 vs 3).

The combinations of the different factors has revealed a synergestic effect in the total liveweight offtake.

Table 15: Total liveweight offtake (TLWOFT), total milk offtake (TMOFT) and forage production change rate (FPCR)

Trials	TLWOFT (tons)	TMOFT (tons)	FPCR
1	19115	19380	-0.0221
2	24218	24111	-0.0345
3	29243	27927	-0.0423
4	20161	20221	-0.0183
5	25449	25197	-0.0300
6	30306	28592	-0.0361
7	19872	20163	-0.0014
8	25845	25544	-0.0108
9	31058	28804	-0.0170
10	20613	20661	-0.0007
11	26550	26146	-0.0066
12	31601	29034	-0.0115

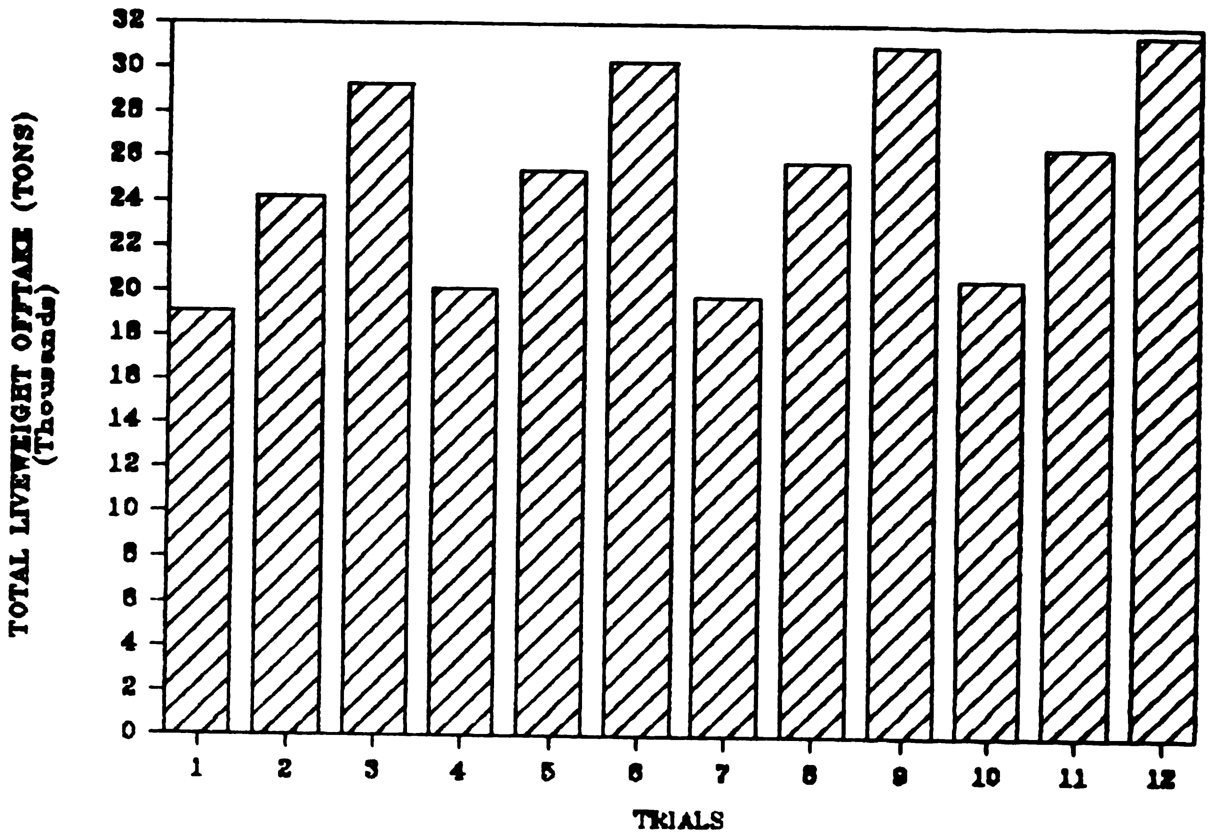


Figure 14: Average total liveweight offtake for the regional system

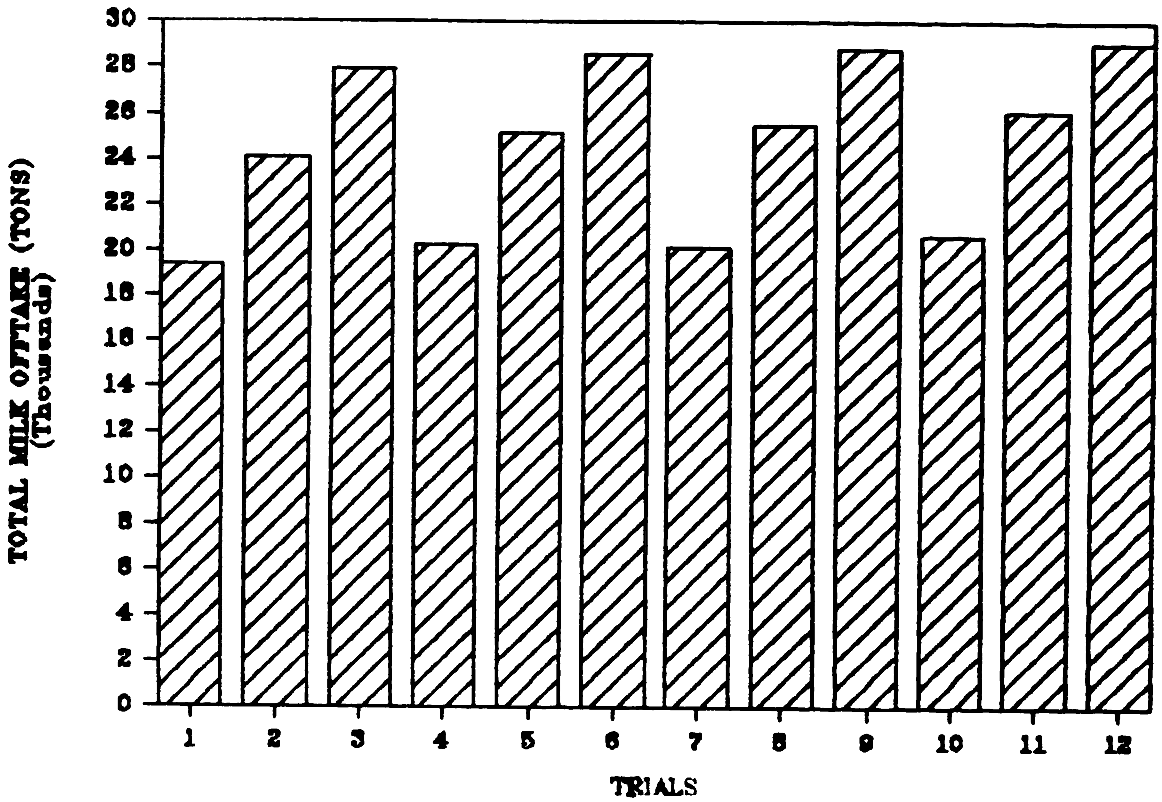


Figure 15: Average total milk offtake for the regional system

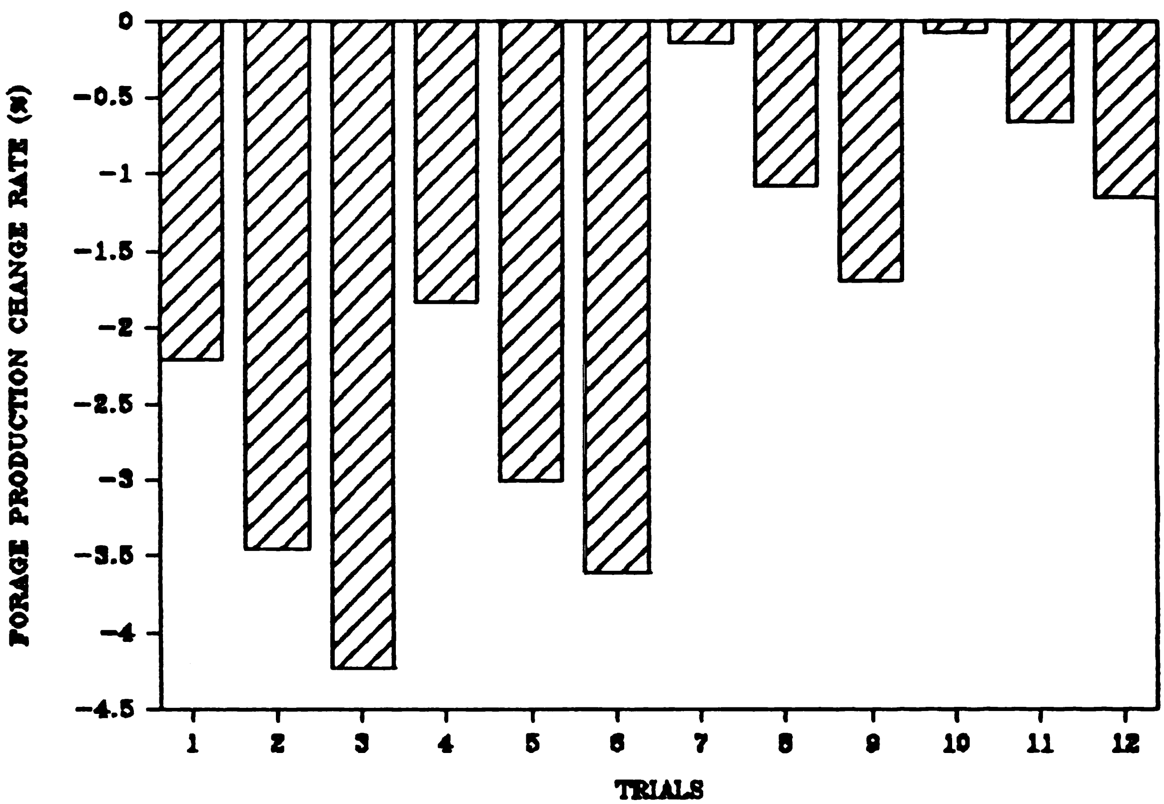


Figure 16: Average forage production change rate for the regional system

Increasing offtake rate and forage availability has resulted in a 8 percent higher production (1 vs 10); whereas the combination of offtake rate and feed supplement increased the output by 33 and 58 percent (1 vs 5 and 1 vs 6). Forage availability and feed supplement together yielded a production 35 and 62 percent higher than the baseline level (1 vs 8 and 1 vs 9). The combination of the three factors boosted the total liveweight output from the baseline level by 39 and 65 percent (1 vs 11 and 1 vs 12).

For the total milk output we have the same scenario with a percent increase for the baseline level of 4, 4, 24, 44, 7, 30, 48, 32, 49, 35 and 50 respctively for comparisons 1 versus 4, 7, 2, 3, 10, 5, 6, 8, 9, 11 and 12.

For the forage production change rate, the increase in the forage availability and accessibility has reduced significantly the rate of deterioration as compared with the baseline situation under which the system has been overstocked. The comparisons of the baseline and the trials where the forage availability has been improved has resulted in a reduction in the deterioration rate of 94, 51, 23, 97, 70 and 48 percent for 1 versus 7, 8, 9, 10, 11 and 12 respectively.

The increase in the offtake rate alone has a positive effect on the deterioration of the rangeland with a 17 percent reduction from the baseline situation (1 versus 4); however when associated with the feed supplement, there is an increase in the deterioration rate of 36 and 63 percent

(1 vs 5 and 1 vs 6). The provision of feed supplement alone has a detrimental effect in the protection of the range resources with an increase in the deterioration rate of 56 and 91 percent (1 vs 2 and 1vs 3).

The provision of feed supplement has resulted, in the different trials, in an increase in the population through the reduction in the mortality rate during the period of feed scarcity. The level of liveweight offtake rate used was not enought to offset the growth in animal population.

The yearly evolution of the production for the different trials (figures 17 and 18) shows that with the level of offtake rate used in the study, there is no sustained increase in the yearly liveweight output. The quantity of liveweight offtake falls bellow the baseline level at the third year and will finally reach again the baseline production only by the end of the seventh year. This suggests that the productive capacity of the system could not keep pace with the level of liveweight offtake rate used.

For the milk production (figures 19 and 20), the yearly output is mainly affected by the occurence of drought (year 4, 6 and 7) through a low nutrition plan and an increase in the mortality of the animals.

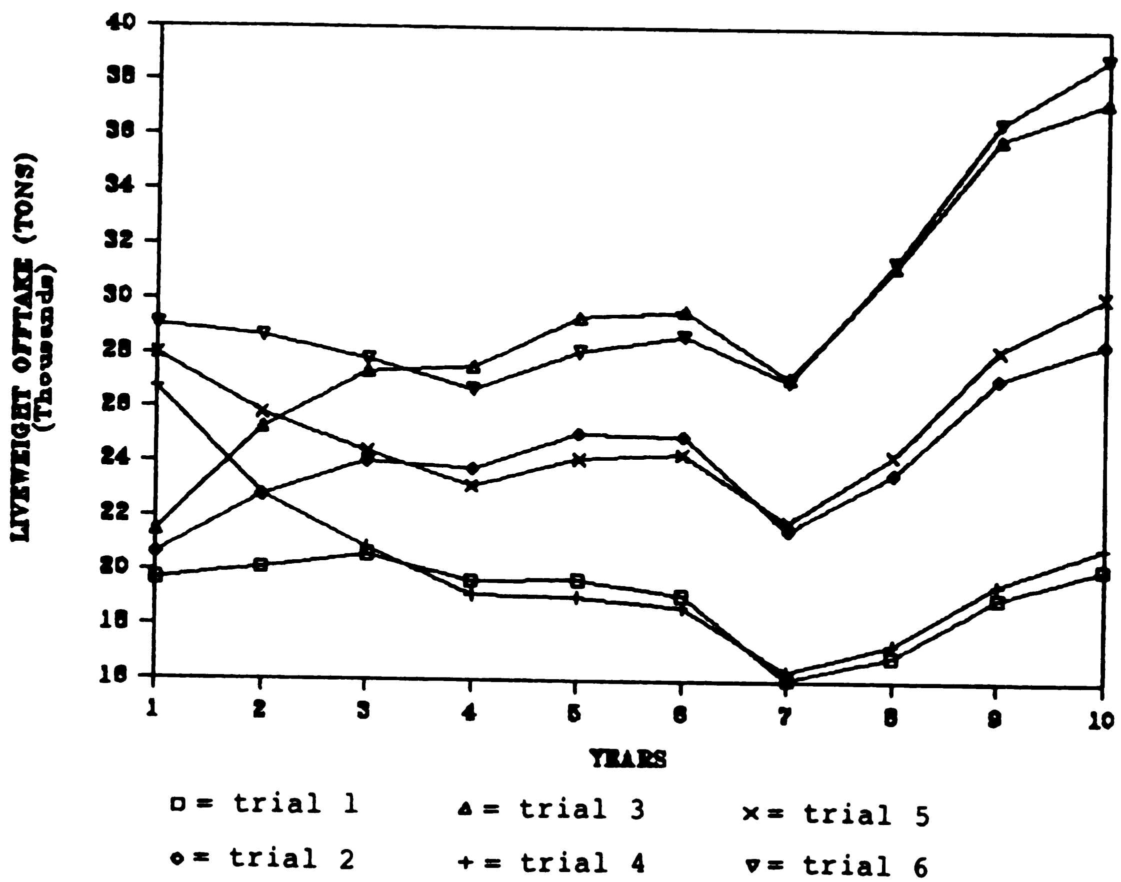


Figure 17: Total annual liveweight offtake for the regional system (1)

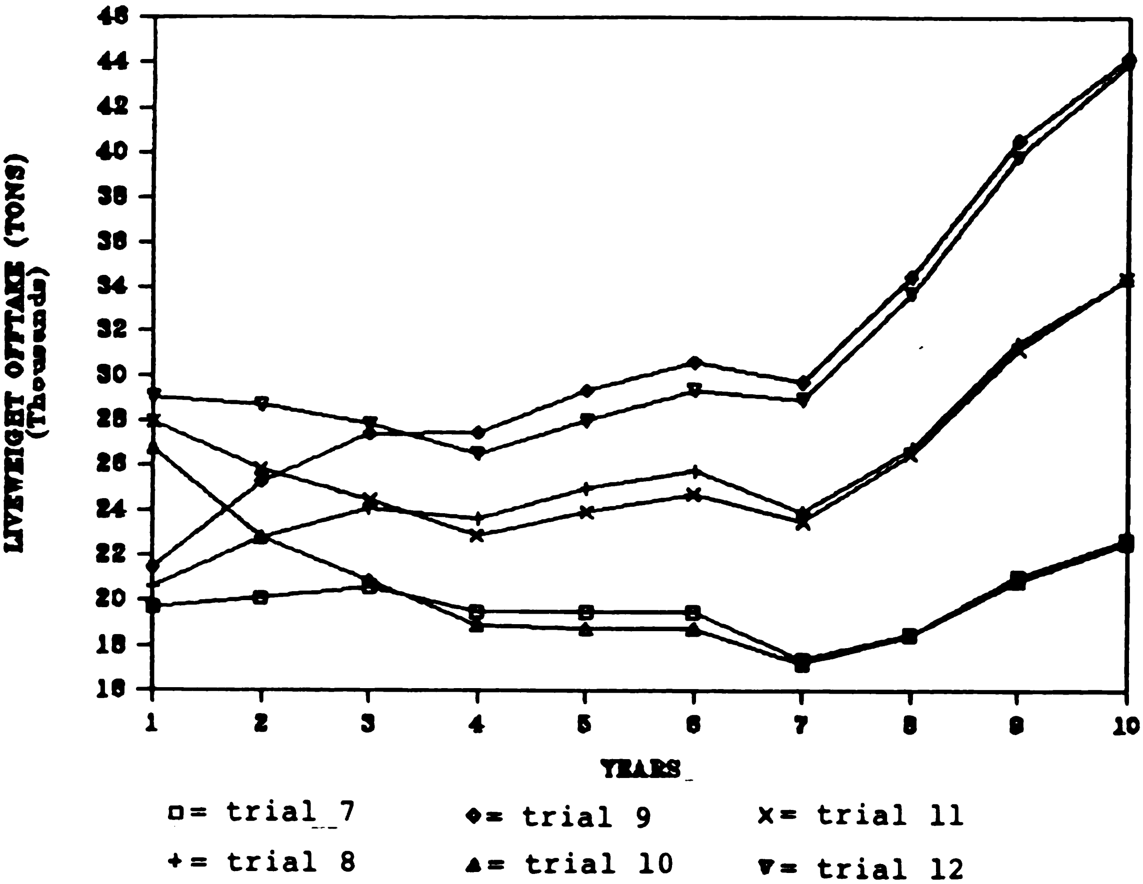


Figure 18: Total annual liveweight offtake for the regional system (2)

