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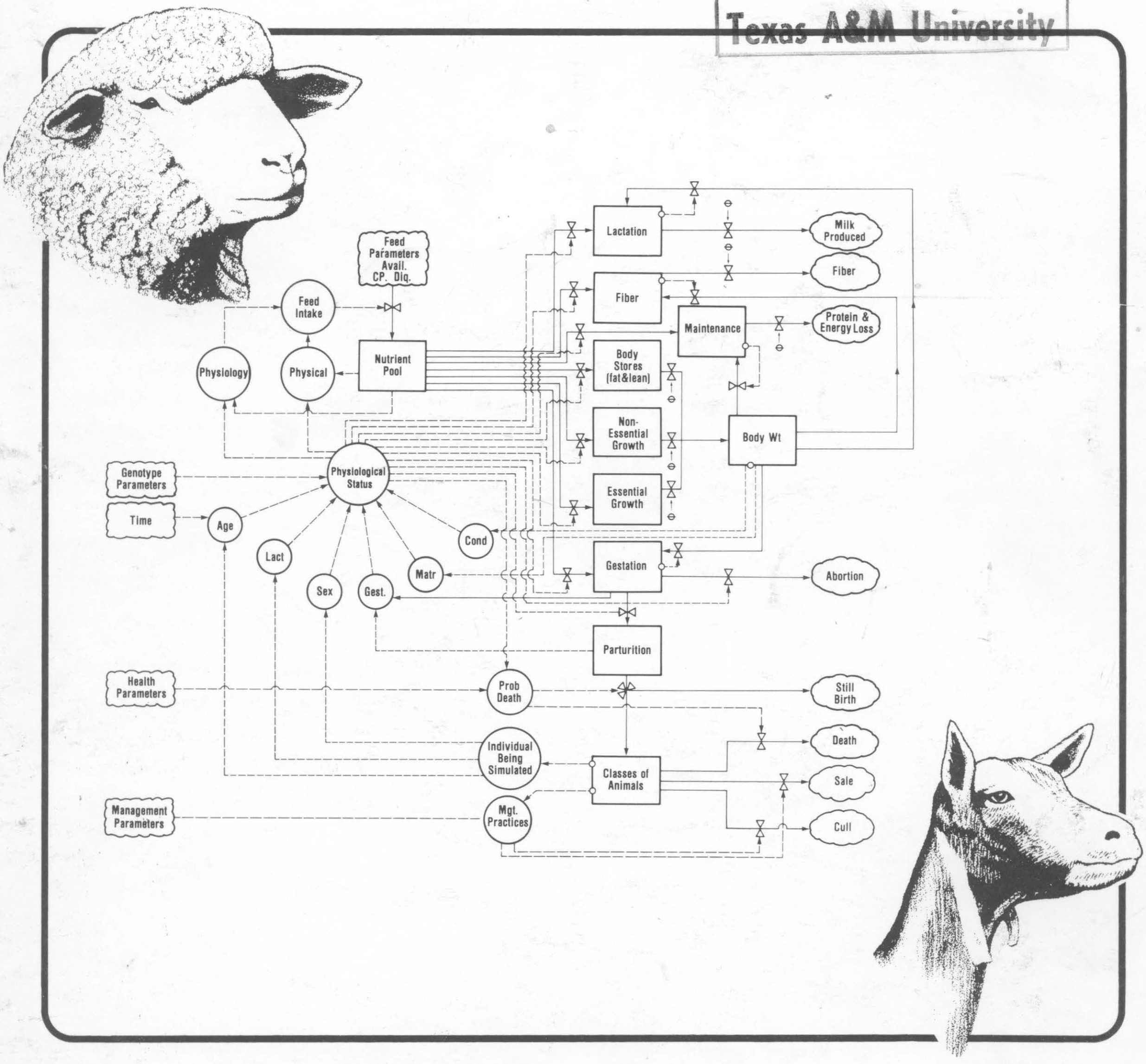
The Texas A&M Sheep and Goat Simulation Models



The Texas Agricultural Experiment Station, Neville P. Clarke, Director
The Texas A&M University System, College Station, Texas
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The Texas A&M Sheep And Goat Simulation Models

Texas Agricultural Experiment Station, Texas 77843

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FOREWORD

Historically, agricultural science has grown through small advances and incremental progress, and the application of research results have often been limited by the time and geographic location. In contrast, the models reported here permit reaching beyond restrictive time and geographic constraints. The models represent major directional progress in ruminant production through quantitative description of animal performance. The models will be useful to other scientists as research tools to evaluate and develop new hypotheses. Also, the models reach across several disciplines and the integration of knowlege from these disciplines is of scientific interest in understanding the dynamics of growth, maturing and reproduction cycles.

Clearly, the models are not intended for direct field use by producers. Their application value lies in use by experts to examine effects of varying nutrition, breeding, and management on practical production or development problems encountered in the field. These applications are especially useful for addressing problems in areas where production research results are lacking and cannot be obtained because of time, funding, facility and personnel constraints or complexity of the problem. These capabilities also provide the means for examining practical problems of individual enterprises; i.e., extending research results directly to the unique set of production resources of individual producers.

These models are reported for their scientific accomplishment and interest and for their use to enhance the capability to make decisions about sheep and goat production that are relevant and practical and in quantitative terms. From a broader perspective, the application of systems science in agricultural research is being employed by TAES to both extend the frontier of knowledge and to make the knowledge more accessible for practical application.

Dudley T. Smith, Associate Director
Texas Agricultural Experiment Station

PREFACE

Animal scientists have become increasingly aware of the need for systematic consolidation of component knowlege obtained through the traditional scientific approaches. Systems analysis is an orderly method of structuring and organizing knowledge and interaction relationships.

The development of models of complex systems, which include sheep and goat production, requires substantitive knowledge of the components which make up a system. The models summarized in this publication were constructed so that any breed of sheep or goat can be simulated for a wide range of nutritional environments and management practices. The simulations reflect the response of sheep or goats to a specified set of inputs and therefore, may be used to evaluate the performance of breeds considered for introduction into an area or to examine the effect of nutritional regimes or management practices as well as the interactions among these variables. Results from simulations allow biological interpretation in quantitative terms and are in a convenient form for economic analysis.

These models have been validated and put into active, continuing use in less developed countries (LDCs) using micro or minicomputers to simulate various versions. Although systems analysis represents a high technology use of science, at the same time it is appropriate for use in LDCs; it is a method by which scientific knowledge from developed countries can be transferred for practical application in LDC settings. "Production experiments" can be simulated as a substitute for much research for which funds, facilities and personnel are limited.

Models are reported in this publication for their scientific accomplishment and interest and for their use to enhance the capability to make decisions about sheep and goat production in quantitative terms.

Appreciation is expresed to numerous coworkers in the United States and host countries who participated in the development or validation of this model. Additionally, graduate students, involved in this research made valuable contributions.

T. C. Cartwright, Professor

Texas A&M University

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1. CONCEPTUAL OVERVIEW OF MODEL STRUCTURE AND FUNCTIONS

A major purpose of the sheep model is to simulate sheep performance for a wide array of genotypes in a wide variety of environments with managerial options implemented as desired. These capabilities make it possible to evaluate performance of different genotypes in different areas employing different production practices. The results from such simulations may be used to develop packages of breeding strategies and feasible alterations in management techniques that can be recommended to increase the productivity of the system.

Two versions of the TAMU sheep model have been developed, the single animal version (SAV) and the flock model (FM). Both models have the general characteristics of a 15-day time increment for a period of simulation, with conception and lambing occurring at the end of a period of simulation. The length of the time increment was chosen because it closely matches the reproductive biology of the sheep (150-day gestation and a 17-day estrus cycle) and it makes a 360-day simulated year feasible. A shorter time frame might add precision to the simulated results, however it would increase the amount of memory, cost and time required for simulation. The SAV is capable of simulating the biological response (maintenance, growth, work, gestation, birth, lactation, fiber and death) of any portion of the life of a sheep. For example, SAV is capable of simulating the biological response of one ewe, her nursing offspring (until weaning) and any fetuses she may be carrying. The FM incorporates the biological components of the SAV and adds to it the accounting and flock management practices required to simulate flocks of sheep. The FM has the capability to simulate six flocks of sheep with 12 classes of animals per flock. The classes in the FM represent differences in age and sex of the simulated sheep. The flock may also be divided into different management groups (e.g., supplemental feeding and pasture assignments).

A conceptual overview of the sheep model is presented in figure 1 and illustrates the interaction among the different biological processes modeled. The physiological status of the sheep interacts with its nutritional intake, partitioning the nutrients for various functions, which results in the final output or sinks on the right hand side of the figure (milk and fiber produced and protein and energy loss, etc.). In figure 1 it is possible to trace the