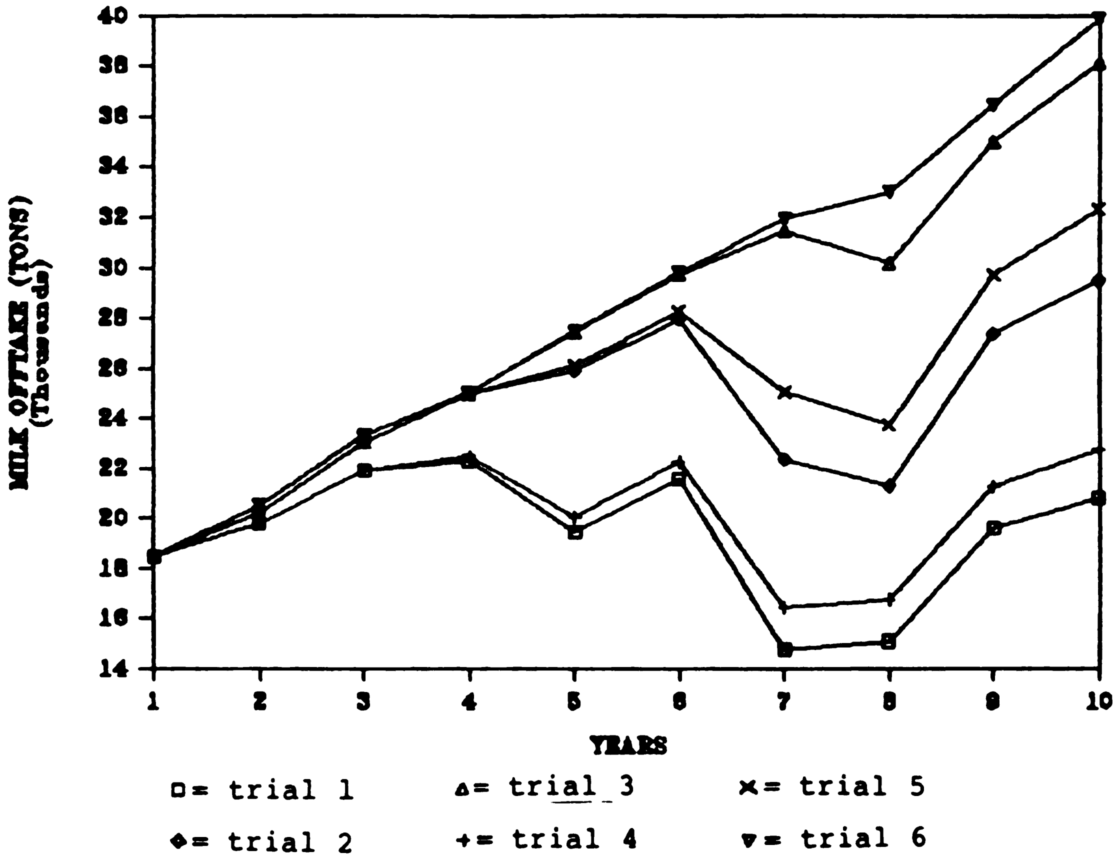


Figure 19: Total annual milk offtake for the regional system (1)

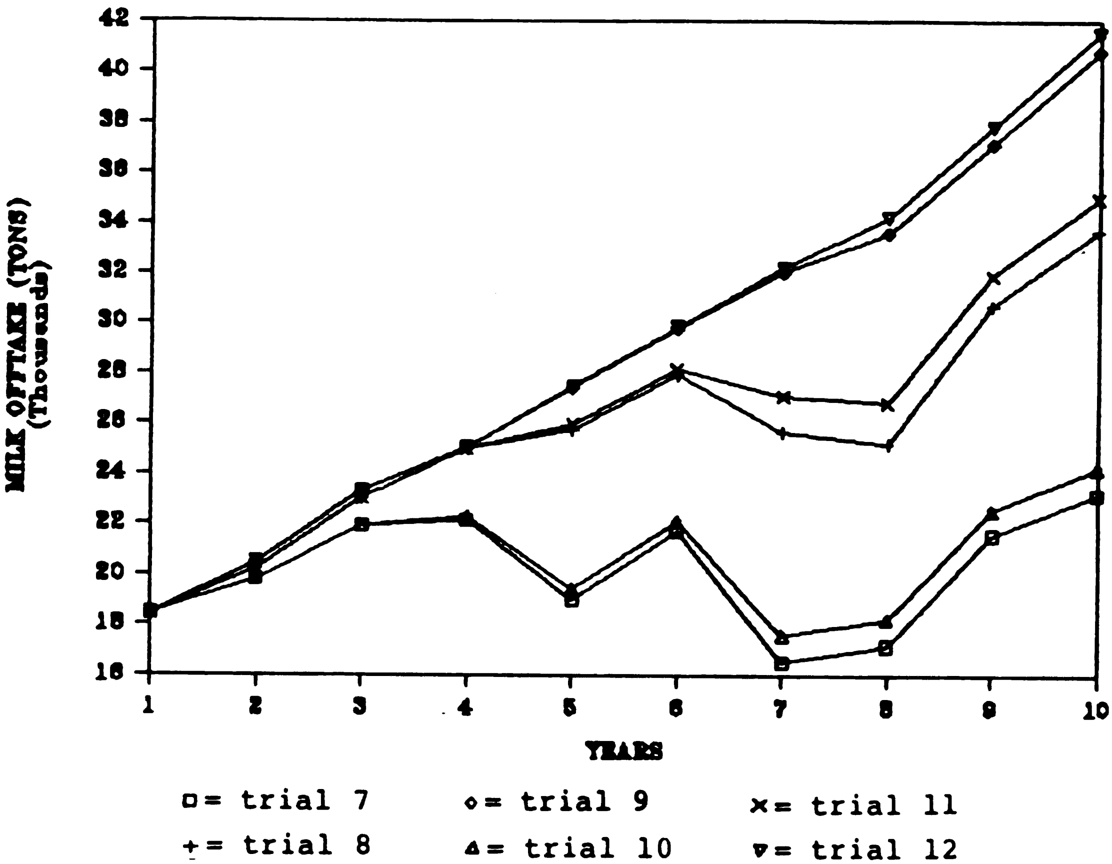


Figure 20: Total annual milk offtake for the regional system (2)

IV.2.2.THE COMMUNAL SYSTEM

Here a 2 by 3 factorial experiment is conducted with:

- 2 levels of liveweight offtake (OFT)
- 3 levels of feed supplementation (FS)

The same levels defined in the regional model are used here and it considered that the forage accessibility and availability are the same as the level 2 in the regional model.

The trials have been numbered as follows:

1. OFT 1-FS 1
2. OFT 1-FS 2
3. OFT 1-FS 3
4. OFT 2-FS 1
5. OFT 2-FS 2
6. OFT 2-FS 3

The milk offtake rate (MOFT) is held constant in the model and is equal to:

MOFT = 0.30 for cattle

= 0.20 for goat

= 0. for sheep

The averaged results of the 10 year simulation runs are presented in table 16 and figures 21, 22, 23, 24 and 25.

The comparisons between the baseline trial and the other trials show a 3 percent increase in the total liveweight offtake and milk offtake when the offtake rate alone has been raised (1 versus 4). For the same comparison, there has

Table 16: Total liveweight offtake (TLWOFT), total milk offtake (TMOFT) and forage production change rate (FPCR)

TRIALS	TLWOFT (tons)	TMOFT (tons)	FPCR
1	394	402	0.0024
2	516	512	-0.0015
3	588	567	-0.0055
4	405	409	0.0030
5	524	518	0.0009
6	622	566	-0.0016

been a 25 percent improvement in the forage production change rate.

Provision of feed supplement alone increases the liveweight output by 31 and 49 percent for 1 vs 2 and 1 vs 3 respectively; the effects on milk production are 27 and 41 percent. However such alternatives do initiate a deterioration of the rangeland at a rate 163 and 329 percent higher than for the baseline where the system was under-stocked. These high deterioration rates as compared with the regional system, are the results of the fact that the communal system is a close system where there is no migration of the animals in periods of drought. The pressure on the land in these periods is very high, causing an acceleration in the degradation of the rangeland.

The combination of increase in the offtake rate and the provision of feed supplement boosts the total liveweight

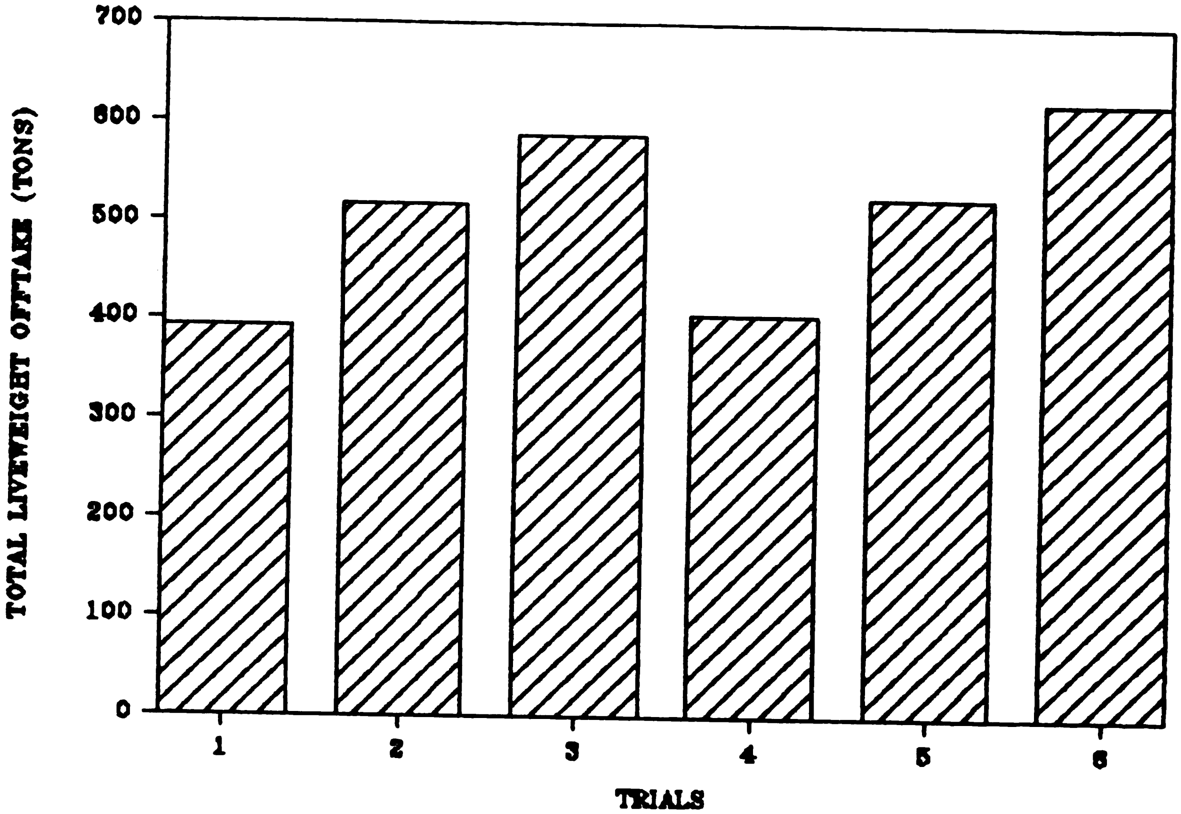


Figure 21: Average total liveweight offtake for the communal system

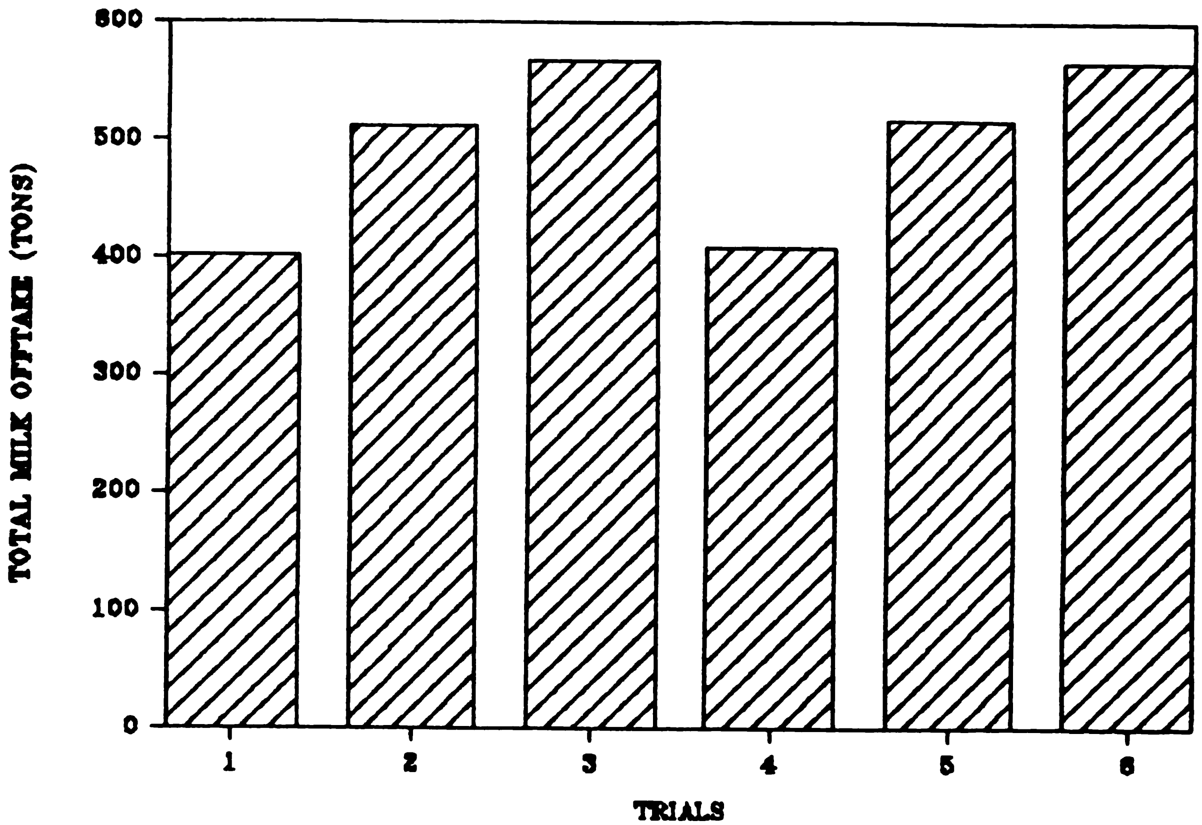


Figure 22: Average total milk offtake for the communal system

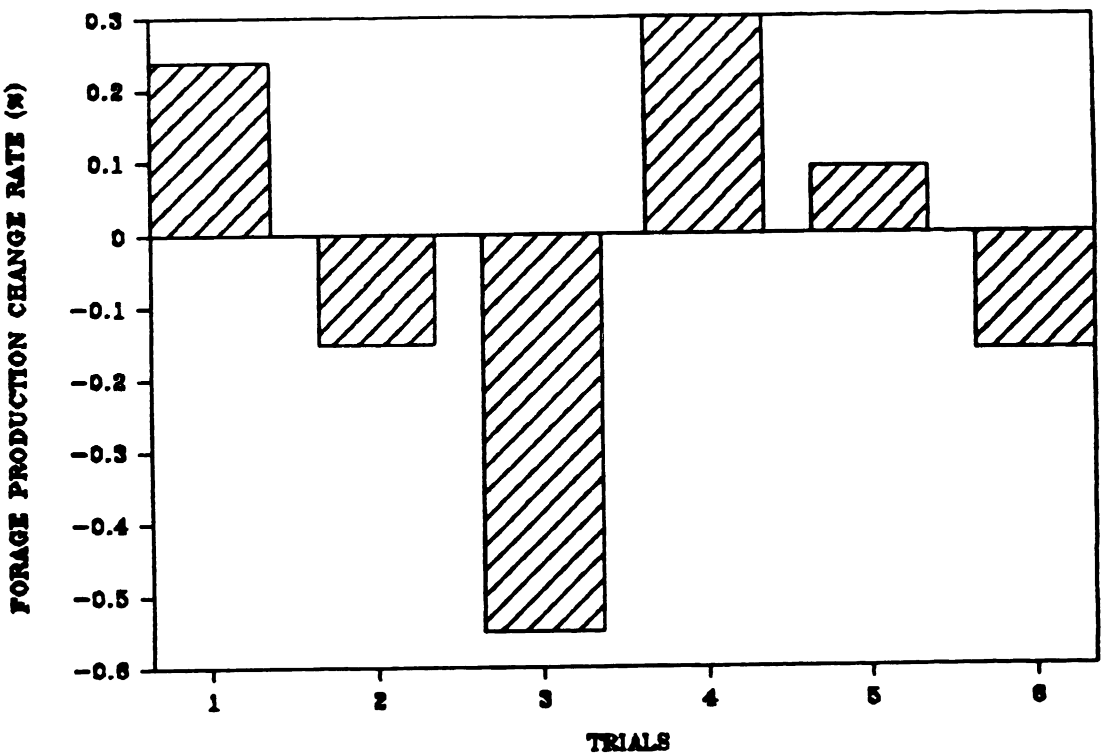


Figure 23: Average forage production change rate for the communal system

output by 33 (1 vs 5) and 58 percent (1 vs 6) form the baseline. For milk offtake the increases are 29 and 41 percent respectively. These increases in the productions are associated with a deterioration of the land 63 and 167 percent higher than the baseline situation.