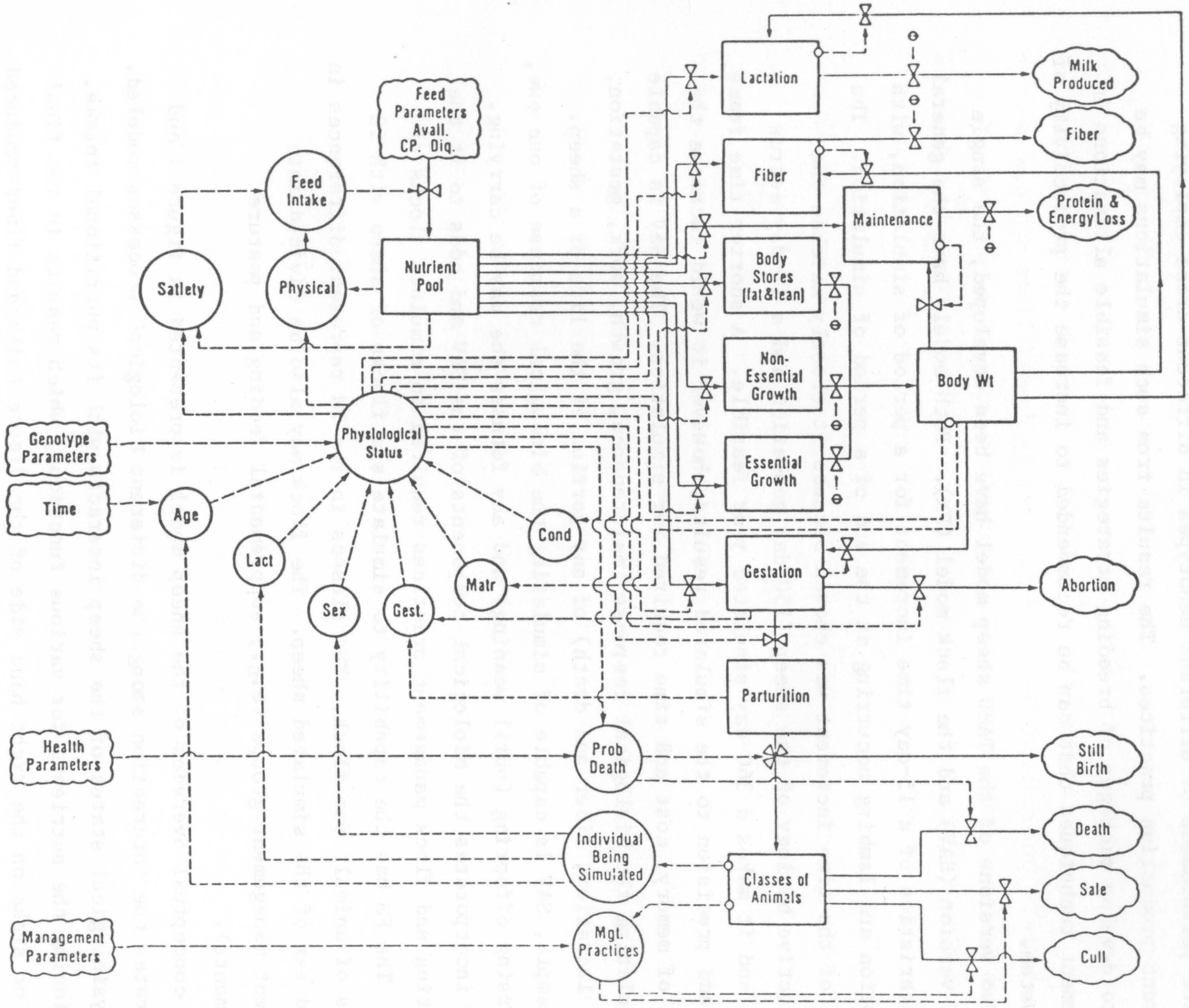

Figure 1. A conceptual information and material flow diagram of the TAMU sheep model showing inputs (left) and outputs (right) of the system.

division of nutrients for any type of sheep simulated. Sources and sinks are illustrated by amorphous cloud shapes. The sources are parameters supplied to the model. Sinks are losses or offtakes from the system.

The nomenclature used follows that described by Forrester (1968). All rectangles represent state variables or physical products (e.g., kg of protein or kg of body weight). The flow of material between levels is denoted by a solid line. The flow of a material is regulated by the valve on the solid line which is turned on or off by the auxiliary variables (circles) or constants. Information flows are depicted by dashed lines and can pass to and from a state variable. That is, information controlling the rate of material flow is altered by an auxiliary or constant, but there is a feedback from the state variable to the auxiliary which may increase or decrease the material flow.

The logic flow of the FM follows a hierarchical design, with the main program calling subroutines in a top down manner. Figure 2 illustrates this concept for the entire program. Due to the importance of the biology and management subroutines in the flock model, their hierarchical structures have been diagrammed in more detail (figures 3 and 4) to show subroutines that are called from biology and management. These two figures demonstrate, in broad outline, the simulation process, the options and the capabilities of the model.

The information for an individual in the FM is kept in one dimensional arrays, with each sheep being assigned a specific position in that array. The records of an animal's traits are connected together by doubly-linked lists (Knuth, 1968). A doubly-linked list has two pointers, one to the previous position in the array, and the other to the next position in the array. These pointers allow individuals to be deleted from any portion on the list without having to reorder the entire list of animals. The doubly-linked list procedure also allows the grouping of animals in the same class and it reduces the computation time for a simulation. Mayfield (1979) described this procedure in detail in his master's thesis at Texas A&M.

From the preceding discussion and flow charts, it can be perceived that the sheep model is primarily a nutrition model. That is, the model is driven by nutrients (just as the energy "driving" real sheep is derived from their

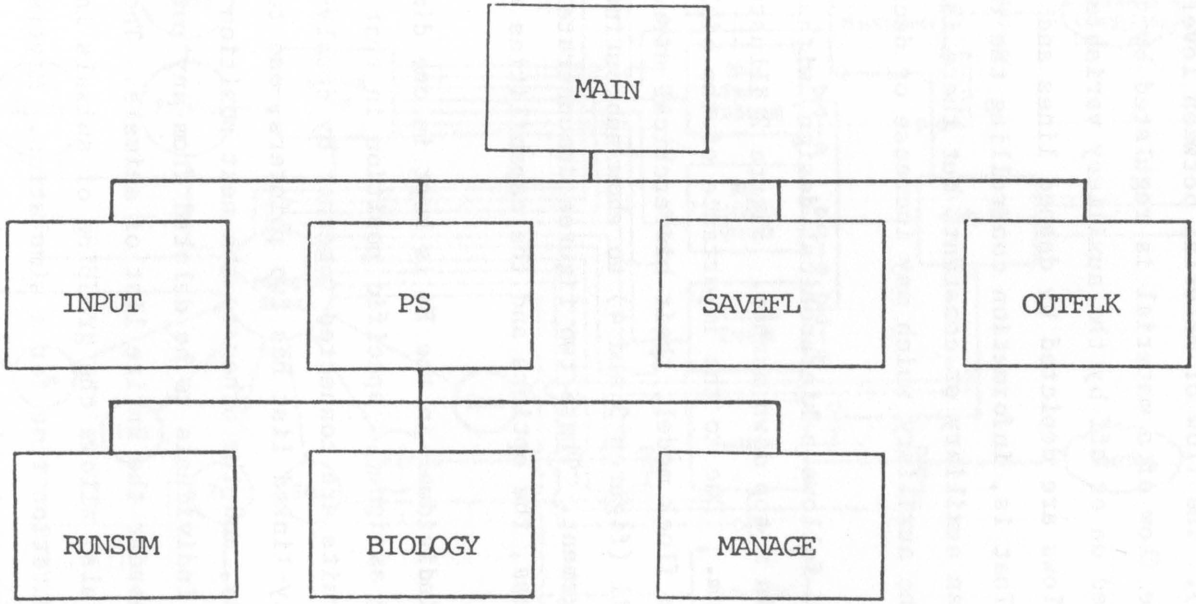

Figure 2. Hierarchical structure of the major categories simulated. PS = period of simulation.

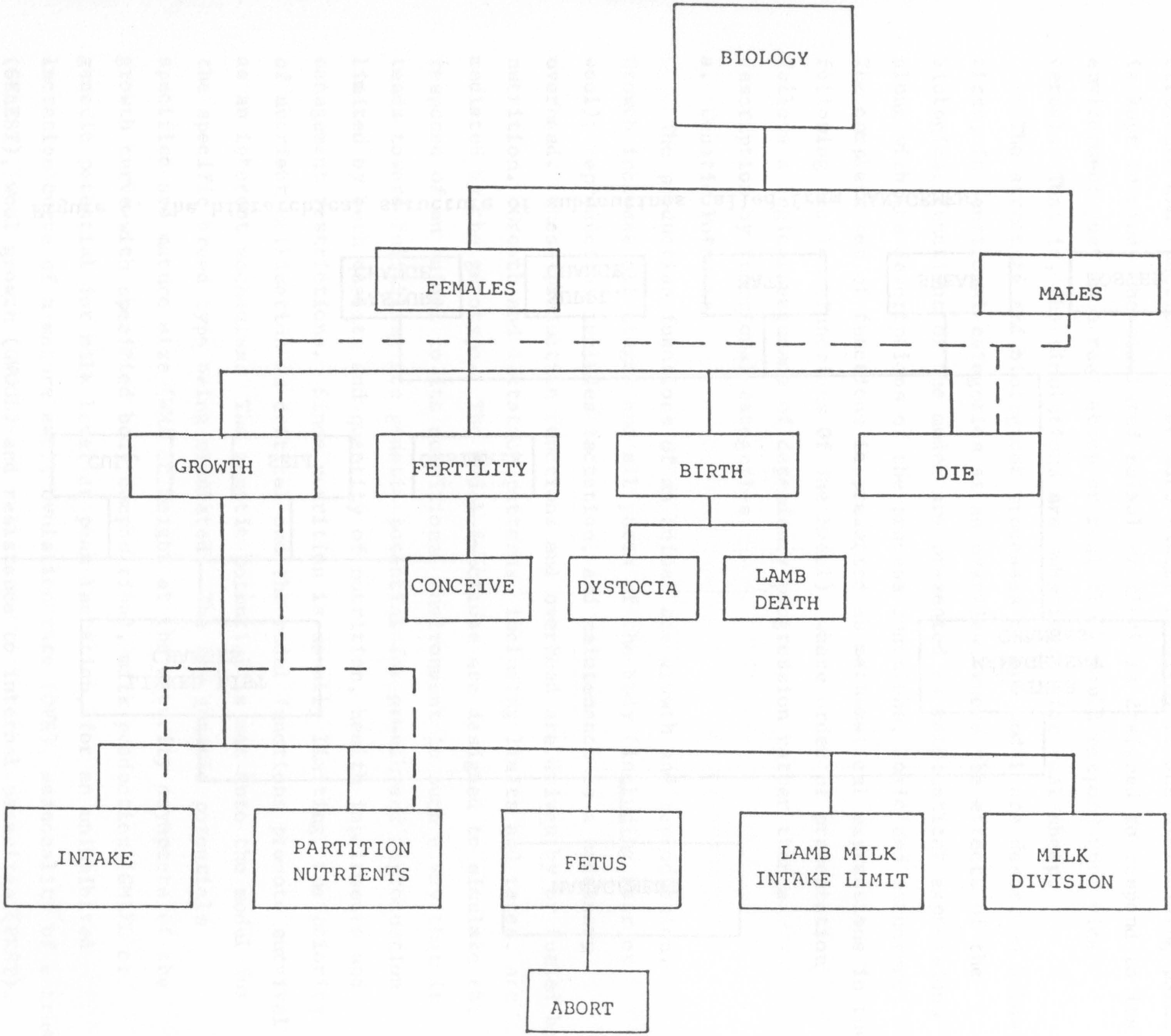

Figure 3. The hierarchical structure of subroutines called from BIOLOGY.