Figures 24 and 25 show that with the level of increase in the liveweight offtake, the total yearly liveweight output falls below the baseline level after the third year. This suggests, as seen in the regional system, that the productive capacity of the system could not keep pace with the level of offtake. For the milk production, the effect of drought seems to be the most significant (year 4, 6 and 7).

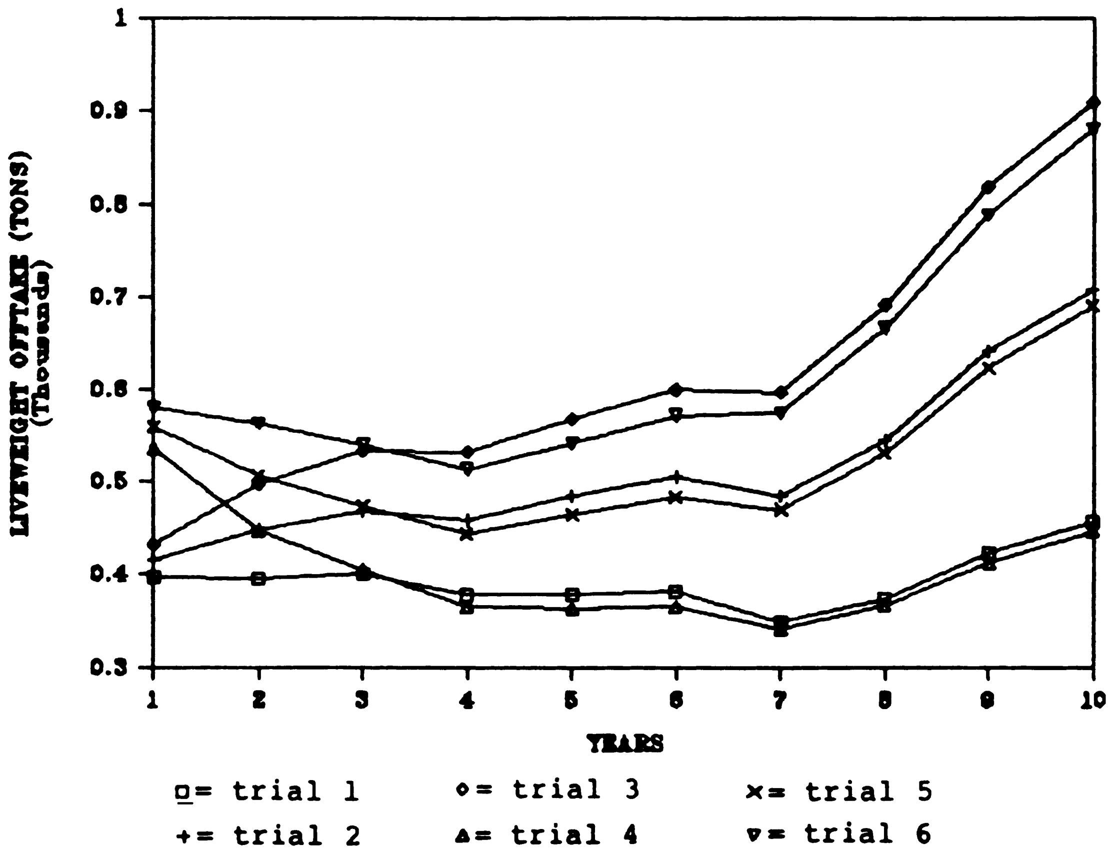


Figure 24: Total annual liveweight offtake for the communal system

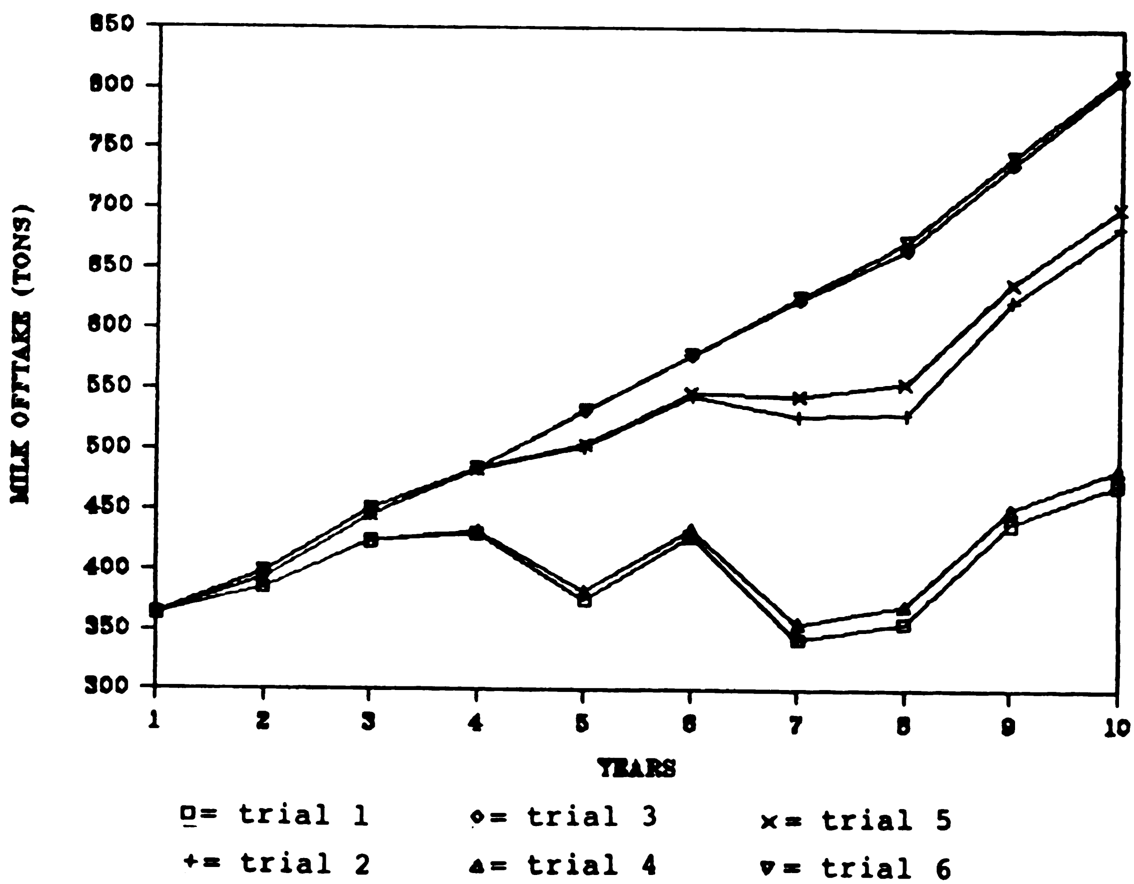


Figure 25: Total annual milk offtake for the communal system

CONCLUSION

The conclusion drawn from this study will be remarks from what we have learned in the process of analysing the pastoral production system in Senegal by using a Systems Approach.

The study did not intend to define options that are to be used as part of recommendations for the improvement of the production system; but rather the goals were the analysis of the system as it is affected by the variability in rainfall and the inter-relations that exist between the forage component and the animal component when different policy options are tested.

What comes out from the results is the necessity of the combination of the three factors tested to achieve the goal of increasing the total liveweight offtake and milk offtake and at the same time, preserving the range resources. Each factor in itself alone cannot make the system achieve the goal of maximazing the liveweight and milk offtakes and minimizing the negative effect of animal overstocking on the rangeland.

The increase in forage availability and accessibility has a positive effect in lowering the range deterioration rate eventhough its effect in increasing the liveweight and milk outputs is very limited. The increase in the liveweight offtake rate alone has had the same effect as the the forage availability and accessibility. However, the provision of feed supplement without the implementation of the other options has resulted in significant increases in the levels of outputs produced with an increase in the range deterioration rate.

It is only with the combination of the different management options that the goals sought for the system can be achieve, with the combination of the three options yielding the best results.

Increasing the liveweight offtake rate may potentially cause a draw back in the adoption of such policy by the herders who will see their revenues from the sells of animals reduced in some years after the beginning of the new policy. The level of increase should be consistant with the reproductive capacity of the livestock.

There is a necessity to improve the availability and accessiblity of the forage resources to the animals if the system has to provide more output and preserve itself from degradation. The length of the simulation runs seems to be short to give significant changes in the forage productivity of the soil and their impact on the performances of the animals, especially when feed supplement is provided without an alternative to lessen the pressure on the rangeland. the defined for the system.

The aggregated system used here has allowed the study of the linkage between the forage component and the animal component but did not address the operation of the system at the household level. The model will be greatly improved if it has a means of incorporating the behavior of a household when the environment in which it operates is subjected to different changes.

The model did not address the problem of spatial variation of the rainfall which is very important in semi arid areas such as the Ferlo region. This element of variability in the systems inputs should be given great consideration in possible implementations of a communal type system. In a drought year, the animal population in the community may suffer heavy losses if it does not have the possibility of migrating in surrounding areas where there may be exploitable pastures.

In the model, the determination of the forage production potential for each year was based on the generation of a random variable and the actual distribution of the annual rainfalls (30 percent dry year, 55 percent average year and 15 percent wet year). However, since the same deviation from the average rainfall is used in the computation of the rainfall distribution, to determine whether a year is dry or wet, in the simulation model, a year considered wet is very wet as compared to a dry year.

The validation of such aggregated system has not been done because of the lack data from the particular area under study. Such validation should be undertaken in order to give to the model further refinements particularly in the estimation of the different functions and parameters used. A use of the Monte Carlo analysis for the estimation of the parameters should be considered with respect to the lack of precision in the different estimates that will be available.

In the model the K values used in the distributed delays vary between 2 and 4; but for the stability of the model, with respect to the distribution of the animals in the cohorts, a sensitivity test with higher values for K should be undertaken.

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ANNEXE

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      PROGRAM PASTO
C
C     DECLARATION OF THE VARIABLES
C
      INTEGER NRUN,IY,IM,IC,IS,IG
      REAL A,DT,PLACC,LAND,PMIG,PMIDY,FPPWY,FPPDY,FPPAY,FLR,RV,FFCR,
     .     DIGS,AFPM1,AFPM2,AFPM3,QFR,TOFRA,JFFPP,CFKT,TFFR,AFPCR
      REAL CMOFT,CTFA,CTDW,TCPMY,CLACL,CFDM,CFAMM,CDWM,CAGEM,CSM,CPM,
     .     CQF,CKMF,CQS,CKMS,CSTP,CAMY,CPMY1,CPMY2,CPMY3,CCRM,SCAGE,
     .     CSTRG,CSR,TCQFC,CMLWOT,TCLWOT,CTMOT,CKM,CKGF,CKGS,CKL,
     .     CKMP,CMEC,CKG,CKMM
      REAL SFDM,STFA,SFAMM,SDWM,STDW,SAGEM,SSM,SPM,SQF,SKMF,SQS,SKMS,
     .     SSTP,SAMY,SPMY1,SPMY2,SPMY3,SCRM,SSR,SSAGE,SSTRG,SLACL,SMOFT,
     .     TSPMY,TSQFC,SMLWOT,TSLWOT,STMOT,SKM,SKGF,SKGS,SKL,SMEC,SKG,
     .     SKMP,SKMM
      REAL GFDM,GTFA,GFAMM,GDWM,GTDW,GAGEM,GSM,GPM,GQF,GKMF,GQS,GKMS,
     .     GAMY,GPMY1,GPMY2,GPMY3,GCRM,GSR,GSAGE,GSTRG,GLACL,GMOFT,
     .     TGPMY,TGQFC,GMLWOT,TGLWOT,GTMOT,GKM,GKGF,GKGS,GKL,GMEC,GKG,
     .     GKMP,GKMM
      DIMENSION AFPM(12),FAM(12),LACC(12),TFA(12),TOFI(12),FRI(100)
      DIMENSION CPOP(14),KCPOP(14,49),CDEL(14),KCD(14),COFT(14),CDR(14),
     .          CPUR(14),CCI(14),CAGER(14,49),CAGE(14),CAWT(14),
     .          CFSI(12,14),CDW(12,14),CFIC(14),CWCV(14),CFINT(14),
     .          CWFC(14),CFIME(14),CFSME(14),
     .          CTMEI(14),CERM(14),CAGE1(14),CTWT(14),COFTN(14),
     .          CWMAX(14),CWMIN(14),CDGMAX(14),CWLM(1),CAWLM(1),CWLL(1),
     .          CDLMAX(14),CERP(1),CERMP(1),CMEDMP(1),CDWL(14),CDWC(14),
     .          CMEEMP(14),CDWG(14),CPMY(12),CERL(1),CMEEM(14),CTDR(14),
     .          CPDMY(12),CMEDL(1),CDWL1(1),CMEDM(14),ACDMY(12),
     .          CQMAC(12),CMEMC(2),CCR(14),CTCR(14),CPREG(14),CLWOT(14),
     .          CDRST(14),CADDRT(14),CPLR(14),CRINR(14),CROUT(14),
     .          CTPMY(12),TCAMY(12),TCMOFT(12),TCOFT(14),CDIGF(12)
      DIMENSION SPOP(14),RSPOP(14,42),SDEL(14),SOFT(14),SDR(14),
     .          SPUR(14),SCI(14),SAGER(14,42),KSD(14),SAGE(14),SAWT(14),
     .          SDIGF(12),SFSI(12,14),SDW(12,14),SFIC(14),SWCV(14),
     .          SFINT(14),SFIME(14),STMEI(14),
     .          SERM(14),SAGE1(14),STWT(14),SWMAX(14),SWLL(1),
     .          SWMIN(14),SDGMAX(14),SDLMAX(14),SWLM(1),SAWLM(1),
     .          SERP(1),SERMP(1),SDWL(14),SMEDMP(1),SDWC(14),SMEEMP(1),
     .          SPMY(12),SERL(1),SMEEM(14),SFDMY(12),SMEDL(1),SDWL1(1),
     .          SMEDM(14),ASDMY(12),SQMAC(12),SMEMC(2),STCR(14),
     .          SCR(14),SPREG(14),SDRST(14),SADDRT(14),SPLR(14),
     .          SRINR(14),SROUT(14),STPMY(12),TSAMY(12),SDWG(14),
     .          TSMOFT(12),TSOFT(12),SFSME(14),SQFC(14),STDR(14),
     .          SOFTN(14),SLWOT(14)
      DIMENSION GPOP(14),KGPOP(14,42),GDEL(14),GOFT(14),GDR(14),
     .          GPUR(14),GCI(14),GAGER(14,42),KGD(14),GAGE(14),GAWT(14),
     .          GDIGF(12),GFSI(12,14),GDW(12,14),GFIC(14),GWCV(14),
     .          GFINT(14),GFIME(14),GFSME(14),
     .          GTMEI(14),GERM(14),GAGE1(14),GTWT(14),
     .          GWMAX(14),GWMIN(14),GDGMAX(14),GWLM(1),GAWLM(1),GWLL(1),
     .          GDLMAX(14),GERP(1),GERMP(1),GDWL(14),GMEDMP(1),GDWC(14),
     .          GMEEMP(1),GPMY(12),GERL(1),GMEEM(14),GPDMY(12),GMEDL(1),
     .          GDWL1(1),GMEDM(14),AGDMY(12),GQMAC(12),GMEMC(2),
     .          GCR(14),GPREG(14),GDRST(14),GADDRT(14),GPLR(14),
     .          GRINR(14),GROUT(14),GTPMY(12),TGAMY(12),GDWG(14),
     .          TGMOFT(12),TGOFT(12),GQFC(14),GTDR(14),GTCR(14),
     .          GOFTN(14),GLWOT(14)
C
      OPEN(10,FILE='INPUT')
      OPEN(20,FILE='OUTPUT')
C
C     INITIAL STAGE OF THE VARIABLES
C
      DATA  A/-1.38693/,DT/0.0833/,LAND/3000000./,PMIG/0.14/,
     .      PMIDY/0.30/,PLACC/0.75/,DIGS/0.65/
      DATA  FPPWY/1.6/,FPPDY/0.8/,FPPAY/1.2/,FLR/0.25/,FFCR/0./
     .      JFFPP/0.5/,(TOFI(IM),IM=1,12)/12*0./,
     .      (TFA(IM),IM=1,12)/12*0./,CFKT/0.001/,TFFR/0.5/
      DATA  NRUN/2/
C
C     CATTLE HERD
C
      DATA  (CPOP(IC),IC=1,14)/75000,20000,30000,40000,40000,30000,
     .      15000,15000,20000,30000,40000,30000,65000.,60000./
```