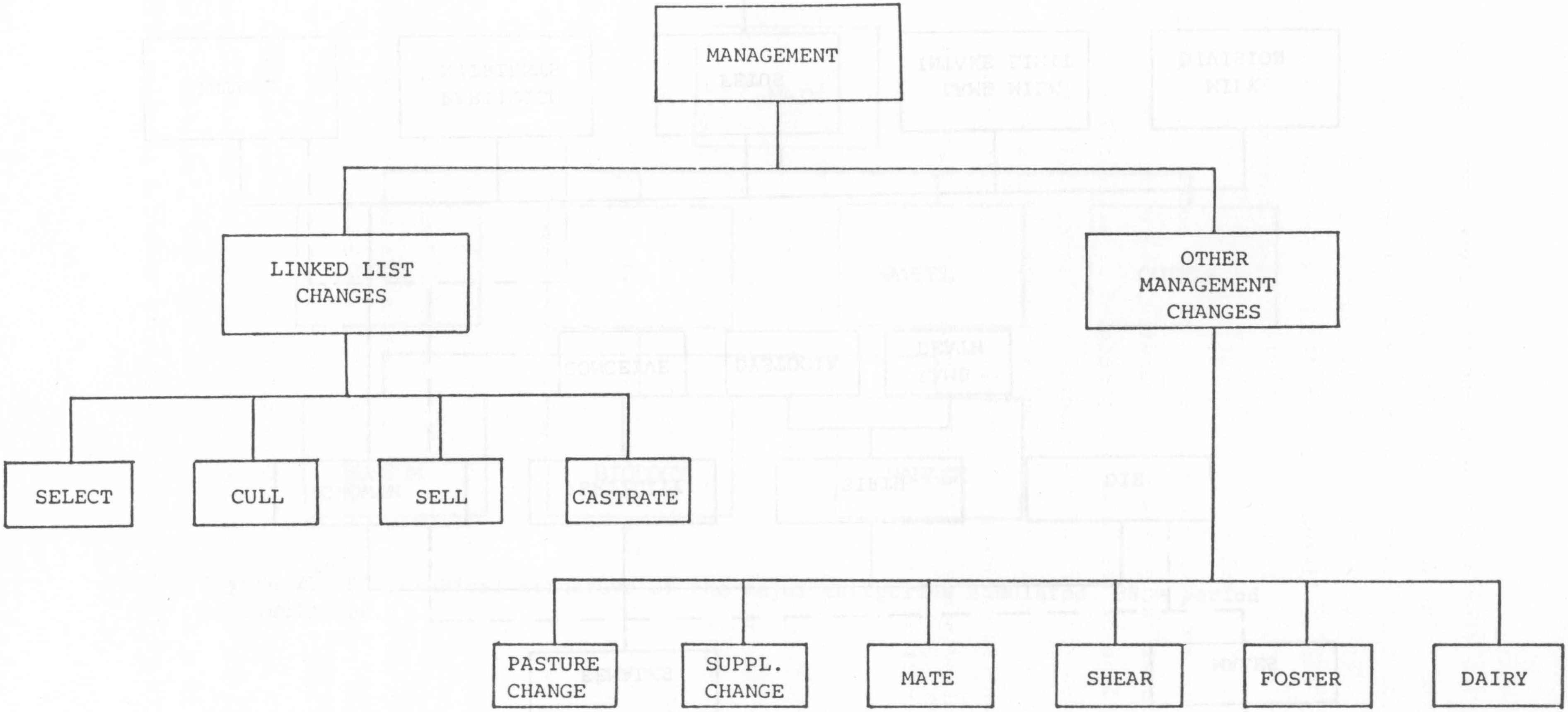

Figure 4. The hierarchical structure of subroutines called from MANAGEMENT.

nutrition), and the flow of nutrients can be followed from consumption to their ultimate end point for a particular time step.

Any questions that might arise as to the rationale of the model structure and functions may be more easily resolved if one over-riding point is kept in mind; the simulated animal or flock is designed to respond to its environment just as a real sheep or real flock would respond (not vice versa). That is, the simulations are substitutes for real sheep.

The structure and biological processes of the model are described below; first, in functional categories as an overview, where the effects of the biological functions of the model are presented as mathematical expressions along with the descriptions of the process functions, logic and structure. The complete set of functions is presented as mathematical expressions in the following section (Functions Of The Model), where order of presentation follows a logical sequence of dependency progression rather than a description by functional categories.

a. Genetic Potential

The production functions of an animal are growth and reproduction. Growth includes all stages and all parts of the body (including hair or wool); reproduction includes lactation, and maintenance as a necessary overhead. These production functions and overhead are driven by or fueled by nutrition. Growth and lactation patterns, including limits and rates, are mediated by the genotype. The model functions are designed to simulate the response of an animal to its nutritional environment in such a way that it tends toward fulfilling its genetic potential for growth and reproduction limited by both quality and quantity of nutrition, health impairments and management restrictions. Since nutrition is usually limiting, the priority of nutrient utilization is critical and the model functions promote survival as an inherent mechanism. The genetic potential is set into the model for the specific breed type being simulated. The key genetic potentials specified are mature size (WMA or weight at the maturity asymptote of the growth curve with specified body composition), milk production (GMLKL or genetic potential for milk level at peak lactation, for an uninhibited lactation curve of a mature ewe), ovulation rate (OVR), seasonality of estrus (SEAEST), wool growth (GWOOL) and resistance to internal parasites (PRST).

These and other genetic parameters are discussed under appropriate headings below.

The key parameters that must always be set in the model to specify the genetic potential of a breed (e.g., WMA) are designed to represent each specific breed and therefore reflect breed variability. Also, the coefficients in many of the functions such as the ones above may be varied to reflect any specific characteristic peculiar to a breed. For example, research characterizing a breed may indicate that the male factor of 1.5 times WMA does not correctly reflect the sexual dimorphism characters for that breed. Therefore, these coefficients would be appropriately "fine tuned" in addition to the other breed parameters. The maturing rates of so called "unimproved" indigenous breeds are usually different from "improved" breeds on a relative as well as absolute basis.

b. Maintenance

The nutritional requirements of the simulated sheep are an accumulation of minimal body maintenance costs (unavoidable losses), expenditures for pregnancy, lactation, growth and fiber production. Maintenance (both protein and energy) requirements, as used in this model are the sum of basal metabolism (MB), endogenous urinary loss (UL) and work (WK). The work component of the equation consists of, on a daily basis, the time spent eating (EAT), distance travelled (DIST) and the time spent ruminating (RUM). The maintenance requirements for protein (MTP) are first calculated as .0164 MTE. This first calculation provides a first estimate of the requirements so that potential performance levels may be considered.

c. Growth

In order to simulate the growth of a sheep, a potential growth curve, specified by a set of parameters describing the breed being simulated, is placed in the model functions. This set of growth parameters specifies the genotype or genetic potential for the growth of an individual. From birth to 50% of mature weight (WMP) potential growth rate is assumed to be linear; after reaching WMP (the point of inflection), potential growth rate decreases until the curve asymptotes at the simulated breed's average mature empty body weight (WMA). This underlying growth curve represents animal growth with no nutritional impediment, therefore an animal following this growth pattern is considered to be in good condition, but not excessively fat. The body composition for such a sheep is assumed to be 3% fat at birth and 25% fat at maturity; the deposition of fat from birth to maturity increases in proportion to the degree of maturity (WM/WMA). The simulated individual has two measures of body size. One is WM, which Sanders and Cartwright (1979a) described as the structural size. The structural size attained at a given age is a combination of the effects of the animal's genetic potential and the environment (principally nutritional environment).

An animal's WM will increase at the rate set by its genotype if there is adequate nutrition until it reaches maturity. The rate of change in WM may be decreased in a growing animal if nutrition is limiting. However, once an individual has obtained a given WM, it will never decrease from that value. In the case of severe nutritional deprivation, stunting may occur and would be reflected in zero increase in WM for that period. The second and more dynamic measure of body size is EBW, which is the summation of the fat and lean (lean includes bone) content of an individual and is a record of the fluctuating empty body weight from period to period. Thus WMA is WM at maturity (or at the asymptote) and when EBW (empty body weight) equals WMA, fat composition is 25% of EBW.

d. Maturing Rate

The rate at which animals mature will influence the initiation and cessation of their body functions. The influence of these factors was taken into account in the development of functions to calculate maturing rates for different breeds of sheep. Taylor (1965) showed that the time taken to reach any particular degree of maturity tends to be directly proportional to an animal's mature weight raised to the .3 power. In this model, rate of maturing (RM), is considered to be inversely proportional to the .3 power of WMA. Therefore, the time taken to reach the point of inflection (WMP(Ti)) on the growth curve is proportional to the .3 power of WMA.

In the development of the model, the breed used as a base was patterned after a fine wooled sheep (Rambouillet). It was assumed that this sheep had a WMA of 60 kg and a Ti of 165 days (Ti = time of inflection) as base or reference points. With this base and the WMA of the breed to be simulated, the appropriate Ti and RM can be calculated for the breed. Males are simulated as having a WMA 1.5 times that of females. Therefore, they also have a larger WMP.

e. Body Composition

Both protein and energy are accounted for in the model; therefore, fat and lean gains are calculated separately. These gains are subdivided into essential and nonessential pools. The essential pool of an animal at one period of time is used as the base for calculating gain in WM from that period to the next period. The composition of this growth of WM must be at least 3% fat and at least 65% of the lean growth expected for that period. Growth in WM may range from these minima up to the full expected growth, depending on the nutrition available. If nutrient requirements for these minima can not be met, then zero growth occurs, representing stunting for the period. It is possible to have greater growth of WM than of EBW; i.e., structural size may increase while condition is lost, a common occurrence, because any portion of the nonessential fat or lean can be catabolized for maintenance or production including growth in WM. Animals weighing less than their structural size (EBW<WM, a thin condition) have an impulse to increase intake striving to gain weight at a compensatory rate reflecting the biological adaptation to tend toward a normal or surplus body composition ($EBW \geq WM$).

f. Pregnancy

The sheep model simulates individuals from conception onward. A ewe may have one to three lambs per pregnancy. The equation used to describe expected growth in conceptus weight (DCW) was presented by Graham et al. (1976). Conceptus weight change is calculated on a daily basis, and the total of conceptus weights of all fetuses of a ewe are then accumulated over each 15-day period.