```
      DATA  ((RCPOP(IC,IRC),IRC=1,3),IC=2,5)/3*4.COOO.,3*4.0000.,
     .      3*5.3333.,3*5.3333./,((RCPOP(IC,IRC),IRC=1,3),IC=7,11)/
     .      3*5.0000.,3*1.5000.,3*2.6667.,3*4.0000.,3*5.3333./,
     .      ((RCPOP(IC,IRC),IRC=1,4),IC=6,12,6)/4*4.0000.,4*4.0000./,
     .      (RCPOP(1,IRC),IRC=1,6)/9*9375./,((RCPOP(IC,IRC),
     .      IRC=1,3),IC=13,14)/3*.86667,3*.80000./
      DATA  (CROUT(IC),IC=1,14)/9375.,20000.,40000.,53333.,53333.,
     .      4.000.,5000.,15000.,26667.,40000.,53333.,40000.,86667.,
     .      80000./
      DATA  (CDEL(IC),IC=3,6)/4*0.75/,(CDEL(IC),IC=9,14)/6*0.75/,
     .      CDEL(1)/8./,(CDEL(IC),IC=2,8,6)/2*1./,
     .      CDEL(7)/3./
      DATA  (COFT(IC),IC=6,12,6)/2*0./,(COFT(IC),IC=7,10)/4*0.35/,
     .      (COFT(IC),IC=2,4)/3*0.03/,(COFT(IC),IC=13,14)/2*0./
     .      COFT(5)/0./,COFT(11)/0.06/,COFT(1)/0.08/
      DATA  (CDR(IC),IC=6,12,6)/2*0.10/,(CDR(IC),IC=5,11,6)/2*0.030/,
     .      (CDR(IC),IC=1,4)/4*0.020/,(CDR(IC),IC=7,10)/4*0.020/,
     .      (CDR(IC),IC=13,14)/2*0.020/
      DATA  (CPUR(IC),IC=1,14)/14*0./
      DATA  (CCI(IC),IC=1,14)/14*0.4/
      DATA  (CAGER(6,IRC),IRC=1,4)/0.09375,0.28125,0.46875,0.65625/,
     .      (CAGER(12,IRC),IRC=1,4)/0.09375,0.28125,0.46875,0.65625/,
     .      (CAGER(5,IRC),IRC=1,3)/0.875,1.125,1.375/,(CAGER(11,IRC),
     .      IRC=1,3)/0.875,1.125,1.375/,(CAGER(3,IRC),IRC=1,3)/2.375,
     .      2.625,2.875/,(CAGER(9,IRC),IRC=1,3)/2.375,2.625,2.875/,
     .      (CAGER(4,IRC),IRC=1,3)/1.625,1.875,2.125/,(CAGER(10,IRC),
     .      IRC=1,3)/1.625,1.875,2.125/,(CAGER(2,IRC),IRC=1,3)/3.125,
     .      3.375,3.625/,(CAGER(8,IRC),IRC=1,3)/3.125,3.375,3.625/,
     .      (CAGER(7,IRC),IRC=1,3)/4.5,5.5,6.5/,(CAGER(1,IRC),IRC=1,8)/
     .      4.5,5.5,6.5,7.5,8.5,9.5,10.5,11.5/,(CAGER(13,IRC),IRC=1,3)/
     .      6.25,6.5,6.75/,(CAGER(14,IRC),IRC=1,3)/7.,7.25,7.5/
      DATA  (KCD(IC),IC=1,14)/8,4*3,4,5*3,4,2*3/
      DATA  (CAGE(IC),IC=1,14)/8.,3.5,2.625,1.875,1.125,0.375,5.75,3.5,
     .      2.625,1.875,1.125,0.375,6.5,7.25/
      DATA  (CTWT(IC),IC=1,14)/300.,272,231.,180.,118.,52.,350.,
     .      319.,272.,219.,143.,63.,370.,300./
      DATA  (CAWT(IC),IC=1,14)/270.,245.,208.,262.,107.,47.,315.,286.,
     .      245.,193.,129.,57.,280.,273./
      DATA  (CDIGF(IM),IM=1,12)/0.54,0.60,0.6,0.57,0.55,0.53,0.52,0.50,
     .      0.50,0.48,0.46,0.45/
      DATA  ((CFSI(IM,IC),IC=1,14),IM=1,6)/84*0./,
     .      ((CFSI(IM,IC),IC=1,13),IM=7,12)/78*0./,
     .      (CFSI(IM,14),IM=7,12)/6*0./
      DATA  ((CDW(IM,IC),IC=6,12,6),IM=1,12)/24*2./,((CDW(IM,IC),
     .      IC=1,4),IM=1,12)/4*6.,4*5.,4*5.,4*6.,4*7.,4*9.,4*10.,4*12.,
     .      4*14.,4*14.,4*16.,4*16./,((CDW(IM,IC),IC=7,10),IM=1,12)
     .      /4*8.,4*5.,4*5.,4*6.,4*7.,4*9.,4*10.,4*12.,4*14.,4*14.,
     .      4*16.,4*16./,((CDW(IM,IC),IC=13,14),IM=1,12)/2*6.,2*5.,2*5.,
     .      2*6.,2*7.,2*9.,2*10.,2*12.,2*14.,2*14.,2*16.,2*16./,
     .      ((CDW(IM,IC),IC=5,11,6),IM=1,12)/2*5.,2*5.,2*5.,2*5.,2*6.,
     .      2*6.,2*8.,2*8.,2*9.,2*9.,2*10.,2*11./
      DATA  (CFIC(IC),IC=1,12)/12*0.096/,CFIC(13)/0.049/,CFIC(14)/0.054/
      DATA  CTFA/0.8/,CTD=/14./,TCPMY/580./,CLACL/270./,CMOFT/0.30/,
     .      CSR/0.5/,CSTP/135./,CMEC/3.5/
      DATA  (CWCV(IC),IC=1,4)/4*0.25/,(CWCV(IC),IC=5,11,6)/2*0.27/,
     .      (CWCV(IC),IC=6,12,6)/2*0.30/,(CWCV(IC),IC=7,10)/4*0.25/
     .      (CWCV(IC),IC=13,14)/2*0.25/
      DATA  (CCR(IC),IC=1,14)/14*0./
      DATA  (COFC(IC),IC=1,14)/14*0./
      DATA  CKL/0.60/,CKMP/0.70/,CKMM/0.75/
C
C     SHEER FLOCK
C
      DATA  (SPOP(IS),IS=1,14)/70000.,10000.,25000.,30000.,20000.,25000.
     .      ,10000.,10000.,20000.,25000.,17000.,25000.,60000.,50000./
      DATA  ((RSPOP(IS,IRS),IRS=1,3),IS=2,4)/3*1.6000.,3*3.3333.,3*3.6000.
     .      /,((RSPOP(IS,IRS),IRS=1,2),IS=5,11,6)/2*6.0000.,2*5.1351./,
     .      ((RSPOP(IS,IRS),IRS=1,3),IS=8,10)/3*1.0000.,3*2.6667.,
     .      3*5.0000./,((RSPOP(IS,IRS),IRS=1,4),IS=6,12,6)/4*5.9995.,
     .      4*5.9995./,((RSPOP(IS,IRS),IRS=1,3),IS=13,14)/3*1.43990.,
     .      3*1.19990./,(RSPOP(1,IRS),IRS=1,4)/4*1.7500./,
     .      (RSPOP(7,IRS),IRS=1,2)/2*5000./
      DATA  (SROUT(IS),IS=1,14)/17500.,10000.,33333.,60000.,60000.,
     .      59995.,5000.,10000.,26667.,50000.,51051.,59995.,
     .      143990.,11999../
      DATA  (SDEL(IS),IS=6,12,6)/2*0.4167/,(SDEL(IS),IS=5,11,6)/
     .      2*0.3333/,(SDEL(IS),IS=4,10,6)/2*0.5/,(SDEL(IS),IS=3,9,6)/
```