The potential birth weight (BW) of a lamb is determined by the number of fetuses, the potential mature size of the fetuses (WMA), and the structural size of the ewe (WM). Birth weight is calculated by an equation similar to one reported by Geisler and Jones (1979). Mammary gland growth is initiated at 105 days of gestation and continues for 30 days after parturition.

g. Feed Intake

The model uses three factors to determine feed intake. The minimum value of either the physiological limit, physical limit, or feed availability determines the feed intake.

Availability is specified externally to the model and is defined as being that amount of feed, of a given quality, available for an animal to consume during a day. The availability for immature sheep is adjusted downward to represent differences which exist in foraging range.

Physiological limit (PSOL) is the animal satiety factor; that is, body condition of the sheep, feed quality, and energy requirements interact to set a limit on feed consumption.

Physical limit (R2) represents the gut capacity of the sheep. The equation used describes the amount of feed the gut will hold and contains an adjustment that varies with feed quality, and may be interpreted as the passage rate of nutrients.

The physical limit of pregnant ewes is adjusted downward depending upon a ewe's age, the number of fetuses she is carrying and the period of gestation. For lactating ewes, intake is adjusted upward and is a function of time (postpartum interval) and potential milk production.

h. Tissue Mobilization

The model has the capability to mobilize tissue when protein and energy intake is insufficient to meet the animal's nutritional requirements. Lean may be catabolized for use as protein or as energy. Fat may only be utilized as a source of energy. Tissue is catabolized in the order of 1) lean for protein, 2) lean and fat for energy, 3) fat for energy, and 4) lean for energy.

i. Partitioning of Nutrients

When the nutrients consumed and the tissue mobilized are still lower than the animal's requirements, the existing nutrients are divided between the various uses. This partitioning is accomplished by dividing the protein and energy available according to functions represented by geometric containers as shown in figure 11. These containers are adjusted to hold the calculated nutrient requirements for the simulated animal. The protein and energy present (from the feed consumed and tissue catabolized) are then "poured" into a separate set of containers for protein and energy. The nutrient which is most limiting or fills its respective containers to the lowest levels is the limiting nutrient. Performance is then adjusted downward to the level of the limiting nutrient.

The shape of the containers and their positions relative to one another are based on interpolations and indications from relevant research and general experience.

j. Lactation

Milk production potential is a function of units of available lactation capacity (ALC) and secretion rate (SR) per unit in a manner similar to that developed by Bywater (1976). Genetic differences in milk level (GMLKL) and period of lactation (LACPP) set an upper limit on ALC. Either the intake capacity of nursing young (MLKLIM) or nutrition may restrict the ALC actually used below that available. In addition, the number of units of lactation capacity used the previous 15-day period (LCU) sets a lower limit on ALC. SR is a function of ewe age in periods (AGEP), genetic difference in persistency (PRS) and LACPP.

k. Fiber

The genetic potential for clean wool growth (GWOOL) is the maximum growth (g/day) which can occur for a breed. It is adjusted for photoperiodicity (SCR), age, and degree of maturity (UCR).

The nutritional requirements are based upon clean wool being 100% protein, which is assumed to be deposited with an efficiency of BVP. The gross energy content of wool is assumed equal to 6.0 Mcal/kg and to be deposited with an efficiency of 20% (Graham and Searle, 1982).

l. Reproduction

The approach used in modeling reproduction was to identify the components which had an influence upon reproduction and then to construct mathematical functions to describe their responses. This method was described and used by Sanders (1974) for beef cattle. A female has a calculated probability of estrus cycling and conceiving if mated; if she conceives, another probability determines the number of ova ovulated (1 to 3).

2. FUNCTIONS OF THE MODEL

The more basic functions are presented initially in order to establish definitions and based upon which to build the functions that follow in sequence. Some expressions of overall structure and functions were presented in the preceding section for illustration and are repeated below.

The order of presentation begins with life-sustaining maintenance followed by the production functions of growth, milk, fiber, pregnancy, and their summation. Next are controlling functions that mediate the flow of nutrients for the above functions and relate to the two sources of nutrients: feed intake and mobilized tissue. The next section describes the mechanism of setting priorities for use of nutrients; it operates in the interface between nutrient "supplies" and nutrient "consumers" directing flow or partition of nutrients. The next updates the animal for changes due to growth, etc., that have taken place during the period. The final section integrates the ewe reproductive functions with other functions.

a. Maintenance

Energy. Maintenance requirements for energy (MTE) are estimated as the sum of basal metabolism (MB), endogenous urinary loss (UL), and work (WK) in terms of net availability of metabolizable energy (ME) for maintenance.

$$MB = .0583(EBW+XWT)^{.75}\ e^{-.00125\ AGEP} + .046DME + .0446DEBW$$

$$UL = .08MB$$

$$WK = (.000526EAT + .000237RUM(DM) + .000598DIST)\ W$$

$$MTE = \frac{MB + UL + WK}{KM}$$

$$KM = .85\ \frac{ME\ (MILK)}{ME(TOTAL)} + (.546 + .3\ (.81\ DIG))\ \frac{ME\ (FEED)}{ME(TOTAL)}$$

where

EBW = empty body weight; W less fill, conceptus, fleece and mammary gland, kg
XWT = rumen fill after fasting; min. (2, .2 AGEP), kg
AGEP = age in periods; period = 15 days
DEBW = change in EBW from the previous period, kg
DME = daily feed ME intake during last period
EAT = hours per day spent eating
RUM = hours per kg DM spent ruminating
DM = daily dry matter intake during last period, kg
DIST = distance walked each day, km
W = body weight, kg
DIG = feed dry matter digestibility
KM = net availability of ME for maintenance

The estimates for MB, UL and WK are the same as used by Graham et al. (1976), except that (1) feed intake is the average of the previous 15-day period rather than the previous day, (2) time spent eating is expressed on a daily basis rather than on a per-kg-intake basis, and (3) for use in conjunction with KM as defined by ARC (1980), the growth rate term in the original equation for MB was set to zero.

The ME content of milk is calculated as 1.08 Mcal per kg from the assumptions of gross energy of 4.8 kJ/g liquid milk with 94% metabolizability (Graham et al., 1976). The net availability of ME from milk of .85 is modified only slightly (Graham, personal communication) from the .84 used by Graham et al. (1976). The ME content of dry feed is estimated as .81 times digestibility and has an assumed net availability for maintenance of .546 + .3 ME (Graham et al., 1976).

Protein. Approximate protein maintenance requirements (MTP) are first estimated as .0164 MTE. After feed intake is estimated, MTP is recalculated similar to the estimate used by Graham et al. (1976).

$$MTP = .44(EBW + FILL)^2 + .01DM(1-DIG) + .0004MLKTK$$

where:

FILL = 2

MLKTK = intake of milk, kg.

b. Growth

Potential. Growth potential (WMG) in structural size (WM) is assumed linear from birth (BW) until a constant fraction (WMP) of mature size (WMA) is reached and to decline monotonically after that point. WMA is a parameter set as part of breed specification; see the next section on composition. The rate of maturing (RM) is inversely proportional to the .3 power of WMA (Taylor, 1965); hence, time taken to reach WMP (t_i) in females is proportional to the .3 power of WMA. Parameters for potential growth of females are as follows:

$BW = C_1WMA$; $C_1 = .06$ as a base; set as part of breed specification.

$WMP = C_2WMA$; $C_2 = .50$ as a base; set as part of breed specification.

The constant C_1 is the percent of mature weight which is attained at birth of a lamb. The base estimate of .06 was based upon summary of literature values (Sidwell and Miller, 1971; Dickerson et al., 1972; Hodgeson and Bell, 1973; Hohenboken et al., 1976; Stobart, 1983; Mathenge, 1981). The constant C_2 represents the degree of maturity attained by a sheep at the point of inflection of its growth curve; C_2 was set at .50 as a base. Most of the data which were utilized to establish this base value were related to attainment of puberty of ewe lambs and are cited in the section describing the reproduction correction factors. The constants C_1 and C_2 may be varied to more closely resemble the breed being simulated. In general, the literature, as a whole, substantiates the use of .06 and .50 for C_1 and C_2, respectively.

$$t = (WMA/WMA')^{.3}\, t'_i \qquad t'_i = 165 \text{ days as a base}$$

$$WMA' = 60 \text{ kg as a base}$$

if $WM \leq WMP$,

$$WMG = \frac{WMP - BW}{t_i}$$

if $WM > WMP$,

$$WMG = \frac{C_2 - C_1}{t_i\ (1-C_2)}$$

Potential growth of males is simulated by assuming an increase in WMA and WMP with t_i adjusted (t_i') to provide a specified growth rate ratio (RSX). WMA' and WMP' are the increased WMA and WMP.

$$WMA' = Q(WMA) \qquad Q = 1.5 \text{ as a base;}$$

$$WMP' = C_2\ WMA';$$

$$t_i' = Pt_i$$

$$RSX = \frac{(WMP'-BW)/Pt_i}{(WMP-BW)/t_i}$$

$$P = \frac{C_2Q-C_1}{C_2 - C_1\ RSX} \qquad RSX = 1.15$$

Differences between sexes for birth weights are simulated, but these birth weight differences are ignored in estimating potential postnatal growth rate.