```
     *      2*0.75/,(SDEL(IS),IS=2,8,6)/2*1./,SDEL(1)/4./,SDEL(7)/2./,
     *      (SDEL(IS),IS=13,14)/2*0.4167/
      DATA  (SOFT(IS),IS=6,12,6)/2*0./,(SOFT(IS),IS=2,4)/3*0.16/,
     *      SOFT(5)/0./,SOFT(11)/0.15/,(SOFT(IS),IS=7,10)/4*0.50/,
     *      SOFT(1)/0.20/,(SOFT(IS),IS=13,14)/2*0./
      DATA  (SDR(IS),IS=6,12,6)/2*0.22/,(SDR(IS),IS=5,11,6)/2*0.12/,
     *      (SDR(IS),IS=1,4)/4*0.06/,(SDR(IS),IS=7,10)/4*0.06/,
     *      (SDR(IS),IS=13,14)/2*0.06/
      DATA  (SPUR(IS),IS=1,14)/14*0./
      DATA  (SCI(IS),IS=1,14)/14*0.4/
      DATA  (SAGER(6,IRS),IRS=1,4)/0.104,0.15625,0.2604,0.365/,
     *      (SAGER(12,IRS),IRS=1,4)/0.104,0.15625,0.2604,0.365/,
     *      (SAGER(5,IRS),IRS=1,2)/0.5,0.6667/,(SAGER(11,IRS),IRS=1,2)/
     *      0.5,0.6667/,(SAGER(4,IRS),IRS=1,3)/0.8333,1.,1.6667/,
     *      (SAGER(10,IRS),IRS=1,3)/0.8333,1.,1.6667/,
     *      (SAGER(3,IRS),IRS=1,3)/1.375,1.625,1.875/,
     *      (SAGER(9,IRS),IRS=1,3)/1.375,1.625,1.875/,
     *      (SAGER(2,IRS),IRS=1,3)/2.125,2.375,2.625/,(SAGER(8,IRS),
     *      IRS=1,3)/2.125,2.375,2.625/,(SAGER(1,IRS),IRS=1,4)/3.5,4.5,
     *      5.5,6.5/,(SAGER(7,IRS),IRS=1,2)/3.5,4.5/,(SAGER(13,IRS),
     *      IRS=1,3)/3.361,3.5,3.6399/,(SAGER(14,IRS),IRS=1,3)
     *      /3.778,3.917,4.056/
      DATA  (KSD(IS),IS=1,14)/4,3*3,2,4,2,3*3,2,4,2*3/
      DATA  (SAGE(IS),IS=1,14)/5.,2.5,1.625,1.,0.58335,0.2083,4.,2.5,
     *      1.625,1.,0.58335,0.2083,3.5,3.9167/
      DATA  (STMT(IS),IS=1,14)/35.,34.,20.,20.,13.,7.,45.,44.,36.,
     *      25.,16.,8.,35.,35./
      DATA  (SAMT(IS),IS=1,14)/32.,31.,26.,18.,12.,6.,41.,40.,33.,23.,
     *      15.,7.5,33.,32./
      DATA  (SDIGF(IM),IM=1,12)/0.56,0.62,0.62,0.58,0.55,0.53,0.53,0.51,
     *      0.51,0.50,0.48,0.48/
      DATA  ((SFSI(IM,IS),IS=1,14),IM=1,6)/84*0./,
     *      ((SFSI(IM,IS),IS=1,13),IM=7,12)/78*0./,
     *      (SFSI(IM,14),IM=7,12)/6*0./
      DATA  ((SDW(IM,IS),IS=6,12,6),IM=1,12)/24*2./,
     *      ((SDW(IM,IS),IS=1,4),IM=1,12)/4*8.,4*5.,4*5.,4*6.,
     *      4*7.,4*9.,4*10.,4*12.,4*14.,4*14.,4*16.,4*16./,
     *      ((SDW(IM,IS),IS=7,10),IM=1,12)/4*8.,4*5.,
     *      4*5.,4*6.,4*7.,4*9.,4*10.,4*12.,4*14.,4*14.,4*16.,4*16./,
     *      ((SDW(IM,IS),IS=13,14),IM=1,12)/2*8.,2*5.,2*5.,2*6.,2*7.,
     *      2*9.,2*10.,2*12.,2*14.,2*14.,2*16.,2*16./,
     *      ((SDW(IM,IS),IS=5,11,6),IM=1,12)/2*5.,2*5.,2*5.,2*5.,
     *      2*6.,2*6.,2*8.,2*8.,2*8.,2*9.,2*10.,2*10./
      DATA  (SFIC(IS),IS=1,12)/12*0.027/,SFIC(13)/0.028/,
     *       SFIC(14)/0.033/
      DATA  STFA/0.75/,STDW/14./,TSPMY/45./,SLACL/150./,SMOFT/0./
      DATA  (SWCV(IS),IS=1,4)/4*0.25/,(SWCV(IS),IS=5,11,6)/2*0.27/,
     *      (SWCV(IS),IS=6,12,6)/2*0.30/,(SWCV(IS),IS=7,10)/4*0.25/
     *      (SWCV(IS),IS=13,14)/2*0.25/
      DATA  (SCR(IS),IS=1,14)/14*0./SSR/0.5/,SSTP/75./
      DATA  (SOFC(IS),IS=1,14)/14*0./
      DATA  SKL/0.60/,SKMP/0.70/,SKMM/0.75/,SMEC/4./
C
C     GOAT FLOCK
C
      DATA  (GPOP(IG),IG=1,14)/40000.,5000.,2*15000.,12000.,17000.,
     *      5000.,8000.,2*12000.,10000.,17000.,45000.,34000./
      DATA  ((RGPOP(IG,IRG),IRG=1,3),IG=2,4)/3*5000.,3*20000.,
     *      3*30000./,((RGPOP(IG,IRG),IRG=1,2),IG=5,11,6)/2*36036.,
     *      2*30030./,((RGPOP(IG,IRG),IRG=1,4),IG=6,12,6)/4*40800.,
     *      4*40800./,((RGPOP(IG,IRG),IRG=1,3),IG=8,10)/3*8000.,
     *      3*16000.,3*24000./,(RGPOP(1,IRG),IRG=1,4)/4*10000./,
     *      (RGPOP(7,IRG),IRG=1,2)/2*2500./,((RGPOP(IG,IRG),
     *      IRG=1,3),IG=13,14)/3*107990.,3*81590./
      DATA  (GROUT(IG),IG=1,14)/10000.,5000.,20000.,30000.,36036.,
     *      40800.,2500.,8000.,16000.,24000.,30030.,40800.,
     *      107990.,81590./
      DATA  (GDEL(IG),IG=6,12,6)/2*0.4167/,(GDEL(IG),IG=5,11,6)/2*0.333/
     *      ,(GDEL(IG),IG=4,10,6)/2*0.5/,(GDEL(IG),IG=3,9,6)/2*0.75/,
     *      (GDEL(IG),IG=2,8,6)/2*1./,GDEL(1)/4./,GDEL(7)/2./,
     *      (GDEL(IG),IG=13,14)/2*0.4167/
      DATA  (GOFT(IG),IG=6,12,6)/2*0./,(GOFT(IG),IG=2,4)/3*0.15/,
     *       GOFT(5)/0./,GOFT(11)/0.18/,(GOFT(IG),IG=7,10)/4*0.60/,
     *      GOFT(1)/0.25/,(GOFT(IG),IG=13,14)/2*0./
      DATA  (GDR(IG),IG=6,12,6)/2*0.27/,(GDR(IG),IG=5,11,6)/2*0.14/,
     *      (GDR(IG),IG=1,4)/4*0.08/,(GDR(IG),IG=7,10)/4*0.08/,
     *      (GDR(IG),IG=13,14)/2*0.08/
```

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      DATA  (GPUR(IG),IG=1,14)/14*3./
      DATA  (GCI(IG),IG=1,14)/14*0.4/
      DATA  (GAGER(6,IRG),IRG=1,4)/0.104,0.15625,0.2604,0.365/,
     *      (GAGER(12,IRG),IRG=1,4)/0.104,0.15625,0.2604,0.365/,
     *      (GAGER(5,IRG),IRG=1,2)/0.5,0.6667/,(GAGER(11,IRG),IRG=1,2)/
     *      0.5,0.6667/,(GAGER(4,IRG),IRG=1,3)/0.8333,1.,1.6667/,
     *      (GAGER(10,IRG),IRG=1,3)/0.8333,1.,1.6667/,(GAGER(3,IRG),
     *      IRG=1,3)/1.375,1.625,1.875/,(GAGER(9,IRG),IRG=1,3)/1.375,
     *      1.625,1.875/,(GAGER(2,IRG),IRG=1,3)/2.125,2.375,2.625/,
     *      (GAGER(8,IRG),IRG=1,3)/2.125,2.375,2.625/,(GAGER(1,IRG),
     *      IRG=1,4)/3.5,4.5,5.5,6.5/,(GAGER(7,IRG),IRG=1,2)/3.5,4.5/,
     *      (GAGER(13,IRG),IRG=1,3)/3.361,3.5,3.6389/,(GAGER(14,IRG),
     *      IRG=1,3)/3.776,3.917,4.056/
      DATA  (KGD(IG),IG=1,14)/4,3*3,2,4,2,3*3,2,4,2*3/
      DATA  (GAGE(IG),IG=1,14)/5.,2.5,1.625,1.,0.58335,0.2083,4.,2.5,
     *      1.625,1.,0.58335,0.2083,3.5,3.9167/
      DATA  (GDIGF(IM),IM=1,12)/0.58,0.60,0.60,0.58,0.56,0.55,0.53,0.53,
     *      0.52,0.52,0.50,0.50/
      DATA  ((GFSI(IM,IG),IG=1,14),IM=1,6)/84*0./,
     *      ((GFSI(IM,IG),IG=1,13),IM=7,12)/78*0./,
     *      (GFSI(IM,14),IM=7,12)/6*0./
      DATA  ((GDW(IM,IG),IG=6,12,6),IM=1,12)/24*2./,
     *      ((GDW(IM,IG),IG=1,4),IM=1,12)/4*8.,4*5.,4*5.,4*6.,
     *      4*7.,4*9.,4*10.,4*12.,4*14.,4*14.,4*16.,4*16./,
     *      ((GDW(IM,IG),IG=7,10),IM=1,12)/4*8.,4*5.,4*5.,
     *      4*6.,4*7.,4*9.,4*10.,4*12.,4*14.,4*14.,4*16.,4*16./,
     *      ((GDW(IM,IG),IG=13,14),IM=1,12)/2*8.,2*5.,2*5.,2*6.,2*7.,
     *      2*9.,2*10.,2*12.,2*14.,2*14.,2*16.,2*16./,
     *      ((GDW(IM,IG),IG=5,11,6),IM=1,12)/2*5.,2*5.,2*5.,2*5.,
     *      2*6.,2*6.,2*8.,2*8.,2*8.,2*9.,2*10.,2*10./
      DATA  (GFIC(IG),IG=1,12)/12*0.0255/,GFIC(13)/0.026/,
     *      GFIC(14)/0.0345/
      DATA  GTFA/0.70/,GTDW/14./,TGPMY/60./,GLACL/150./,GMOFT/0.2/
      DATA  (GWCV(IG),IG=1,4)/4*0.25/,(GWCV(IG),IG=5,11,6)/2*0.27/,
     *      (GWCV(IG),IG=6,12,6)/2*0.30/,(GWCV(IG),IG=7,10)/4*0.25/
     *      (GWCV(IG),IG=13,14)/2*0.25/
      DATA  (GTWT(IG),IG=1,14)/30.,29.,24.,18.,12.,6.,35.,34.,28.,
     *      20.,13.,7.,30.,30./
      DATA  (GAWT(IG),IG=1,14)/28.,27.,22.5,17.,11.,5.5,33.,32.,26.,
     *      19.,12.,6.5,29.,28./
      DATA  (GCR(IG),IG=1,14)/14*0./,GSR/0.5/,GSTP/75./
      DATA  (GOFC(IG),IG=1,14)/14*0./
      DATA  GKL/0.60/,GKMP/0.70/,GKMM/0.75/,GMCC/3.75/
C
C     SIMULATION PROCESS
C
      YEAR =0.
      DO 10 IY=1,NRUN
       WRITE(20,100)IY
100    FORMAT(45X,*YEAR *,I2,/,/)
C
C     COMPUTATION OF FORAGE AVAILABILITY
C
         RV=RANF()
C
         IF(RV .LT. 0.3)GOTO 15
         IF(RV .GT. 0.85)GOTO 16
         IF(RV .GE.0.3 .AND. RV .LE. 0.85)GOTO 17
C
15       AFPM(1)=(FPPDY*(1+FPCR))*JFFPP
         AFPM(2)=FPPDY*(1+FPCR)
         AFPM(3)=FPPDY*(1+FPCR)
         GOTO 18
C
16       AFPM(1)=(FPPWY*(1+FPCR))*JFFPP
         AFPM(2)=FPPWY*(1+FPCR)
         AFPM(3)=FPPWY*(1+FPCR)
         GOTO 18
C
17       AFPM(1)=(FPPAY*(1+FPCR))*JFFPP
         AFPM(2)=FPPAY*(1+FPCR)
         AFPM(3)=FPPAY*(1+FPCR)
C
18     CTMOT=0.
       STMOT=0.
       GTMOT=0.
       TCLWOT=0.
```

```
      TSLWOT=0.
      TGLWOT=0.
C
      DO 20 IM=1,12
       IF(RV .LT. 0.3)THEN
         IF(IM .LE. 3)THEN
           LACC(IM)=LAND
           TFA(IM)=AFPM(IM)*LACC(IM)
         ELSE IF(IM .EQ. 4)THEN
           LACC(IM)=LAND
           TFA(IM)=TFA(IM-1)*(1-(FLR/9.))
         ELSE IF(IM .EQ. 5)THEN
           LACC(IM)=LAND
           TFA(IM)=TFA(IM-1)*(1-(FLR/9.))-TQFI(IM-1)
         ELSE IF(IM .EQ. 6)THEN
           LACC(IM)=(LAND*PLACC)+(LAND*PMIDY)
           TFA(IM)=((TFA(IM-1)*(1-(FLR/9.)))-TQFI(IM-1))*(1+PMIDY)
         ELSE
           LACC(IM)=(LAND*PLACC)+(LAND*PMIDY)
           TFA(IM)=TFA(IM-1)*(1-(FLR/9.))-TQFI(IM-1)
         ENDIF
       ELSE IF(RV .GE. 0.3)THEN
         IF(IM .LE. 3)THEN
           LACC(IM)=LAND
           TFA(IM)=AFPM(IM)*LACC(IM)
         ELSE IF(IM . EQ. 4)THEN
           LACC(IM)=LAND
           TFA(IM)=TFA(IM-1)*(1-(FLR/9.))
         ELSE IF(IM .EQ. 5)THEN
           LACC(IM)=LAND*PLACC
           TFA(IM)= (TFA(IM-1)*(1-(FLR/9.)))-TQFI(IM-1)
         ELSE IF(IM .EQ. 6)THEN
           LACC(IM)=(LAND*PLACC)+(LAND*PMIG)
           TFA(IM)=((TFA(IM-1)*(1-(FLR/9.)))-TQFI(IM-1))*(1+PMIG)
         ELSE
           LACC(IM)=(LAND*PLACC)+(LAND*PMIG)
           TFA(IM)=TFA(IM-1)*(1-(FLR/9.))-TQFI(IM-1)
         ENDIF
       ENDIF
C
       FAM(IM)=TFA(IM)/LACC(IM)
C
       IF (IM .EQ. 3 .OR. IM .EQ. 12)THEN
       WRITE(20,150)IM,FAM(IM)
150    FORMAT(1X,'FORAGE AVAILABILITY MONTH ',I2,' =',F5.3,/,/)
       WRITE(20,160)
160    FORMAT(45X,'CATTLE HERD',/,/)
       ENDIF
C
C     COMPUTATION OF CATLLE PERFORMANCE
C
      DO 40 IC=1,14
       IF(CDIGF(IM) .LE. 0.4)THEN
         CFDM=((CDIGF(IM)/0.4)**0.6)/(1-CDIGF(IM))
       ELSE IF(CDIGF(IM) .GT. 0.4 .AND. CDIGF(IM) .LE. 0.65)THEN
         CFDM=1/(1-CDIGF(IM))
       ELSE
         IF(CAGE(IC) .LE. 1.5)THEN
           CFDM=1/(1-CDIGF(IM))
         ELSE
           CFDM=1.86/CDIGF(IM)
         ENDIF
       ENDIF
C
       IF(FAM(IM) .LE. CTFA)THEN
         CFAMM=FAM(IM)/CTFA
       ELSE
         CFAMM=1.
       ENDIF
C
       IF(CDW(IM,IC) .LE. CTDW)THEN
         CDWM=1.
       ELSE
         CDWM=1.0-0.05*(CDW(IM,IC)-CTDW)
       ENDIF
C
       IF(CAGE(IC) .LE. 8.)THEN
```

```
            CAGEM=1.
          ELSE
            CAGEM=1.0-0.03*(CAGE(IC)-8.)
          ENDIF
C
          IF(IC .LT. 7 .OR. IC .GT. 12)THEN
            CSM=1.0
          ELSE
            IF(CAGE(IC) .LE. 1.5)THEN
              CSM=1.1
            ELSE
              CSM=1.0
            ENDIF
          ENDIF
C
          IF(IC .EQ. 14)THEN
            CPM=1.10
          ELSE IF(IC .EQ. 13)THEN
            CPM=EXP(0.00837*CSTP)
          ELSE IF(IC .EQ. 6 .OR. IC .EQ. 12)THEN
            CPM=0.53
          ELSE
            IF(CAGE(IC) .LE. 1.5)THEN
              CPM=0.53+0.47*(CAGE(IC)-0.5)
            ELSE
              CPM=1.0
            ENDIF
          ENDIF
C
          CFINT(IC)=CFDM*CFAMM*CDWM*CAGEM*CSM*CPM*CFIC(IC)*
     *    (CTWT(IC)**0.73)
C
          COFC(IC)=CFINT(IC)*CPOP(IC)*CFKT*30.
C
          IF(IC .NE. 6 .OR. IC .NE. 12)THEN
            CFIME(IC)=14.6*CFINT(IC)*CDIGF(IM)
            COF=0.81*CDIGF(IM)
            CKMF=0.55+0.3*COF
            CFSME(IC)=14.6*CFSI(IM,IC)*CAWT(IC)*DIGS
            COS=0.81*DIGS
            CKMS=0.55+0.3*COS
            CKGF=0.03+0.81*COF
            CKGS=0.03+0.81*COS
C
            CTMEI(IC)=CFIME(IC)+CFSME(IC)
C
            CKM=(CFIME(IC)*CKMF+CFSME(IC)*CKMS)/CTMEI(IC)
            CKG=(CFIME(IC)*CKGF+CFSME(IC)*CKGS)/CTMEI(IC)
C
            CERM(IC)=(0.376*(CAWT(IC)**0.73)/CKM)+(0.0021*CAWT(IC)*
     *               CDW(IM,IC))
C
            IF(IC .EQ. 13 .OR. IC .EQ. 14)THEN
              IF(CAGE(IC) .LT. 5.)THEN
                CAGE1(IC)=CAGE(IC)*12.
                CTWT(IC)=-6.122+10.204*(CAGE1(IC)+1)-0.085*((CAGE1(IC)+1)
     *                   **2)
              ELSE
                CTWT(IC)=300.
              ENDIF
              CWMAX(IC)=CTWT(IC)*(1+1.96*CWCV(IC))
              CWMIN(IC)=CTWT(IC)*(1-1.96*CWCV(IC))
              CDGMAX(IC)=(CWMAX(IC)-CAWT(IC))/30.
              CDLMAX(IC)=(CAWT(IC)-CWMIN(IC))/30.
C
              IF(IC .EQ. 13)THEN
                CSTP=(45.*RCPOP(13,1)+135*RCPOP(13,2)+225*RCPOP(13,3))/
     *               (RCPOP(13,1)+RCPOP(13,2)+RCPOP(13,3))
                CERP(IC)=1.13*EXP(0.0106*CSTP)
                CERMP(IC)=CERM(IC)+CERP(IC)
C
                  IF(CERMP(IC) .GT. CTMEI(IC))THEN
                    CMEDMP(IC)=CERMP(IC)-CTMEI(IC)
                    CDWL(IC)=(CMEDMP(IC)*0.82)/16.4
                    CDWC(IC)=-(AMIN1(CDWL(IC),CDLMAX(IC)))
                  ELSE
                    CMEEMP(IC)=CTMEI(IC)-CERMP(IC)
```

```
                 CDWG(IC)=(CMEEMP(IC)*CKG)/(0.28+0.018*CAWT(IC)+
     *                   0.3*CMEEMP(IC)*CKG)
                 CDWC(IC)=AMIN1(CDWG(IC),CDGMAX(IC))
               ENDIF
             CAWT(IC)=CAWT(IC)+CDWC(IC)*30.
             CCI(IC)=(CAWT(IC)-CWMIN(IC))/(CWMAX(IC)-CWMIN(IC))
C
           ELSE IF(IC .EQ. 14)THEN
             IF(CAGE(IC) .LE. 6.)THEN
               CAMY=-0.152+0.363*CAGE(IC)-0.032*(CAGE(IC)**2)
             ELSE IF(CAGE(IC) .GT. 6. .AND. CAGE(IC) .LE. 9.)THEN
               CAMY=1.
             ELSE
               CAMY=-2.6+0.8*CAGE(IC)-0.044*(CAGE(IC)**2)
             ENDIF
             CPMY1=0.504*TCPMY*CAMY
             CPMY2=0.340*TCPMY*CAMY
             CPMY3=0.155*TCPMY*CAMY
             CPMY(IM)=3*(CPMY1*RCPOP(14,1)+CPMY2*RCPOP(14,2)+CPMY3*
     *              RCPOP(14,3))/(RCPOP(14,1)+RCPOP(14,2)+RCPOP(14,3))
             IF(CCI(IC) .LT. 0.3)THEN
               CPDMY(IM)=(CPMY(IM)/CLACL)*(CCI(IC)/0.3)
             ELSE
               CPDMY(IM)=CPMY(IM)/CLACL
             ENDIF
C
             CERL(IC)=1.67*CMEC*CPDMY(IM)
C
             IF(CERM(IC) .LT. CTMEI(IC))THEN
               CMEEM(IC)=CTMEI(IC)-CERM(IC)
C
                 IF(CERL(IC) .LT. CMEEM(IC))THEN
                   CDWG(IC)=((CMEEM(IC)-CERL(IC))*CKL)/(6.29+0.6186*
     *                      CAWT(IC)+0.3*(CMEEM(IC)-CERL(IC))*CKL)
                   CDWC(IC)=AMIN1(CDWG(IC),CDGMAX(IC))
                   ACDMY(IM)=CPDMY(IM)
                 ELSE
                   CMEDL(IC)=CERL(IC)-CMEEM(IC)
                   CDWL1(IC)=(CMEDL(IC)*0.82)/16.4
                   CDWL(IC)=AMIN1(CDWL1(IC),CDLMAX(IC))
                   CDWC(IC)=-(AMIN1(CDWL(IC),CDLMAX(IC)))
                  ACDMY(IM)=((CDWL(IC)*16.4/0.82)+CMEEM(IC))/
     *                      (1.67*CMEC)
                 ENDIF
             ELSE
               CMEDM(IC)=CERM(IC)-CTMEI(IC)
               CWLM(IC)=(CMEDM(IC)*0.82)/16.4
                 IF(CWLM(IC) .GT. CDLMAX(IC))THEN
                   ACDMY(IM)=0.
                   CDWL(IC)=CDLMAX(IC)
                 ELSE
                   CAWLM(IC)=CDLMAX(IC)-CWLM(IC)
                   CWLL(IC)=CERL(IC)/16.4
                     IF(CWLL(IC) .GT. CAWLM(IC))THEN
                       CDWL(IC)=CDLMAX(IC)
                       ACDMY(IM)=(CAWLM(IC)*16.4)/CMEC
                     ELSE
                       CDWL(IC)=CWLM(IC)+CWLL(IC)
                       ACDMY(IM)=CPDMY(IM)
                     ENDIF
                 ENDIF
               CDWC(IC)=-(AMIN1(CDWL(IC),CDLMAX(IC)))
             ENDIF
             CAWT(IC)=CAWT(IC)+CDWC(IC)*30.
             CCI(IC)=(CAWT(IC)-CWMIN(IC))/(CWMAX(IC)-CWMIN(IC))
C
               CTPMY(IM)=CPDMY(IM)*CPOP(14)*30.
               TCAMY(IM)=ACDMY(IM)*CPOP(14)*30.
               TCMOFT(IM)=TCAMY(IM)*CMOFT*0.001
           ENDIF
C
         ELSE
           IF(IC .LE. 5)THEN
             IF(CAGE(IC) .LE. 1.5)THEN
                 CAGE1(IC)=CAGE(IC)*12.
                 CTWT(IC)=19.+7.413*(CAGE1(IC)+1)-0.0075*
     *                    ((CAGE1(IC)+1)**2)
```

```
         ELSE IF(CAGE(IC) .GT. 1.5 .AND. CAGE(IC) .LT. 5.)THEN
              CAGE1(IC)=CAGE(IC)*12.
              CTWT(IC)=-6.122+10.204*(CAGE1(IC)+1)-0.095*
     *                   ((CAGE1(IC)+1)**2)
         ELSE
              CTWT(IC)=300.
         ENDIF
       ELSE
         IF(CAGE(IC) .LE. 1.5)THEN
           CAGE1(IC)=CAGE(IC)*12.
           CTWT(IC)=21.+9.57*(CAGE1(IC)+1)-0.041*
     *                  ((CAGE1(IC)+1)**2)
         ELSE IF(CAGE(IC) .GT. 1.5 .AND. CAGE(IC) .LT. 5.)THEN
              CAGE1(IC)=CAGE(IC)*12.
            CTWT(IC)=3.061+11.365*(CAGE1(IC)+1)-0.096*
     *                   ((CAGE1(IC)+1)**2)
         ELSE
              CTWT(IC)=350.
         ENDIF
       ENDIF
      CWMAX(IC)=CTWT(IC)*(1+1.96*CWCV(IC))
      CWMIN(IC)=CTWT(IC)*(1-1.96*CWCV(IC))
      CDGMAX(IC)=(CWMAX(IC)-CAWT(IC))/30.
      COLMAX(IC)=(CAWT(IC)-CWMIN(IC))/30.
C
      IF(CERM(IC) .LT. CTMEI(IC))THEN
        CMEEM(IC)=CTMEI(IC)-CERM(IC)
        CDWG(IC)=(CMEEM(IC)*CKG)/(6.28+0.3188*CAWT(IC)+0.3*
     *            CMEEM(IC)*CKG)
        CDWC(IC)=AMIN1(CDWG(IC),CDGMAX(IC))
      ELSE
        CMEDM(IC)=CERM(IC)-CTMEI(IC)
        CDWL(IC)=(CMEDM(IC)*0.82)/16.4
        CDWC(IC)=-(AMIN1(CDWL(IC),CDLMAX(IC)))
      ENDIF
C
      CAWT(IC)=CAWT(IC)+CDWC(IC)*30.
      CCI(IC)=(CAWT(IC)-CWMIN(IC))/(CWMAX(IC)-CWMIN(IC))
    ENDIF
C
   ELSE
   GO TO 40
   ENDIF
   IF(IC .EQ. 14)THEN
     GO TO 41
   ENDIF
   GO TO 40
C
41 DO 43 ICC=6,12,6
     CFIME(ICC)=14.6*CFINT(ICC)*CDIGF(IM)
     CQF=0.81*CDIGF(IM)
     CKMF=0.55+0.3*CQF
     CFSME(ICC)=14.6*CFSI(IM,ICC)*CAWT(ICC)*DIGS
     CQS=0.81*DIGS
     CKMS=0.55+0.3*CKMS
     CQMAC(IM)=ACDMY(IM)*(1-CMOFT)
     CMEMC(ICC)=0.93*CMEC*CQMAC(IM)
     CKGF=0.43*0.81*CQF
     CKGS=0.03*0.81*CQS
C
     CTMEI(ICC)=CFIME(ICC)+CFSME(ICC)+CMEMC(ICC)
C
     CKM=(CKMF*CFIME(ICC)+CKMS*CFSME(ICC)+CKMM*CMEMC(ICC))/
     *       CTMEI(ICC)
     CKG=(CKGF*CFIME(ICC)+CKGS*CFSME(ICC)+CKMM*CMEMC(ICC))/
     *       CTMEI(ICC)
C
     CERM(ICC)=(0.376*(CAWT(ICC)**0.73)/CKM)+(0.0021*CAWT(ICC)*
     *            CDW(IM,IC))
C
     IF(ICC .EQ. 6)THEN
       CAGE1(ICC)=CAGE(ICC)*12.
       CTWT(ICC)=19.+7.413*(CAGE1(ICC)+1)-0.0075*
     *             ((CAGE1(ICC)+1)**2)
     ELSE
       CAGE1(ICC)=CAGE(ICC)*12.
       CTWT(ICC)=21.+9.57*(CAGE1(ICC)+1)-0.041*
```

```
     *                   ((CAGE1(ICC)+1)**2)
          ENDIF
          CWMAX(ICC)=CTWT(ICC)*(1+1.96*CWCV(ICC))
          CWMIN(ICC)=CTWT(ICC)*(1-1.96*CWCV(ICC))
          CDGMAX(ICC)=(CWMAX(ICC)-CAWT(ICC))/30.
          CDLMAX(ICC)=(CAWT(ICC)-CWMIN(ICC))/30.
C
          IF(CERM(ICC) .LT. CTMEI(ICC))THEN
             CMEEM(ICC)=CTMEI(ICC)-CERM(ICC)
             CDWG(ICC)=(CMEEM(ICC)*CKG)/(6.28+3.0188*CAWT(ICC)+0.3*
     *                  CMEEM(ICC)*CKG)
             CDWC(ICC)=AMIN1(CDWG(ICC),CDGMAX(ICC))
          ELSE
             CMEDM(ICC)=CERM(ICC)-CTMEI(ICC)
             CDWL(ICC)=(CMEDM(ICC)*0.82)/16.4
             CDWC(ICC)=-(AMIN1(CDWL(ICC),CDLMAX(ICC)))
          ENDIF
          CAWT(ICC)=CAWT(ICC)+CDWC(ICC)*30.
          CCI(ICC)=(CAWT(ICC)-CWMIN(ICC))/(CWMAX(ICC)-CWMIN(ICC))
43     CONTINUE
C
40     CONTINUE
C
       DO 9999 IC=1,14
        IF(IC .LE. 3 .OR. IC .EQ. 14)THEN
          IF(CAGE(IC) .LE. 4)THEN
            CTCR(IC)=-2.173+1.437*CAGE(IC)-0.198*(CAGE(IC)**2)
          ELSE IF(CAGE(IC) .GT. 4. .AND. CAGE(IC) .LE. 8.)THEN
            CTCR(IC)=0.7
          ELSE
            CTCR(IC)=-3.211+0.978*CAGE(IC)-0.061*(CAGE(IC)**2)
          ENDIF
       IF(CCI(IC) .LE. 0.20)THEN
          CCRM=0.6+1.5*CCI(IC)
          CCR(IC)=CTCR(IC)*CCRM
       ELSE IF(CCI(IC) .GT. 0.20 .AND. CCI(IC) .LE. 0.90)THEN
          CCRM=0.933+0.33*CCI(IC)
          CCR(IC)=CTCR(IC)*CCRM
       ELSE
          CCRM=3.233-2.333*CCI(IC)
          CCR(IC)=CTCR(IC)*CCRM
       ENDIF
C
       IF(IC .LE. 3)THEN
          CPREG(IC)=CPOP(IC)*CCR(IC)*DT
       ELSE IF(IC .EQ. 14)THEN
          CPREG(IC)=RCPOP(IC,3)*CCR(IC)*DT*(CDEL(IC)/KCD(IC))
       ENDIF
       ELSE
          CTCR(IC)=0.
          CCRM=0.
          CCR(IC)=0.
          CPREG(IC)=0.
       ENDIF
C
       TCOFT(IC)=COFT(IC)*CPOP(IC)
C
       IF(CCI(IC) .LE. 0.5)THEN
          CORST(IC)=EXP(A*CCI(IC))-0.50
       ELSE
          CORST(IC)=0.
       ENDIF
       CTOR(IC)=CORST(IC)+COR(IC)
       CADDRT(IC)=COFT(IC)-CFUR(IC)/CPOP(IC)
       CPLR(IC)=CTOR(IC)+CADDRT(IC)+((CPREG(IC)/CPOP(IC))/DT)
       COFTN(IC)=COFT(IC)*CPOP(IC)*DT
       CLWOT(IC)=COFTN(IC)*CAWT(IC)*0.001
9999  CONTINUE
C
      DO 44 IC=13,14
       IF(IC .EQ. 13)THEN
          CRINR(IC)=(CPREG(1)+CPREG(2)+CPREG(3)+CPREG(14))/DT
       ELSE IF(IC .EQ. 14)THEN
          CRINR(IC)=CROUT(13)
       ENDIF
       CALL DELAY (IC,IRC,CRINR,CROUT,RCPOP,CDEL,DT,KCD,CPLR)
44    CONTINUE
```