Baseline Body Composition. An animal that is never stressed by disease, treatment, or nutrition (quality and quantity) is expected to be in "good" condition. The percent body fat of an animal that is always in "good" condition is assumed to increase linearly from 3% at birth to 25% at maturity (Sanders, 1977). The minimum amount of fat a sheep must have at any age is 3%. The lower limit of 3% fat and the average unstressed mature level of 25% fat correspond with data of Farrell and Reardon (1972), who undernourished

Merino ewes for 4 months and maintained them in that state for an additional 9 months at which time they were slaughtered. Two groups of undernourished ewes had 9 and 5% body fat, respectively, compared to 27% for control ewes. The 25% body fat for mature ewes in average "good" condition also corresponds closely with data of Notter et al. (1984) who found body fat of Rambouillet, Dorset and Finn to be 27.7, 24.4 and 21.6%, respectively. For an animal in "good" condition, empty body weight (EBW) will equal structural size (WM); hence, expected fat (XFAT) and expected lean (XLN) are functions of degree of maturity (lean is defined as muscle).

$$Z_1 = e_1 + e_2 \frac{(WM - C_1\ WMA)}{(1-C_1)\ WMA} \qquad e_1 = .03, \text{ minimum fat} \quad e_2 = .22$$

$$XFAT = Z_1\ (WM)$$

$$XLN = WM - XFAT$$

Composition Of Gain. The fat (FG) and lean (LG) gain associated with a gain in WM can be calculated from expected normal compositions.

$$WMX = WM + 15\ WMG$$

$$Z_{1x} = e_1 + e_2 \frac{(WMX - C_1\ WMA)}{(1-C_1)\ WMA}$$

$$FG = Z_{1x}\ WMX - Z_1\ (WM)$$

$$LG = WMG - FG$$

Partition Of Gain. FG and LG are partitioned between that amount which is essential (FGE and LGE) for a unit growth in WM and the remainder which is normal (FGN and LGN) (figure 5). A unit of WM growth must be at least 3% fat and at least 65% of the expected lean fraction must be met. The percentage fat considered minimal for body functions is that suggested by Sanders (1977) and substantiated by Farrell and Reardon (1972). The percentage lean is approximately equal to that fraction of body protein that can not be depleted during protein starvation (N. Graham, personal communication).

$$FGE = e_1\ (WMG)$$

$$FGN = FG - (FGE)$$

$$LGE = p_1\ (LG); \qquad p_1 = .65$$

$$LGN = LG - LGE$$

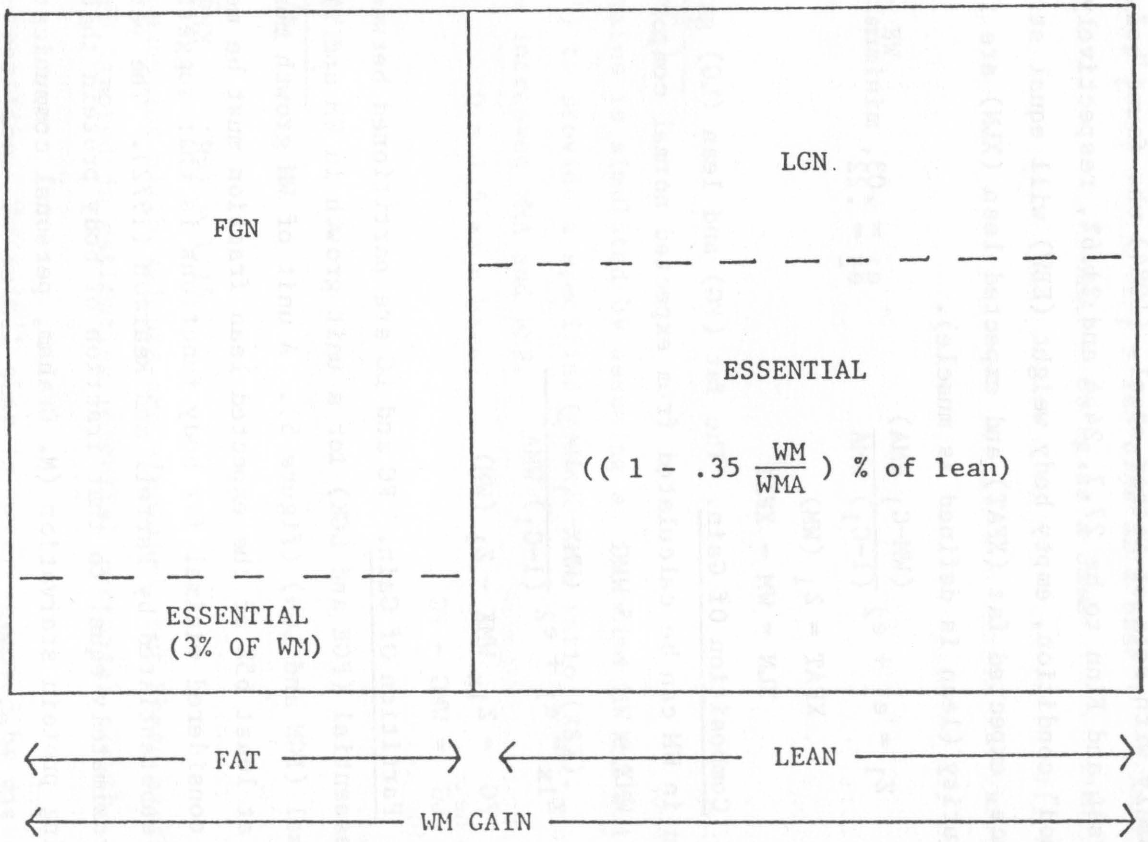

Figure 5. Partition of WM gain.

Hence, a unit's growth of WM is made whenever FGE and LGE are met. The ratio of FG to LG is linearly proportional to degree of maturity with FG increasing from 3% at birth to 25% at maturity.

Composition Correction. A necessary component of grazing ruminant production is the capability for compensatory gain. This ability is vital to an animal which must survive in an environment where forage quality and quantity constantly change with seasons of the year. The ratio in which protein and energy are lost during nutritional stress is variable, depending upon the maturity of the sheep (Thorton et al., 1979). However, when realimentation occurs, a sheep's impetus is to reach the normative proportions of protein and fat for its given degree of maturity. This biological mechanism is embodied in the conceptual structure of the TAMU model. That is, a simulated sheep will always strive to attain its normative condition, and if the nutrient supply permits, the sheep will accumulate body reserves. The compensating rates of gain during compensatory growth are varied. Graham and Searle (1975) reported that a compensatory group of lambs gained 280g/day while the control gained 160g/day. Thorton et al. (1979) reported a 330g/day gain for lambs undergoing realimentation vs the 60g/day of their control. Both of the articles cited state that greater feed intake during rehabilitation was the cause of compensatory growth and not an alteration in efficiency of nutrient utilization or lower basal metabolism. The rationale for the model structure and functions for feed intake for under-conditioned animals is described in the section on the physiological limit to feed intake and incorporates the concept of animal condition determining feed intake.

In the model, animals that have fat and protein levels below amounts expected for their structural size (WM) have a compensatory impulse to gain fat (FGC) and lean (LGC) to bring their composition back to baseline (realimentation). The difference between empty body weight (EBW) and actual lean weight (WL) is actual fat (AFAT). The redeposition of expected fat is set at 1%/day (Sanders, 1977). The requirement for this gain does not lower the physiological limit on intake and does not necessarily compete with other energy requirements. The rate of lean composition correction, which becomes part of the upper limit on lean gain, is set at 2%, twice the rate for fat. Further research may be required to obtain more precise estimates of the rate for compensatory growth; however, lean deposited at a faster rate than fat agrees with Drew and Reid (1975).

Animals that have fat and protein levels above WM have a compensatory dampening.

$AFAT = EBW - WL$

$FGC = .01(XFAT - AFAT)$

$FGC = \max(FGC, 0.0)$

$LGC = .02(XLN - WL)$.

Requirements. Energy requirements for gain are based upon ARC (1980) requirements. The net availability of ME for gain (KG) is assumed equal for both fat and lean and to be dependent upon physiological status (lactating vs nonlactating) of the animal and upon source and digestability of nutrients. The energy content of gain (Mcal/kg) is assumed equal to 9.4 for fat and 5.7 for protein. The percentage protein of lean (PPL) is currently set equal to 20%. That is, 20% of the weight of lean (WL) is protein. This was the estimate reported by Searle and Graham (1975) and Searle et al. (1979). The efficiency of depositing protein is assumed to equal the biological value of absorbed amino acids (BVP) which is set to .72.

Nonlactating

$$KG = .70 \frac{ME(milk)}{ME(total)} + (.03 + .81(.81(DIG))) \frac{ME(dry)}{ME(total)}$$

Lactating

$$KG = .95(.47 + .35(.81\ DIG))$$

$KF = 9.4/KG$

$KLN = 5.7PPL/KG$

$RGE = KF(FGE) + KLN(LGE)$

$RGEX = KF(FGN + FGC) + KP(LGN + LGC)$

$GL = PPL/BVP$

$RGP = GL(LGE)$

$RGPX = GL(LGN + LGC)$

The separation of requirements into those for essential gain and those for nonessential (normal plus compensatory) gain allows assignment of different priorities to these.

c. Lactation

Potential. Milk production is simulated as an interactive process where the amount of milk produced is dependent upon the ewe's genetic potential, body condition, age, nutrition, period of lactation, and the number of lambs nursing. The concept used for modeling milk production was suggested by Bywater (1976). Bywater's approach assumes that milk production is comprised of two components, lactation capacity available (ALC), which is determined by the environment and the genetic capability of the female, and secretion rate (SR) which defines the rate and pattern of milk production for a given unit of time.

The TAMU sheep model uses the same concepts of SR and ALC. However, several modifications to Bywater's approach have been made. Secretion rate may be viewed as the output of milk per unit, where units are defined as ALC. Therefore, as lactation proceeds over time the milk produced per unit (ALC) decreases. Secretion rate not only varies within an individual's lactation, (figure 6) but there are a family of SR curves determined by ewe age. As a ewe grows older the SR curve is increased. The incremental changes occur at one, two, and over three years of age (figure 7). Secretion rate is described by the following equation:

$$SR= \frac{(ARC)e^{-.22(1-P)(LACPP-2)}}{10.0}$$

where:

ARC=An age adjustment for the initial level of SR (figure 7).

$ARC=.6349+.005636AGEP-.00002402AGEP^2$

P=Persistency currently set to zero.

LACPP=Period of lactation.

where:

AGEP=Age of the ewe in periods of 15 days.

Lactation capacity available describes the number of units available at any one time to produce milk. Bywater (1976) states that these units are not alveoli but, conceptually, may be looked upon as performing the same function. Lactation capacity available is initially expressed in percentage until it is multiplied by the genetic potential (GMLKL). Figure 8 represents the ALC curve. For this model the development stage is the first 30 days of lactation, with day 30 being the lactational peak provided there are no

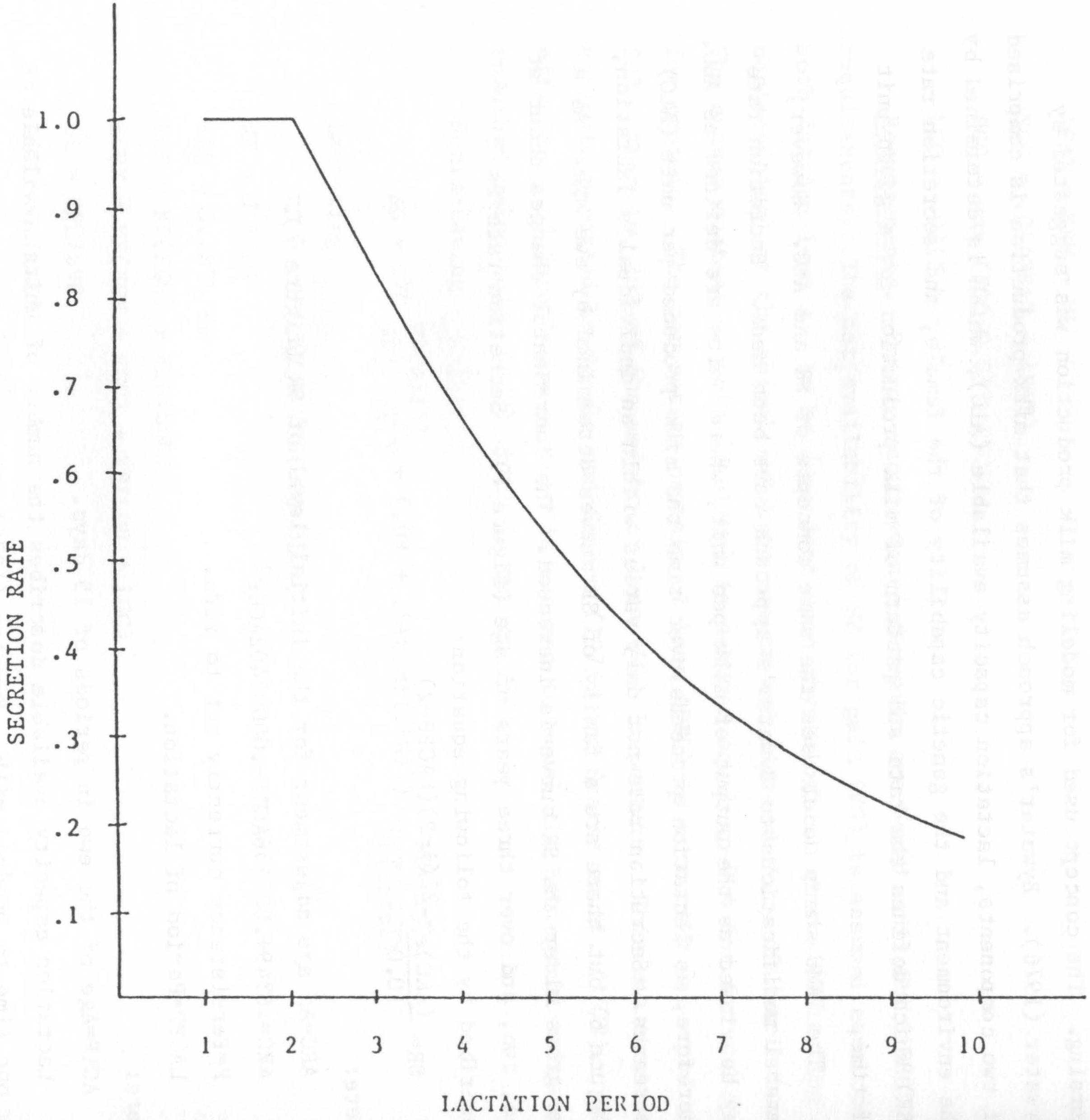

Figure 6. The secretion rate pattern for a mature ewe.

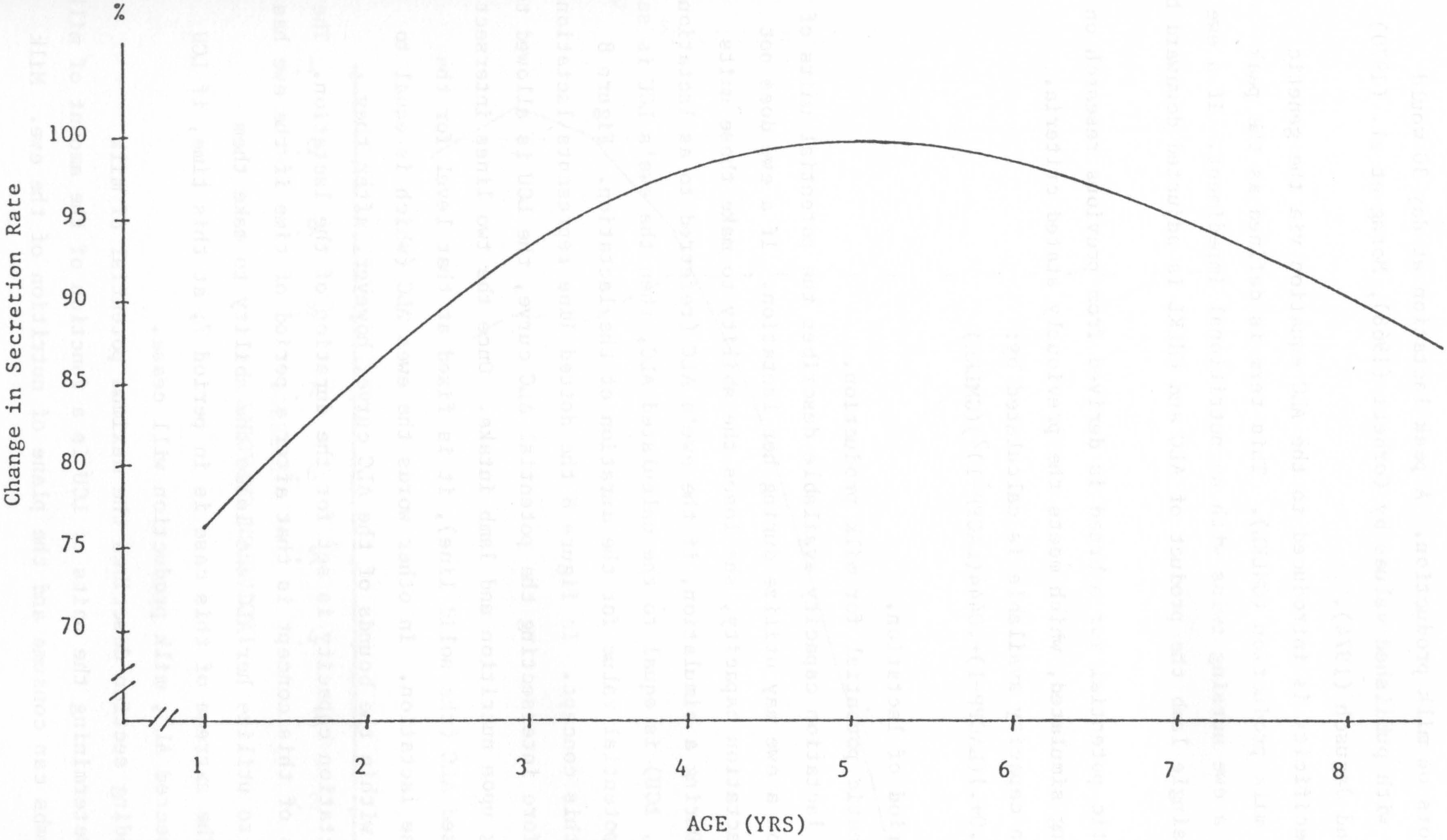

Figure 7. How ewe age will alter secretion rate.

limiting factors on milk production. A peak lactation at day 30 would closely agree with published values by Corbett (1968), Morag et al. (1970) and Geentry and Jagusch (1974).

Breed specificity is introduced to the ALC equation via the genetic potential for milk production (GMLKL). This term is defined as the peak production of a ewe nursing twins with no nutritional impediment. If a ewe is nursing a single lamb the product of ALC and GMLKL is adjusted downward by 25%.

The genetic potential for a breed is derived from previous research on the breed being simulated, which meets the previously stated criteria.

Lactation capacity available is calculated by:

$$ALC=(1.0+.1(LACPP-1)-.0444(LACPP-1)^2)(GMLKL)$$

where:

LACPP=Period of lactation.

GMLKL=Genetic potential for milk production.

The curve for lactation capacity available describes the potential units of milk production a ewe may utilize during her lactation. If a ewe does not utilize her lactation capacity, she loses the ability to make these units functional. During a simulation, if the ewe's ALC (referred to as lactation capacity used, LCU) is equal to the calculated ALC, then the ewe's LCU is set equal to the potential value for the duration of the lactation. Figure 8 demonstrates this concept. In figure 8 the dotted line represents lactation of a ewe. Before intersecting the potential ALC curve, the LCU is allowed to vary depending upon nutrition and lamb intake. Once the two lines intersect at the idealized ALC (the solid line), it is fixed at that level for the duration of the lactation. In other words the ewes ALC (which is equal to LCU) can vary within the bounds of the ALC curve, however, after they intersect, lactation capacity is set for the duration of the lactation. The major emphasis of this concept is that after a period of time if the ewe has not been able to utilize her ALC she loses the ability to make them functional. The extreme of this case is in period 7; at this time, if LCU has not intersected ALC, milk production will cease.