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C
      DO 42 IC=12,1,-1
         IF(IC .EQ. 6 .OR. IC .EQ. 12)THEN
           CRINR(IC)=CROUT(13)+CSR
         ELSE IF(IC .EQ. 1)THEN
           CRINR(IC)=CROUT(14)+CROUT(2)
         ELSE
           CRINR(IC)=CROUT(IC+1)
         ENDIF
        CALL DELAY (IC,IRC,CRINR,CROUT,RCPOP,CDEL,DT,KCD,CPLR)
42    CONTINUE
C
      DO 91 IC=1,14
        IF(IC .LT. 13)THEN
          SCAGE=0.
          CSTRG=0.
          DO 92 IP=1,KCD(IC)
             CSTRG=CSTRG+RCPOP(IC,IP)
             SCAGE=SCAGE+(RCPOP(IC,IP)*CAGER(IC,IP))
92        CONTINUE
          CPOP(IC)=CSTRG+(CDEL(IC)/KCD(IC))
          CAGE(IC)=SCAGE/CSTRG
        ELSE IF(IC .EQ. 13)THEN
          CAGE(IC)=(CAGE(1)*CPREG(1)+CAGE(2)*CPREG(2)+CAGE(3)*CPREG(3)+
     *      CAGE(14)*CPREG(14))/(CPREG(1)+CPREG(2)+CPREG(3)+CPREG(14))
          CPOP(IC)=(RCPOP(IC,1)+RCPOP(IC,2)+RCPOP(IC,3))+(CDEL(IC)/
     *             KCD(IC))
        ELSE IF(IC .EQ. 14)THEN
          CAGE(IC)=CAGE(13)+0.75
          CPOP(IC)=(RCPOP(IC,1)+RCPOP(IC,2)+RCPOP(IC,3))+(CDEL(IC)/
     *             KCD(IC))
        ENDIF
91    CONTINUE
      TCOFC=0.
      CMLWOT=0.
      TCPOP=0.
      DO 47 ICF=1,14
        TCPOP=TCPOP+CPOP(ICF)
        TCOFC=TCOFC+COFC(ICF)
        CMLWOT=CMLWOT+CLWOT(ICF)
47    CONTINUE
C
      TCLWOT=TCLWOT+CMLWOT+(((CROUT(1)+(CDEL(1)/KCD(1)))*DT*CAWT(1))+
     *         ((CROUT(7)+(CDEL(7)/KCD(7)))*DT*CAWT(7)))*0.001
C
      IF(IM .EQ. 3 .OR. IM .EQ. 12)THEN
      WRITE(20,220)IM,CTPMY(IM),TCAMY(IM),ACDMY(IM)
220   FORMAT(/,1X,I2,2X,'CTPMY=',2X,F8.0,2X,'TCAMY=',2X,F8.0,2X,
     *       'ACDMY=',F6.3,/)
      DO 46 IK=1,IM
        CTMOT=CTMOT+TCMOFT(IK)
46    CONTINUE
      WRITE(20,230)IM,TCLWOT,CTMOT
230   FORMAT(1X,I2,2X,'TOTAL CATTLE LIVEWEIGHT OFFTAKE=',F10.3,2X,
     *       'TONS',3X,'CATTLE TOTAL MILK OFFTAKE=',F10.3,2X,'TONS',/,/)
      WRITE(20,231)IM,TCPOP
231   FORMAT(1X,I2,2X,'CATTLE POPULATION=',F8.0,/,/)
      ENDIF
C
      IF(IM .EQ. 3 .OR. IM .EQ. 12)THEN
       WRITE(20,260)
260    FORMAT(45X,'SHEEP FLOCK',/,/)
      ENDIF
C
C     COMPUTATION OF SHEEP PERFORMANCE
C
      DO 59 IS=1,14
        IF(SDIGF(IM) .LE. 0.4)THEN
          SFDM=((SDIGF(IM)/0.4)**0.6)/(1-SDIGF(IM))
        ELSE IF(SDIGF(IM) .GT. 0.4 .AND. SDIGF(IM) .LE. 0.65)THEN
          SFDM=1/(1-SDIGF(IM))
        ELSE
          IF(SAGE(IS) .LE. 0.75)THEN
            SFDM=1/(1-SDIGF(IM))
          ELSE
            SFDM=1.86/SDIGF(IM)
          ENDIF
```