The preceding section describes the maximum potential of milk production. Determining the units of LCU is a function of the amount of milk the lamb or lambs can consume and the plane of nutrition of the ewe. Milk

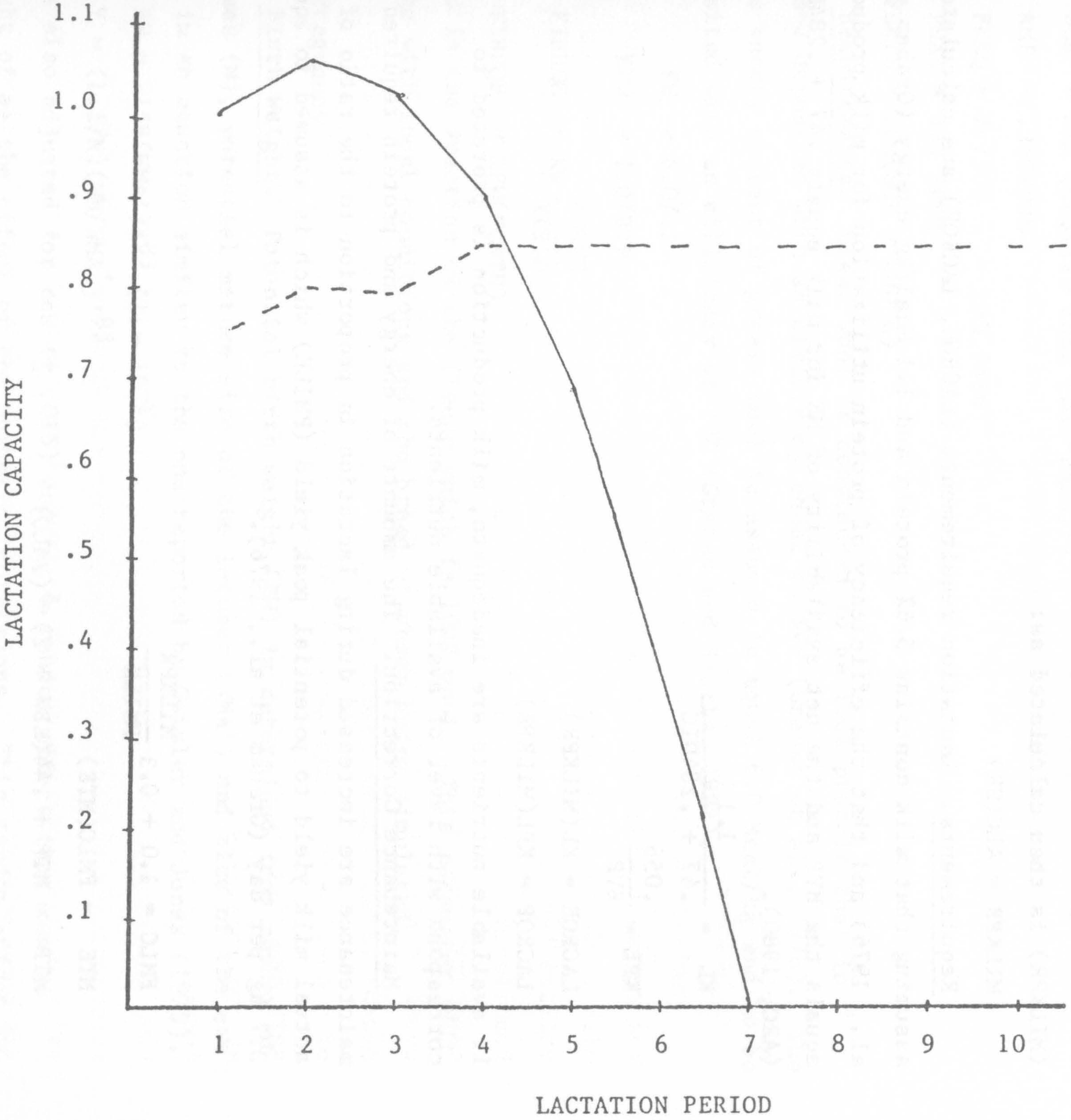

Figure 8. The potential lactation capacity (solid line) and the actual lactation capacity of a simulated ewe.

taken from a ewe by hand is treated in the same way as that consumed by a lamb except, of course, the lamb does not receive the nutrition.

The steps which interface these variables are as follows: First, an estimate of ALC is determined for a particular breed. At the start of lactation the LCU is estimated from the intake capacity of the lamb or lambs. If LCU is greater than ALC, LCU is set equal to ALC. Milk production (MILKPR) is then calculated as:

$$\mathrm{MILKPR} = \mathrm{ALC(SR)}$$

Requirements. Lactation requirements (LACRQE, LACRQP) are calculated by assuming that milk contains 5.6% protein and 1.1 Mcal/kg energy (Graham et al., 1976) and that the efficiency of protein utilization for milk production equals the BVP and the net availability of ME for milk equals .47 + .284DIG, (ARC, 1980).

$$\mathrm{KL} = \frac{1.1}{.47 + .284\mathrm{DIG}}$$

$$\mathrm{KPL} = \frac{.056}{\mathrm{BVP}}$$

$$\mathrm{LACRQE} = \mathrm{KL(MILKPR)}$$

$$\mathrm{LACRQP} = \mathrm{KPL(MILKPR)}$$

If available nutrients are inadequate, milk production is prorated to correspond with level of available nutrients.

Maintenance Correction. The amounts of energy and protein required for maintenance are increased during lactation in proportion to the ratio of actual milk yield to potential peak yield (PMILK) which is assumed to equal 3.7 kg per day (Graham et al., 1976).

$$\mathrm{FMLC} = 1.0 + 0.3\,\frac{\mathrm{MILKPR}}{\mathrm{PMILK}}$$

$$\mathrm{MTE} = \mathrm{FMLC(MTE)}$$

$$\mathrm{MTP} = \mathrm{MTP} + .44(\mathrm{EBW} + 2)^{.5}(\mathrm{FMLC})$$

d. Fiber Production

Potential. Genetic potential for clean wool growth (GWOOL, g/day) is adjusted for photoperiodicity (SCR), age and degree of maturity (UCR). The photoperiod effect is taken from Nagorcka (1979) and requires specification of amplitude (AMP) of seasonal differences (distance from equator effect), frequency (FREQ) of pattern (once/year) and time of peak growth (PHAS, mid-June in Northern Hemisphere). The adjustment for age and degree of maturity is taken from a model by Christian et al. (1978).

$$\mathrm{UCR} = (1 + e^{-165(\mathrm{AGEP}-1)})(\mathrm{WM}/\mathrm{WMA})^{.67}$$

$$\mathrm{SCR} = \mathrm{AMP}\ (\cos(120\ \mathrm{FREQ}\ (\mathrm{DAY}-\mathrm{PHAS})))$$

$$\mathrm{AMP} = .35\mathrm{GWOOL}$$

$$\mathrm{FREQ} = 2\pi/360 \qquad \pi = 3.1416$$

$$\mathrm{PHAS} = 165\ \mathrm{FREQ}$$

$$\mathrm{FGRTH} = \mathrm{UCR}(\mathrm{SCR} + \mathrm{GWOOL})$$

Requirements. Clean wool is considered to be 100% protein that is assumed deposited with an efficiency equal to BVP (Graham et al., 1976). The gross energy content of grease wool is assumed to equal 6.0 Mcal/kg and to be deposited with an efficiency of 20% (Graham and Searle, 1982).

$$\mathrm{KW} = 6.0/.2$$

$$\mathrm{KPW} = 1.0/\mathrm{BVP}$$

$$\mathrm{FIBRQE} = \mathrm{KW}\,\frac{\mathrm{FGRTH}}{\mathrm{YIELD}}$$

$$\mathrm{FIBRQP} = \mathrm{KPW}(\mathrm{FGRTH})$$

Yield is the fraction of the fleece which is 100% wool. This parameter will change with local conditions and the breed of sheep being simulated.

e. Pregnancy

Birth Weight. Potential birth weight (BW) is determined from number of fetuses (N), potential mature size of the fetuses (WMA') and size of the ewe (WM) in an equation similar to the one reported by Geisler and Jones (1979).

$$\mathrm{BW} = .158(\mathrm{WMA}')^{.83}\ (1 - 10^{-Y})$$

$$Y = (1.1/N)(\mathrm{WM}/\mathrm{WMA}')^{.83}$$

BW is also adjusted for sex ($\pm$ .015) and for a random effect that can be thought of as the effect of the number of cotyledons. This random effect is necessary in order to simulate birth weight differences between twin-born lambs of the same sex.

males,

$BW_m = 1.015BW$

females,

$BW_f = .985BW$

$R_x = N(1.0, .04)$

$BW' = R_x(BW_m \text{ or } BW_f)$

Conceptus Growth And Requirements. Expected conceptus growth rate (DCW) is calculated based upon day (DAY) of gestation and total BW of all fetuses (Graham et al., 1976) and accumulated by 15-day period.

$$DCW = \sum_{d_1}^{d_2} .0000388 \frac{\Sigma BW}{4.9} DAY^{1.6}$$

Energy and protein requirements for conceptus maintenance (RME, RMP) are based upon conceptus weight (CW) at the beginning of the period. Energy and protein requirements for conceptus growth (RGE, RGP) are calculated daily and averaged for the period. The net availability of ME for conceptus growth is assumed to be 0.7. Protein is assumed to be deposited with an efficiency equal to BVP.