```
      ENDIF
C
      IF(FAM(IM) .LE. STFA)THEN
        SFAMM=FAM(IM)/STFA
      ELSE
        SFAMM=1.
      ENDIF
C
      IF(SDW(IM,IS) .LE. STDW)THEN
        SDWM=1.
      ELSE
        SDWM=1.0 -0.05*(SDW(IM,IS)-STDW)
      ENDIF
C
      IF(SAGE(IS) .LE. 5.)THEN
        SAGEM=1.
      ELSE
        SAGEM=1.0-0.03*(SAGE(IS)-5)
      ENDIF
C
      IF(IS .LT. 7)THEN
        SSM=1.
      ELSE
        IF(SAGE(IS) .LE.0.75)THEN
          SSM=1.1
        ELSE
          SSM=1.
        ENDIF
      ENDIF
C
      IF(IS .EQ. 14)THEN
        SPM=1.10
      ELSE IF(IS .EQ. 13)THEN
        SPM=EXP(0.00067*SSTP)
      ELSE IF(IS .EQ. 6 .OR. IS .EQ. 12)THEN
        SPM=0.53
      ELSE
        IF(SAGE(IS) .LE. 0.75)THEN
          SPM=0.53+0.47*(SAGE(IS)*0.25)
        ELSE
          SPM=1.
        ENDIF
      ENDIF
C
      SFINT(IS)=SFOM*SFAMM*SDWM*SAGEM*SSM*SPM*SFIC(IS)*
     *          (STWT(IS)**0.73)
C
      SOFC(IS)=SFINT(IS)*SPOP(IS)*CFKT*30.
C
      IF(IS .NE.6 .OR. IS .NE. 12)THEN
        SFIME(IS)=14.6*SFINT(IS)*SDIGF(IM)
        SQF=0.81*SDIGF(IM)
        SKMF=0.55+0.3*SQF
        SFSME(IS)=14.6*SFSI(IM,IS)*SAWT(IS)*DIGS
        SQS=0.81*DIGS
        SKMS=0.55+0.3*SQS
        SKGF=0.03+0.81*SQF
        SKGS=0.03+0.81*SQS
C
        STMEI(IS)=SFIME(IS)+SFSME(IS)
C
        SKM=(SKMF*SFIME(IS)+SKMS*SFSME(IS))/STMEI(IS)
        SKG=(SKGF*SFIME(IS)+SKGS*SFSME(IS))/STMEI(IS)
C
        SERM(IS)=(0.243*(SAWT(IS)**0.73)/SKM)+(0.0024*SAWT(IS)*
     *           SDW(IM,IS))
C
        IF(IS .EQ. 13 .OR. IS .EQ. 14)THEN
          IF(SAGE(IS) .LT. 3.)THEN
            SAGE1(IS)=SAGE(IS)*12.
            STWT(IS)=1.25+1.875*(SAGE1(IS)+1)-0.026*((SAGE1(IS)+1)**2)
          ELSE
            STWT(IS)=35.
          ENDIF
          SWMAX(IS)=STWT(IS)*(1+1.96*SWCV(IS))
          SWMIN(IS)=STWT(IS)*(1-1.96*SWCV(IS))
          SDGMAX(IS)=(SWMAX(IS)-SAWT(IS))/31.
```

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      SDLMAX(IS)=(SAWT(IS)-SWMIN(IS))/3.
C
      IF(IS .EQ. 13)THEN
        SSTP=(25*RSPOP(13,1)+75*RSPOP(13,2)+125*RSPOP(13,3))/
     *       (RSPOP(13,1)+RSPOP(13,2)+RSPOP(13,3))
        SERM (IS)=01.2+0.05*SAWT(IS))+EXP(0.0372*SSTP)
     *       +(0.0024*SAWT(IS)*SDW(IM,IS))
          IF(SFRMP(IS) .GT. STMEI(IS))THEN
            SMEDMP(IS)=SFRMP(IS)-STMEI(IS)
            SDWL(IS)=(SMEDMP(IS)*0.82)/16.4
            SDWC(IS)=-(AMIN1(SDWL(IS),SDLMAX(IS)))
          ELSE
            SMEEMP(IS)=STMEI(IS)-SERMF(IS)
            SDWG(IS)=(SMEEMP(IS)*SKG)/(6.28+0.3168*SAWT(IS)+0.3..*
     *               SMEEMP(IS)*SKG)
            SDWC(IS)=AMIN1(SDWG(IS),SDGMAX(IS))
          ENDIF
          SAWT(IS)=SAWT(IS)+SDWC(IS)*30.
          SCI(IS)=(SAWT(IS)-SWMIN(IS))/(SWMAX(IS)-SWMIN(IS))
C
      ELSE IF(IS .EQ. 14)THEN
        IF(SAGE(IS) .LE. 2.5)THEN
          SAMY=0.20+0.533*SAGE(IS)-0.083*(SAGE(IS)**2)
        ELSE IF(SAGE(IS) .GT. 2.5 .AND. SAGE(IS) .LE. 5.5)THEN
          SAMY=1.
        ELSE
          SAMY=-13.4+4.8*SAGE(IS)-0.40*(SAGE(IS)**2)
        ENDIF
        SPMY1=0.45*TSPMY*SAMY
        SPMY2=0.35*TSPMY*SAMY
        SPMY3=0.20*TSPMY*SAMY
        SPMY(IM)=3.*(SPMY1*RSPOP(14,1)+SPMY2*RSPOP(14,2)+
     *           SPMY3*RSPOP(14,3))/(RSPOP(14,1)+RSPOP(14,2)+
     *           RSPOP(14,3))
        IF(SCI(IS) .LT.0.3)THEN
          SPDMY(IM)=(SPMY(IM)/SLACL)*(SCI(IS)/0.3)
        ELSE
          SPDMY(IM)=SPMY(IM)/SLACL
        ENDIF
C
        SERL(IS)=1.67*SMEC*SPDMY(IM)
C
          IF(SERM(IS) .LT. STMEI(IS))THEN
            SMEEM(IS)=STMEI(IS)-SERM(IS)
              IF(SERL(IS) .LT. SMEEM(IS))THEN
                SDWG(IS)=((SMEEM(IS)-SERL(IS))*SKL)/(6.28+0.018F*
     *                    SAWT(IS)+0.30*(SMEEM(IS)-SERL(IS))*SKL)
                SDWC(IS)=AMIN1(SDWG(IS),SDGMAX(IS))
                ASDMY(IM)=SPDMY(IM)
              ELSE
                SMEDL(IS)=SERL(IS)-SMEEM(IS)
                SDWL1(IS)=(SMEDL(IS)*0.82)/16.4
                SDWL(IS)=AMIN1(SDWL1(IS),SDLMAX(IS))
                SDWC(IS)=-(AMIN1(SDWL(IS),SDLMAX(IS)))
              ASDMY(IM)=((SDWL(IS)*16.4/0.82)+SMEEM(IS))/
     *                   (1.67*SMEC)
              ENDIF
          ELSE
             SMEDM(IS)=SERM(IS)-STMEI(IS)
             SWLM(IS)=(SMEDM(IS)*0.82)/16.4
               IF(SWLM(IS) .GT. SDLMAX(IS))THEN
                 ASDMY(IM)=0.
                 SDWL(IS)=SDLMAX(IS)
               ELSE
                 SAWLM(IS)=SDLMAX(IS)-SWLM(IS)
                 SWLL(IS)=(SERL(IS)*0.82)/16.4
                 IF(SWLL(IS) .GT. SAWLM(IS))THEN
                   SDWL(IS)=SDLMAX(IS)
                   ASDMY(IM)=(SAWLM(IS)*16.4)/SMEC
                 ELSE
                   SDWL(IS)=SWLM(IS)+SWLL(IS)
                   ASDMY(IM)=SPDMY(IM)
                 ENDIF
               ENDIF
             SDWC(IS)=-(AMIN1(SDWL(IS),SDLMAX(IS)))
          ENDIF
          SAWT(IS)=SAWT(IS)+SDWC(IS)*30.
```

```
                  SCI(IS)=(SAWT(IS)-SWMIN(IS))/(SWMAX(IS)-SWMIN(IS))
C
                  STPMY(IM)=SPOMY(IM)*SPOP(14)*30.
                  TSAMY(IM)=ASDMY(IM)*SPOP(14)*30.
                  TSMOFT(IM)=TSAMY(IM)*SMOFT*0.001
                ENDIF
C
            ELSE
              IF(IS .LE. 5)THEN
                IF(SAGE(IS) .LE. 1.)THEN
                  SAGE1(IS)=SAGE(IS)*12.
                  STWT(IS)=2.2+1.717*(SAGE1(IS)+1)-0.019*
     *                    ((SAGE1(IS)+1)**2)
                ELSE IF(SAGE(IS) .GT. 1. .AND. SAGE(IS) .LT. 3.)THEN
                    SAGE1(IS)=SAGE(IS)*12.
                    STWT(IS)=1.25+1.975*(SAGE1(IS)+1)-0.026*
     *                      ((SAGE1(IS)+1)**2)
                ELSE
                    STWT(IS)=35.
                ENDIF
              ELSE
                IF(SAGE(IS) .LE. 1.)THEN
                  SAGE1(IS)=SAGE(IS)*12.
                  STWT(IS)=2.5+2.083*(SAGE1(IS)+1)-0.017*
     *                    ((SAGE1(IS)+1)**2)
                ELSE IF(SAGE(IS) .GT. 1. .AND. SAGE(IS) .LE. 3.)THEN
                    SAGE1(IS)=SAGE(IS)*12.
                    STWT(IS)=2.5*(SAGE1(IS)+1)-0.035*((SAGE1(IS)+1)**2)
                ELSE
                    STWT(IS)=45.
                ENDIF
              ENDIF
              SWMAX(IS)=STWT(IS)*(1+1.96*SWCV(IS))
              SWMIN(IS)=STWT(IS)*(1-1.96*SWCV(IS))
              SDGMAX(IS)=(SWMAX(IS)-SAWT(IS))/30.
              SDLMAX(IS)=(SAWT(IS)-SWMIN(IS))/30.
C
              IF(SERM(IS) .LT.STMEI(IS))THEN
                SMEEM(IS)=STMEI(IS)-SERM(IS)
                SDWG(IS)=(SMEEM(IS)*SKG)/(6.28+0.0188*SAWT(IS)*0.3*
     *                  SMEEM(IS)*SKG)
                SDWC(IS)=AMIN1(SDWG(IS),SDGMAX(IS))
              ELSE
                SMEDM(IS)=SERM(IS)-STMEI(IS)
                SDWL(IS)=(SMEDM(IS)*0.92)/16.4
                SDWC(IS)=-(AMIN1(SDWL(IS),SDLMAX(IS)))
              ENDIF
              SAWT(IS)=SAWT(IS)+SDWC(IS)*30.
              SCI(IS)=(SAWT(IS)-SWMIN(IS))/(SWMAX(IS)-SWMIN(IS))
            ENDIF
C
          ELSE
            GO TO 50
          ENDIF
          IF(IS .EQ. 14)THEN
            GO TO 51
          ENDIF
          GO TO 50
C
51        DO 53 ISC=6,12,6
            SFIME(ISC)=14.6*SFINT(ISC)*SDIGF(IM)
            SOF=0.91*SDIGF(IM)
            SKMF=0.55+0.3*SOF
            SFSME(ISC)=14.6*SFSI(IM,ISC)*SAWT(ISC)*DIGS
            SQS=0.81*DIGS
            SKMS=0.55+0.3*SQS
            SQMAC(IM)=ASDMY(IM)*(1-SMOFT)
            SMEMC(ISC)=0.93*SMEC*SQMAC(IM)
            SKGF=0.03+0.81*SOF
            SKGS=0.03+0.81*SOS
C
            STMEI(ISC)=SFIME(ISC)+SFSME(ISC)+SMEMC(ISC)
C
            SKM=(SKMF*SFIME(ISC)+SKMS*SFSME(ISC)+SKPM*SMEMC(ISC))/
     *          STMEI(ISC)
            SKG=(SKGF*SFIME(ISC)+SKGS*SFSME(ISC)+SKMM*SMEMC(ISC))/
     *          STMEI(ISC)
```

```
      C
            SERM(ISC)=(0.293*(SAWT(ISC)**0.73)/SKM)+(0.0024*SAWT(ISC)*
     *           SDW(IM,ISC))
      C
            IF(ISC .EQ. 6)THEN
              SAGE1(ISC)=SAGE(ISC)*12.
              STWT(ISC)=2.2+1.717*(SAGE1(ISC)+1)-0.019*
     *                  ((SAGE1(ISC)+1)**2)
            ELSE IF(ISC .EQ. 12)THEN
              SAGE1(ISC)=SAGE(ISC)*12.
              STWT(ISC)=2.5+2.083*(SAGE1(ISC)+1)-0.017*
     *                  ((SAGE1(ISC)+1)**2)
            ENDIF
            SWMAX(ISC)=STWT(ISC)*(1+1.96*SWCV(ISC))
            SWMIN(ISC)=STWT(ISC)*(1-1.96*SWCV(ISC))
            SDGMAX(ISC)=(SWMAX(ISC)-SAWT(ISC))/30.
            SDLMAX(ISC)=(SAWT(ISC)-SWMIN(ISC))/30.
      C
            IF(SERM(ISC) .LT. STMEI(ISC))THEN
              SMEEM(ISC)=STMEI(ISC)-SERM(ISC)
              SDWG(ISC)=(SMEEM(ISC)*SKG)/(6.28+0.0188*SAWT(ISC)+0.3*
     *                  SMEEM(ISC)*SKG)
              SDWC(ISC)=AMIN1(SDWG(ISC),SDGMAX(ISC))
            ELSE
              SMEDM(ISC)=SERM(ISC)-STMEI(ISC)
              SDWL(ISC)=(SMEDM(ISC)*0.82)/16.4
              SDWC(ISC)=-(AMIN1(SDWL(ISC),SDLMAX(ISC)))
            ENDIF
            SAWT(ISC)=SAWT(ISC)+SDWC(ISC)*30.
            SCI(ISC)=(SAWT(ISC)-SWMIN(ISC))/(SWMAX(ISC)-SWMIN(ISC))
   53     CONTINUE
      C
   50    CONTINUE
      C
          DO 9998 IS=1,14
            IF(IS .LE. 4 .OR. IS .EQ.14)THEN
              IF(SAGE(IS) .LE. 2.)THEN
                STCR(IS)=-1.103+2.203*SAGE(IS)-0.551*(SAGE(IS)**2)
              ELSE IF(SAGE(IS) .GT. 2. .AND. SAGE(IS) .LE. 5.)THEN
                STCR(IS)=1.10
              ELSE
                STCR(IS)=-7.233+3.333*SAGE(IS)-0.333*(SAGE(IS)**2)
              ENDIF
            IF(SCI(IS) .LE. 0.2)THEN
              SCRM=0.6+1.5*SCI(IS)
              SCR(IS)=STCR(IS)*SCRM
            ELSE IF(SCI(IS) .GT. 0.20 .AND. SCI(IS) .LE. 0.90)THEN
              SCRM=0.833+0.333*SCI(IS)
              SCR(IS)=STCR(IS)*SCRM
            ELSE
              SCRM=3.233-2.333*SCI(IS)
              SCR(IS)=STCR(IS)*SCRM
            ENDIF
            IF(IS .LE.4)THEN
              SPREG(IS)=SPOP(IS)*SCR(IS)*DT
            ELSE IF(IS .EQ. 14)THEN
              SPREG(IS)=RSPOP(IS,3)*SCR(IS)*DT*(SDEL(IS)/KSD(IS))
            ENDIF
           ELSE
            STCR(IS)=0.
            SCRM=0.
            SCR(IS)=0.
            SPREG(IS)=0.
           ENDIF
      C
           TSOFT(IS)=SOFT(IS)*SPOP(IS)
      C
           IF(SCI(IS) .LE. 0.5)THEN
             SDRST(IS)=EXP(A*SCI(IS))-0.50
           ELSE
             SDRST(IS)=0.
           ENDIF
           STDR(IS)=SDRST(IS)+SUR(IS)
           SADURT(IS)=SOFT(IS)-SPUR(IS)/SPOP(IS)
           SPLR(IS)=STDR(IS)+SADDRT(IS)+((SPREG(IS)/SPOP(IS))/DT)
           SOFTN(IS)=SOFT(IS)*SPOP(IS)*DT
           SLWOT(IS)=SOFTN(IS)*SAWT(IS)*0.001
```

```
 9998 CONTINUE
 C
      DO 54 IS=13,14
        IF(IS .EQ. 13)THEN
           SRINR(IS)=(SPREG(1)+SPREG(2)+SPREG(3)+SPREG(4)+SPREG(14))/DT
        ELSE IF(IS .EQ. 14)THEN
           SRINR(IS)=SROUT(13)
        ENDIF
        CALL DELAY (IS,IRS,SRINR,SROUT,RSPOP,SDEL,DT,KSD,SPLR)
 54   CONTINUE
 C
      DO 52 IS=12,1,-1
         IF(IS .EQ. 6 .OR. IS .EQ. 12)THEN
           SRINR(IS)=SROUT(13)+SSR
        ELSE IF(IS .EQ. 1)THEN
           SRINR(IS)=SROUT(14)+SROUT(2)
        ELSE
           SRINR(IS)=SROUT(IS+1)
        ENDIF
        CALL DELAY (IS,IRS,SRINR,SROUT,RSPOP,SDEL,DT,KSD,SPLR)
 52   CONTINUE
 C
      DO 93 IS=1,14
        IF(IS .LT. 13)THEN
          SSAGE=0.
          SSTRG=0.
          DO 94 IQ=1,KSD(IS)
             SSTRG=SSTRG+RSPOP(IS,IQ)
             SSAGE=SSAGE+(RSPOP(IS,IQ)*SAGER(IS,IQ))
 94       CONTINUE
          SPOP(IS)=SSTRG*(SDEL(IS)/KSD(IS))
          SAGE(IS)=SSAGE/SSTRG
        ELSEIF(IS .EQ. 13)THEN
          SAGE(IS)=(SAGE(1)*SPREG(1)+SAGE(2)*SPREG(2)+SAGE(3)*SPREG(3)+
     *              SAGE(4)*SPREG(4)+SAGE(14)*SPREG(14))/(SPREG(1)+
     *              SPREG(2)+SPREG(3)+SPREG(4)+SPREG(14))
         SPOP(IS)=(RSPOP(IS,1)+RSPOP(IS,2)+RSPOP(IS,3))*(SDEL(IS)/
     *              KSD(IS))
        ELSE IF(IS .EQ. 14)THEN
          SAGE(IS)=SAGE(13)+0.4167
         SPOP(IS)=(RSPOP(IS,1)+RSPOP(IS,2)+RSPOP(IS,3))*(SDEL(IS)/
     *              KSD(IS))
        ENDIF
 93   CONTINUE
      TSOFC=0.
      SMLWOT=0.
      TSPOP=0.
      DO 57 ISF=1,14
        TSPOP=TSPOP+SPOP(ISF)
        TSOFC=TSOFC+SOFC(ISF)
        SMLWOT=SMLWOT+SLWOT(ISF)
 57   CONTINUE
 C
      TSLWOT=TSLWOT+SMLWOT+((SROUT(1)*(SDEL(1)/KSD(1))*DT*SAWT(1))+
     *         (SROUT(7)*(SDEL(7)/KSD(7))*DT*SAWT(7)))*0.001
 C
       IF(IM .EQ. 3 .OR. IM .EQ. 12)THEN
      WRITE(20,320)IM,STPMY(IM),TSAMY(IM),ASDMY(IM)
 320  FORMAT(/,1X,I2,2X,'STPMY=',2X,F8.0,2X,'TSAMY=',2X,F8.0,2X,
     *         'ASDMY=',F6.3,/)
      DO 56 IE=1,IM
       STMOT=STMOT+TSMOFT(IE)
 56   CONTINUE
      WRITE(20,330)IM,TSLWOT,STMOT
 330  FORMAT(1X,I2,2X,'TOTAL SHEEP LIVEWEIGHT OFFTAKE=',F10.3,2X,'TONS',
     *        3X,'SHEEP TOTAL MILK OFFTAKE=',F10.3,2X,'TONS',/,/)
      WRITE(20,331)IM,TSPOP
 331  FORMAT(1X,I2,2X,'SHEEP POPULATION=',F8.0,/,/)
      ENDIF
 C
      IF (IM .EQ. 3 .OR. IM .EQ. 12)THEN
       WRITE(20,360)
 360   FORMAT(45X,'GOAT FLOCK',/,/)
      ENDIF
 C
 C    COMPUTATION OF GOAT PERFORMANCE
 C
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```
      DO 60 IG=1,14
        IF(GDIGF(IM) .LE. 0.4)THEN
           GFDM=((GDIGF(IM)/0.4)**0.6)/(1-GDIGF(IM))
        ELSE IF(GDIGF(IM) .GT. 0.4 .AND. GDIGF(IM) .LE. 0.65)THEN
           GFDM=1/(1-GDIGF(IM))
        ELSE
           IF(GAGE(IG) .LE. 0.75)THEN
             GFDM=1/(1-GDIGF(IM))
           ELSE
             GFDM=1.86/GDIGF(IM)
           ENDIF
        ENDIF
C
        IF(FAM(IM) .LE. GTFA)THEN
           GFAMM=FAM(IM)/GTFA
        ELSE
           GFAMM=1.
        ENDIF
C
        IF(GDW(IM,IG) .LE. GTDW)THEN
          GDWM=1.
        ELSE
          GDWM=1.-0.05*(GDW(IM,IG)-GTDW)
        ENDIF
C
        IF(GAGE(IG) .LE. 5.)THEN
          GAGEM=1.
        ELSE
          GAGEM=1.-0.03*(GAGE(IG)-5.)
        ENDIF
C
        IF(IG .LT. 7 .OR. IG .GT.12)THEN
          GSM=1.
        ELSE
          IF(GAGE(IG) .LE. 0.75)THEN
            GSM=1.1
          ELSE
            GSM=1.
          ENDIF
        ENDIF
C
        IF(IG .EQ. 14)THEN
          GPM=1.10
        ELSE IF(IG .EQ. 13)THEN
          GPM=EXP(0.00067*GSTP)
        ELSE IF(IG .EQ. 6 .OR. IG .EQ. 12)THEN
          GPM=0.53
        ELSE
          IF(GAGE(IG) .LE. 0.75)THEN
            GPM=0.53+0.47*(GAGE(IG)*0.25)
          ELSE
            GPM=1.
          ENDIF
        ENDIF
C
      GFINT(IG)=GFDM*GFAMM*GDWM*GAGEM*GSM*GPM*GFIC(IG)*(GTWT(IG)**0.73)
C
      GQFC(IG)=GFINT(IG)*GPOP(IG)*CFKT*30.
C
      IF(IG .NE. 6 .OR. IG .NE. 12)THEN
        GFIME(IG)=14.6*GFINT(IG)*GDIGF(IM)
        GQF=0.91*GDIGF(IM)
        GKMF=0.55+0.30*GQF
        GFSME(IG)=14.6*GFSI(IM,IG)*GAWT(IG)*DIGS
        GQS=0.91*DIGS
        GKMS=0.55+0.30*GQS
        GKGS=0.03+0.81*GQS
        GKGF=0.03+0.91*GQF
C
        GTMEI(IG)=GFIME(IG)+GFSME(IG)
C
        GKM=(GKMF*GFIME(IG)+GKMS*GFSME(IG))/GTMEI(IG)
        GKG=(GKGF*GFIME(IG)+GKGS*GFSME(IG))/GTMEI(IG)
C
        GERM(IG)=(0.243*(GAWT(IG)**0.73)/GKM)+(0.0024*GAWT(IG)*
     *            GDW(IM,IG))
C
```

```
      IF(IG .EQ. 13 .OR. IG .EQ. 14)THEN
        IF(GAGE(IG) .LT. 3.)THEN
          GAGE1(IG)=GAGE(IG)*12.
          GTWT(IG)=3.0+1.50*(GAGE1(IG)+1)-0.021*((GAGE1(IG)+1)**2)
        ELSE
          GTWT(IG)=30.
        ENDIF
        GWMAX(IG)=GTWT(IG)*(1+1.96*GWCV(IG))
        GWMIN(IG)=GTWT(IG)*(1-1.96*GWCV(IG))
        GDGMAX(IG)=(GWMAX(IG)-GAWT(IG))/30.
        GDLMAX(IG)=(GAWT(IG)-GWMIN(IG))/30.
C
        IF(IG .EQ. 13)THEN
          GSTP=(25.*RGPOP(13,1)+75*RGPOP(13,2)+125*RGPOP(13,3))/
     *         (RGPOP(13,1)+RGPOP(13,2)+RGPOP(13,3))
          GERMP(IG)=(1.2+0.05*GAWT(IG))*EXP(0.0072*GSTP)
     *              +(0.0024*GAWT(IG)*GDW(IM,IG))
          IF(GERMP(IG) .GT. GTMEI(IG))THEN
            GMEDMP(IG)=GERMP(IG)-GTMEI(IG)
            GDWL(IG)=(GMEDMP(IG)*0.82)/16.4
            GDWC(IG)=-(AMIN1(GDWL(IG),GDLMAX(IG)))
          ELSE
            GMEEMP(IG)=GTMEI(IG)-GERMP(IG)
            GDWG(IG)=(GMEEMP(IG)*GKG)/(6.28+0.0198*GAWT(IG)+0.3*
     *               GMEEMP(IG)*GKG)
            GDWC(IG)=AMIN1(GDWG(IG),GDGMAX(IG))
          ENDIF
          GAWT(IG)=GAWT(IG)+GDWC(IG)*30.
          GCI(IG)=(GAWT(IG)-GWMIN(IG))/(GWMAX(IG)-GWMIN(IG))
C
        ELSE IF(IG .EQ. 14)THEN
          IF(GAGE(IG) .LE. 2.5)THEN
            GAMY=0.2+0.533*GAGE(IG)-0.089*(GAGE(IG)**2)
          ELSE IF(GAGE(IG) .GT. 2.5 .AND. GAGE(IG) .LE. 5.5)THEN
            GAMY=1.
          ELSE
            GAMY=-13.4+4.8*GAGE(IG)-0.4*(GAGE(IG)**2)
          ENDIF
          GPMY1=0.45*IGPMY*GAMY
          GPMY2=0.35*IGPMY*GAMY
          GPMY3=0.20*IGPMY*GAMY
          GPMY(IM)=3*(GPMY1*RGPOP(14,1)+GPMY2*RGPOP(14,2)+GPMY3*
     *         RGPOP(14,3))/(RGPOP(14,1)+RGPOP(14,2)+RGPOP(14,3))
          IF(GCI(IG) .LT. 0.3)THEN
            GPDMY(IM)=(GPMY(IM)/GLACL)*(GCI(IG)/0.3)
          ELSE
            GPDMY(IM)=GPMY(IM)/GLACL
          ENDIF
C
          GERL(IG)=1.67*GMEC*GPDMY(IM)
C
            IF(GERM(IG) .LT. GTMEI(IG))THEN
              GMEEM(IG)=GTMEI(IG)-GERM(IG)
                IF(GERL(IG) .LT. GMEEM(IG))THEN
                  GDWG(IG)=((GMEEM(IG)-GERL(IG))*GKL)/(6.28+0.0188*
     *                     GAWT(IG)+0.3*(GMEEM(IG)-GERL(IG))*GKL)
                  GDWC(IG)=AMIN1(GDWG(IG),GDGMAX(IG))
                  AGDMY(IM)=GPDMY(IM)
                ELSE
                  GMEDL(IG)=GERL(IG)-GMEEM(IG)
                  GDWL1(IG)=(GMEDL(IG)*0.82)/16.4
                  GDWL(IG)=AMIN1(GDWL1(IG),GDLMAX(IG))
                  GDWC(IG)=-(AMIN1(GDWL(IG),GDLMAX(IG)))
                  AGDMY(IM)=((GDWL(IG)*16.4)/0.82+GMEEM(IG))/
     *                      (1.67*GMEC)
                ENDIF
              ELSE
                GMEDM(IG)=GERM(IG)-GTMEI(IG)
                GWLM(IG)=(GMEDM(IG)*0.82)/16.4
                  IF(GWLM(IG) .GT. GDLMAX(IG))THEN
                    AGDMY(IM)=0.
                    GDWL(IG)=GDLMAX(IG)
                  ELSE
                    GAWLM(IG)=GDLMAX(IG)-GWLM(IG)
                    GWLL(IG)=(GERL(IG)*0.82)/16.4
                    IF(GWLL(IG) .GT. GAWLM(IG))THEN
                      GDWL(IG)=GDLMAX(IG)
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                  AGDMY(IM)=(GAWLM(IG)*16.4)/GMEC
               ELSE
                  GDWL(IG)=GWLM(IG)*GWLL(IG)
                  AGDMY(IM)=GPDMY(IM)
               ENDIF
            ENDIF
            GDWC(IG)=-(AMIN1(GDWL(IG),GDLMAX(IG)))
         ENDIF
         GAWT(IG)=GAWT(IG)+GDWC(IG)*30.
         GCI(IG)=(GAWT(IG)-GWMIN(IG))/(GWMAX(IG)-GWMIN(IG))
C
         GTPMY(IM)=GPDMY(IM)*GPOP(14)*30.
         TGAMY(IM)=AGDMY(IM)*GPOP(14)*30.
         TGMOFT(IM)=TGAMY(IM)*GMOFT*0.001
      ENDIF
C
      ELSE
        IF(IG .LE. 5)THEN
          IF(GAGE(IG) .LE. 1.)THEN
            GAGE1(IG)=GAGE(IG)*12.
            GTWT(IG)=2.0+1.667*(GAGE1(IG)+1)-0.028*
     *               ((GAGE1(IG)+1)**2)
          ELSE IF(GAGE(IG) .GT. 1. .AND. GAGE(IG) .LT. 3.)THEN
              GAGE1(IG)=GAGE(IG)*12.
              GTWT(IG)=3.+1.5*(GAGE1(IG)+1)-0.021*
     *                 ((GAGE1(IG)+1)**2)
          ELSE
              GTWT(IG)=30.
          ENDIF
        ELSE
          IF(GAGE(IG) .LE. 1.)THEN
            GAGE1(IG)=GAGE(IG)*12.
            GTWT(IG)=2.2+1.717*(GAGE1(IG)+1)-0.019*
     *               ((GAGE1(IG)+1)**2)
         ELSE IF(GAGE(IG) .GT. 1. .AND. GAGE(IG) .LT. 3.)THEN
              GAGE1(IG)=GAGE(IG)*12.
            GTWT(IG)=1.25+1.875*(GAGE1(IG)+1)-0.026*
     *                 ((GAGE1(IG)+1)**2)
         ELSE
            GTWT(IG)=35.
         ENDIF
        ENDIF
          GWMAX(IG)=GTWT(IG)*(1+1.96*GWCV(IG))
          GWMIN(IG)=GTWT(IG)*(1-1.96*GWCV(IG))
          GDGMAX(IG)=(GWMAX(IG)-GAWT(IG))/30.
          GDLMAX(IG)=(GAWT(IG)-GWMIN(IG))/30.
C
          IF(GERM(IG) .LT. GTMEI(IG))THEN
            GMEEM(IG)=GTMEI(IG)-GERM(IG)
            GDWG(IG)=(GMEEM(IG)*GKG)/(6.28+0.0188*GAWT(IG)+0.3*
     *               GMEEM(IG)*GKG)
            GDWC(IG)=AMIN1(GDWG(IG),GDGMAX(IG))
          ELSE
            GMEDM(IG)=GERM(IG)-GTMEI(IG)
            GDWL(IG)=(GMEDM(IG)*0.92)/16.4
            GDWC(IG)=-(AMIN1(GDWL(IG),GDLMAX(IG)))
          ENDIF
          GAWT(IG)=GAWT(IG)+GDWC(IG)*30.
          GCI(IG)=(GAWT(IG)-GWMIN(IG))/(GWMAX(IG)-GWMIN(IG))
        ENDIF
C
      ELSE
        GO TO 60
      ENDIF
      IF(IG .EQ. 14)THEN
        GO TO 61
      ENDIF
      GO TO 60
C
61    DO 63 IGC=6,12,6
        GFIME(IGC)=14.6*GFINT(IGC)*GDIGF(IM)
        GOF=0.81*GDIGF(IM)
        GKMF=0.55+0.3*GOF
        GFSME(IGC)=14.6*GFSI(IM,IGC)*GAWT(IGC)*DIGS
        GOS=0.81*DIGS
        GKMS=0.55+0.3*GOS
        GOMAC(IM)=AGDMY(IM)*(1-GMOFT)
```

```
                  GMEMC(IGC)=0.93*GMEC*GOMAC(IM)
                  GKGF=0.03*0.81*GOF
                  GKGS=0.03*0.81*GOS
C
                  GTMEI(IGC)=GFIME(IGC)+GFSME(IGC)+GMEMC(IGC)
C
                  GKM=(GKMF*GFIME(IGC)+GKMS*GFSME(IGC)+GKMM*GMEMC(IGC))/
     *                GTMEI(IGC)
                  GKG=(GKGF*GFIME(IGC)+GKGS*GFSME(IGC)+GKMM*GMEMC(IGC))/
     *                GTMEI(IGC)
C
                  GERM(IGC)=(0.243*(GAWT(IGC)**0.73)/GKM)+(0.0029*
     *                          GAWT(IGC)*GDW(IM,IGC))
C
                  IF(IGC .EQ. 6)THEN
                    GAGE1(IGC)=GAGE(IGC)*12.
                    GTWT(IGC)=2.0+1.667*(GAGE1(IGC)+1)-0.028*
     *                        ((GAGE1(IGC)+1)**2)
                  ELSE IF(IGC .EQ. 12)THEN
                    GAGE1(IGC)=GAGE(IGC)*12.
                    GTWT(IGC)=2.2+1.717*(GAGE1(IGC)+1)-0.019*
     *                        ((GAGE1(IGC)+1)**2)
                  ENDIF
                  GWMAX(IGC)=GTWT(IGC)*(1+1.96*GWCV(IGC))
                  GWMIN(IGC)=GTWT(IGC)*(1-1.96*GWCV(IGC))
                  GDGMAX(IGC)=(GWMAX(IGC)-GAWT(IGC))/30.
                  GDLMAX(IGC)=(GAWT(IGC)-GWMIN(IGC))/30.
C
                  IF(GERM(IGC) .LT. GTMEI(IGC))THEN
                    GMEEM(IGC)=GTMEI(IGC)-GERM(IGC)
                    GDWG(IGC)=(GMEEM(IGC)*GKG)/(6.28+0.0188*GAWT(IGC)+0.3*
     *                        GMEEM(IGC)*GKG)
                    GDWC(IGC)=AMIN1(GDWG(IGC),GDGMAX(IGC))
                  ELSE
                    GMEDM(IGC)=GERM(IGC)-GTMEI(IGC)
                    GDWL(IGC)=(GMEDM(IGC)*0.82)/16.4
                    GDWC(IGC)=-(AMIN1(GDWL(IGC),GDLMAX(IGC)))
                  ENDIF
                  GAWT(IGC)=GAWT(IGC)+GDWC(IGC)*30.
                GCI(IGC)=(GAWT(IGC)-GWMIN(IGC))/(GWMAX(IGC)-GWMIN(IGC))
   63           CONTINUE
C
   60     CONTINUE
C
          DO 9997 IG=1,14
               IF(IG .LE. 4 .OR. IG .EQ. 14)THEN
                  IF(GAGE(IG) .LE. 2.)THEN
                    GTCR(IG)=-1.343+2.643*GAGE(IG)-0.661*(GAGE(IG)**2)
                  ELSE IF(GAGE(IG) .GT. 2. .AND. GAGE(IG) .LE. 5.)THEN
                    GTCR(IG)=1.30
                  ELSE
                    GTCR(IG)=-8.7+4.0*GAGE(IG)-0.4*(GAGE(IG)**2)
                  ENDIF
                  IF(GCI(IG) .LE. 0.2)THEN
                    GCRM=0.6+1.5*GCI(IG)
                    GCR(IG)=GTCR(IG)*GCRM
                  ELSE IF(GCI(IG) .GT. 0.2 .AND. GCI(IG) .LE. 0.9)THEN
                    GCRM=0.833+0.33*GCI(IG)
                    GCR(IG)=GTCR(IG)*GCRM
                  ELSE
                    GCRM=3.233-2.333*GCI(IG)
                    GCR(IG)=GTCR(IG)*GCRM
                  ENDIF
                  IF(IG .LE. 4)THEN
                    GPREG(IG)=GPOP(IG)*GCR(IG)*DT
                  ELSE IF(IG .EQ. 14)THEN
                    GPREG(IG)=RGPOP(IG,3)*GCR(IG)*DT*(GDEL(IG)/KGD(IG))
                  ENDIF
               ELSE
                  GTCR(IG)=0.
                  GCRM=0.
                  GCR(IG)=0.
                  GPREC(IG)=0.
               ENDIF
C
              TGOFT(IG)=GOFT(IG)*GPOP(IG)
C
```

```
               IF(GCI(IG) .LE. 0.5)THEN
                  GDRST(IG)=EXP(A*GCI(IG))-0.50
               ELSE
                  GDRST(IG)=0.
               ENDIF
               GTDR(IG)=GDRST(IG)+GDR(IG)
               GADDRT(IG)=GOFT(IG)-GPUR(IG)/GPOP(IG)
               GPLR(IG)=GTDR(IG)+GADDRT(IG)+((GPHF6(IG)/GPOP(IG))/DT)
               GOFTN(IG)=GOFT(IG)*GPOP(IG)*DT
               GLWOT(IG)=GOFTN(IG)*GAWT(IG)*0.001
9997   CONTINUE
C
       DO 95 IG=13,14
          IF(IG .EQ. 13)THEN
             GRINR(IG)=(GPREG(1)+GPREG(2)+GPREG(3)+GPREG(4)+GPREG(14))/DT
          ELSE IF(IG .EQ. 14)THEN
             GRINR(IG)=GROUT(13)
          ENDIF
          CALL DELAY(IG,IRG,GRINR,GROUT,RGPOP,GDEL,DT,KGD,GPLR)
95     CONTINUE
C
       DO 62 IG=12,1,-1
          IF(IG .EQ. 6 .OR. IG .EQ. 12)THEN
             GRINR(IG)=GROUT(13)*GSR
          ELSE IF(IG .EQ. 1)THEN
             GRINR(IG)=GROUT(14)+GROUT(2)
          ELSE
             GRINR(IG)=GROUT(IG+1)
          ENDIF
          CALL DELAY(IG,IRG,GRINR,GROUT,RGPOP,GDEL,DT,KGD,GPLR)
62     CONTINUE
C
       DO 97 IG=1,14
             IF(IG .LT. 13)THEN
                GSAGE=0.
                GSTRG=0.
                DO 98 IR=1,KGD(IG)
                   GSTRG=GSTRG+RGPOP(IG,IR)
                   GSAGE=GSAGE+(RGPOP(IG,IR)*GAGER(IG,IR))
98              CONTINUE
                GPOP(IG)=GSTRG*(GDEL(IG)/KGD(IG))
                GAGE(IG)=GSAGE/GSTRG
             ELSE IF(IG .EQ. 13)THEN
                GAGE(IG)=(GAGE(1)*GPREG(1)+GAGE(2)*GPREG(2)+GAGE(3)*
     *                   GPREG(3)+GAGE(4)*GPREG(4)+GAGE(14)*GPREG(14))/
     *                (GPREG(1)+GPREG(2)+GPREG(3)+GPREG(4)+GPREG(14))
              GPOP(IG)=(RGPOP(IG,1)+RGPOP(IG,2)+RGPOP(IG,3))*GDEL(IG)/
     *                   KGD(IG)
              ELSE IF(IG .EQ. 14)THEN
                 GAGE(IG)=GAGE(13)+0.4167
                 GPOP(IG)=(RGPOP(IG,1)+RGPOP(IG,2)+RGPOP(IG,3))*GDEL(IG)/
     *                     KGD(IG)
              ENDIF
C
97     CONTINUE
       TGOFC=0.
       GMLWOT=0.
       TGPOP=0.
       DO 67 IGF=1,14
          TGPOP=TGPOP+GPOP(IGF)
          TGOFC=TGOFC+GOFC(IGF)
          GMLWOT=GMLWOT+GLWOT(IGF)
67     CONTINUE
C
       TGLWOT=TGLWOT+GMLWOT+((GROUT(1)*(GDEL(1)/KGD(1))*DT*GAWT(1))+
     *          (GROUT(7)*(GDEL(7)/KGD(7))*DT*GAWT(7)))*0.001
C
        IF(IM .EQ. 3 .OR. IM .EQ. 12)THEN
        WRITE(20,620)IM,GTPMY(IM),TGAMY(IM),AGDMY(IM)
620     FORMAT(/,1X,I2,2X,'GTPMY=',2X,F6.0,3X,'TGAMY=',2X,F9.0,3X,
     *        'AGDMY=',F6.3,/)
       DO 66 ID=1,IM
         GTMOT=GTMOT+TGMOFT(ID)
66     CONTINUE
        WRITE(20,630)IM,TGLWOT,GTMOT
630     FORMAT(1X,I2,2X,'TOTAL GOAT LIVEWEIGHT OFFTAKE=',2X,F10.3,2X,
     *      'TONS',3X,'GOAT TOTAL MILK OFFTAKE=',2X,F10.3,2X,'TONS',/,/)
```

```
      WRITE(20,631)IM,TGPOP
 631  FORMAT(1X,I2,2X,'GOAT POPULATION=',F8.3,/,/)
      ENUIF
C
       TOFI(IM)=TCOFC+TSOFC+TGOFC
C
 20   CONTINUE
C
       TLWOFT=TCLWOT+TSLWOT+TGLWOT
       TMOFT=CTMOT+STMOT+GTMOT
C
C     COMPUTATION OF FORAGE CONSUMPTION
C
      TOFRA=0.
      DO 80 IJ=1,12
        TOFRA=TOFRA+TOFI(IJ)
 80   CONTINUE
      OFR=TOFRA*(FLR*TFA(3))
      FRI(IY)=OFR/TFA(3)
      IF(FRI(IY) .GT. TFFR)THEN
        AFPCR=((TFFR/2)-0.5*FRI(IY))/3.
      ELSE
        AFPCR=((TFFR/2)-0.5*FRI(IY))/20.
      ENDIF
      WRITE(20,690)IY,TLWOFT,TMOFT
 690  FORMAT(1X,'YEAR ',I3,2X,'TOTAL LIVEWEIGHT OFFTAKE=',F10.3,3X,
     .        'TOTAL MILK OFFTAKE=',F10.3,/)
      WRITE(20,700)IY,FRI(IY),AFPCR
 700  FORMAT(1X,'FORAGE REMOVAL INTENSITY FOR YEAR',1X,I3,' =',F9.3,
     .     3X,'ANNUAL FORAGE PRODUCTION CHANGE RATE =',1X,F7.5,/,/,/)
C
      FPCR=FPCR+AFPCR
C
 10   CONTINUE
      STOP
      END
```

DS=-LONG/-OT,ARG=-COMMON/-FIXED,CS= USER/-FIXED,DB=-TB/-SB/-SL/ ER/-ID/-PMD/-ST,PL=5000
FTNS,ET=F,OPT=0.

```
C                                                                      11720
      SUBROUTINE DELAY(J,I,RINR,ROUTR,CROUTR,DEL,DT,K,PLR)             11730
      DIMENSION RINR(14),ROUTR(14),CROUTR(14,49),DEL(14),K(14),PLR(14) 11740
      D=DEL(J)/FLOAT(K(J))                                             11750
      DEL1=DEL(J)/(FLOAT(K(J))*DT)                                     11760
      RIN =RINR(J)                                                     11770
      DO 1 I =1,K(J)                                                   11780
      ABC=CROUTR(J,I)                                                  11790
      CROUTR(J,I)=ABC+(RIN-ABC*(1+PLR(J)*D))/DEL1                      11800
    1 RIN=ABC                                                          11810
      ROUTR(J)=CROUTR(J,K(J))                                          11820
      RETURN                                                           11830
      END                                                              11840
```