$RME = .079\ CW$

$$RGE = \frac{1}{15} \sum_{d_1}^{d_2} \frac{.00107 \frac{\Sigma BW}{4.9} DAY^{2.66}}{4184\ KLNG}$$

$KLNG = .7$

$RMP = .0164RME$

$$RGP = \frac{1}{15} \sum_{d_1}^{d_2} \frac{.000018375 \frac{\Sigma BW}{4.9} DAY^{2.79}}{1000\ BVP}$$

Mammary Gland Growth. Mammary gland weight (MGW) is assumed to increase (DMGW) from .35 kg on day 105 of gestation through day 30 of lactation. Growth rate is calculated separately for single and multiple births from estimates provided by Rattray (1974).

$$DMGW = C_x\ (MGW - MGWI)\ \frac{MMGW - MGW}{MMGW}$$

where,

	multiple	single	
C	.095	.110	(coefficient)
MGWI	.20	.25	(initial wt)
MMGW	3.0	2.3	(maximum wt)

Requirements for mammary gland growth are calculated assuming 3 kcal/g gross energy density, 13% crude protein and the same efficiencies of depositing fat and lean as for weight gain.

$$RMGE = \frac{3.0\ DMGW}{KF}$$

$$RMGP = \frac{.13\ DMGW}{BVP}$$

Requirements for mammary gland growth are calculated only through parturition based upon the assumption that the postpartum requirements would be offset by tissue mobilized as the uterus regresses. No maintenance costs are made for the regression of the mammary gland. MGW is added to body weight and is thus included in the estimation of ewe maintenance requirements via the work equation.

Conceptus And Mammary Gland Growth. Conceptus maintenance requirements are added to ewe maintenance requirements and have equivalent priority of nutrient use. The actual amount of conceptus and mammary gland growth is dependent upon the fraction of their requirements (FRP) that is met after nutrients are partitioned among all requirements.

$MTE' = MTE + RME$

$MTP' = MTP + RMP$

$PRGRQE = RGE + RMGE$

$PRGRQP = RGP + RMGP$

$CW' = CW + FRP(DCW)$

$MGW' = MGW + FRP(DMGW)$

f. Total Requirements

Total requirements for energy and protein are summed including the nonessential component of growth (RQEX, RQPX).

$REQE = MTE + RGE + FIBRQE + LACRQE + PRGRQE$

$REQP = MTP + RGP + FIBRQP + LACRQP + PRGRQP$

$$RQEX = REQE + RGEX$$

$$RQPX = REQP + RGPX.$$

g. Feed Intake

The estimation of feed intake for sheep is at best difficult, especially when they are free grazing on heterogenous pastures. Ellis (1978) stated that "the inability to consistently predict voluntary intake of forage by ruminants reflects an incomplete quantitative understanding of the dynamic process". Prediction of intake deals with a vast array of variables that include forage selectivity, physiological status of the sheep, forage quality and its seasonal changes, and the availability of forage. These variables are in turn affected by stocking rate.

The TAMU model uses three factors to determine feed intake of a simulated sheep. The physical capacity of the rumen is the first of these. The volume of the reticulorumen and the rates of chemical and physical processes which determine the turnover of the content of this volume (Ellis, 1978) are reflected in the physical limit equation. For sheep in extensive production systems, volume and turnover rate are the influential factors determining feed intake, except for when forage availability is limiting. The second limiting factor is physiological limit which is expressed as a representation of metabolic control taking into account diet quality and animal condition. Both physical and physiological limits are calculated within the model. The availability of forage for grazing is the third factor determining intake. It is specified to the model on a 15-day (one period) basis.

Physiological limit (PSOL). As digestibility of the diet increases, voluntary intake is controlled less by physical factors and more by the energy requirements of the animal (Freer, 1981). Ellis (1978) stated that there is a transition point between gut fill control and metabolic control which varies with the animal's physiological status. Physiological limit is the metabolic control of feed intake. It is calculated as a function of the sheep's body condition, nutritional requirements and the quality of the diet. Physiological limits are expressed as:

$$PSOL = (REQE - RGE + MXEG/KG)/3.69$$

where

REQE = The total requirements for energy, and is calculated as the summation of the requirements for maintenance, lactation, gestation, fiber and growth.

RGE = The summation of essential fat and lean gains where each component is multiplied by its respective efficiency factor to determine the energy content of the gain. These values are 9.4 Mcal/kg for fat and 5.7 Mcal/kg for protein which is also multiplied by 20%, the percent protein in lean.

KG = An efficiency factor representing the net availability of ME for gain and is assumed to be equal for both fat and lean and to be dependent upon physiological status (lactating vs nonlactating) of the animal and upon the source and digestibility of nutrients.

MXEG = The maximum possible daily energy gain.

The MXEG equation describes the maximum daily rate of energy gain in mcal/kg/day when an animal's weight (EBW) equals its WM. This rate is adjusted downward for mature animals and as condition increases:

$$MXEG = .03EBW(WM/WMA)^{.10}(1.6+.75714(EBW/WM)-1.35714(EBW/WM)^2)$$

The quadratic portion of the MXEG equation sets the adjustment for condition. Where EBW/WM = 1, this portion of the equation equals 1; when condition (EBW/WM) > 1, this portion < 1; when EBW/WM < 1, this portion > 1. For nursing lambs, the amount of energy obtained from milk is deducted from PSOL to estimate feed intake for the physiological limit (R_1). Milk is assumed to have a gross energy concentration of 1.15 Mcal/kg with 98% digestibility (Graham et al., 1976). R_1 is set at a minimum of 1% of WM for nursing young.

$TM = a_1 MILK/3.69$; $a_1 = 1.12$; 3.69 is a conversion factor, Mcal ME to kg

$$R_1 = \frac{PSOL - TM}{DIG}$$

$$R_1 = MAX(R_1, 0.01WM)$$

Physical limit. The physical limit on feed intake (R2) corresponds to gut capacity and rate of passage. It is calculated as:

$$R2 = TAU\ (WM^{.75})\ e^{-5.8(.85-DIG)^2}$$

The equation allows intake to increase as the digestibility of the forage increases up to a maximum digestibility of .85, a limit suggested by Egan (1977). Intake will also increase as structural size increases. The form of this equation is similar to that used by Graham et al. (1976).

The variable TAU allows younger animals to consume feed as a larger portion of their metabolic size and is calculated as:

$TAU = .09799(WMA/WM)^{.3964}$

$TAU = MAX(TAU, .12)$

This adjustment has the greatest effect on intake for sheep between weaning and 2 years of age, which is consistent with Hadjipieris et al. (1965) report that wethers from 4 to 5 mo age had greater intakes than 5 yr old wethers.

The estimate for R_2 is not explicitly reduced for low protein diets, however the high correlation between digestibility and protein will indirectly result in adjustment for protein level for herbage. R_2 is increased in lactating ewes by FLACT, a function of milk production (MILKPR) and lactation period (LACPP) and PNCR, a derived correction factor for each period (lactation curve).

$R_2 = FLACT\ (R_2)$

$FLACT = PNCR\ \frac{MILKPR}{MILKP}$

MILKP = the potential peak milk production

where,

LACTATION PERIOD:	1	2	3	4	5	6	7	8	9	10
PNCR:	1.3	1.65	1.6	1.55	1.5	1.4	1.3	1.2	1.1	1.0

Feed intake of a ewe is reduced by the developing fetus in the latter stages of pregnancy. Forbes (1969) found a negative relationship between the volume of rumen contents and the volume of abdominal contents. His results showed that after 120 days of pregnancy, intake is progressively reduced as pregnancy advances.

After the seventh 15-day gestation period (PGEST), R_2 is restricted for all ewes except mature ewes carrying singles (NFET = 1).

$RSTRC = a_5\ ((1-WM/WMA)/.4)+(NFET-1))(PGEST-1)$

$a_5 = .0333$

$R_2 = (1-RSTRC)R_2.$

Availability. The maximum amount of feed available to a mature ewe (AV, kg/head/day) is set externally for each period (see section on Simulation Parameters). It is adjusted downward in immature sheep.

$$R_3 = AV(WM/WMA)^{a6}, \qquad a_6 = .15$$

Energy And Protein Intake. Total energy intake (DME, Mcal ME) equals energy from dry matter intake (DM) plus energy from milk intake.

$$DM = MIN\ (R_1,\ R_2,\ R_3);\ R_1 = \text{physiological limit},$$

$$R_2=\text{physical limit},\ R_3=\text{availability adjusted for immaturity}$$

$$DME = DIG(DM) + TM$$

The amount of crude protein available for absorption in the small intestine (DP, kg digestible protein) is estimated from ME and crude protein intake (Hogan and Weston, 1981) of feed and added to that obtained from milk (CPM). Milk is assumed to be 5.6% protein with 100% digestibility.

$$CPM = .056MILKPR$$

$$DP = .00494(28.3(CP)DM + 29DME -5.2) + CPM$$

It has been well documented that sheep are selective grazers utilizing grass, forbs and browse. Grazing behavior has not been included in the model as an interactive component, but instead is accounted for in the specification of the crude protein and digestibility which are model inputs.

h. Tissue Mobilization

Basis. Body tissue, if available, is mobilized if either DME or DP are inadequate to meet an animal's nutrient requirements for maintenance, fiber, gestation, lactation and essential growth. Tissue is not mobilized to meet requirements for the normal and compensatory (i.e., nonessential) components of growth. The efficiency of using the energy stored in lean (KLNM) and fat (KFM) is assumed to be 100% when used for maintenance. Hence, for accounting purposes, the gross energy content of the tissue is divided by the net availability of ME for maintenance (KM).

$$KFM = \frac{9.4}{KM}$$

$$KLNM = \frac{5.7\ PPL}{KM}$$

Consequently, the efficiency of utilizing mobilized energy for requirements other than maintenance is equal to the ratio of the efficiency of energy use for production (KG, growth; KL, lactation; KW, fiber; KPG, gestation) to KM.

Mobilized lean is assumed to have the same percentage protein as lean deposited during growth. The efficiency of utilizing protein from lean is assumed to be 100% for all uses; hence, for accounting purposes, mobilized protein is divided by BVP (biological value of protein) to convert it to the units of dietary requirements.

The order of calculating the amount of tissue mobilized is (1) lean for protein, (2) lean and fat for energy, (3) fat for energy and (4) lean for energy. The amount mobilized in each step is subtracted from the maximum amount available.

Tissue Availability. Catabolism of tissue is dependent upon the availability of fat (AVFAT) and the availability of lean (AVLN). Both of these variables calculate the amount of non-essential tissue which can be mobilized per day.

$AVFAT = (AFAT-e_1(WM))/15.0$

where

$AFAT$ = total fat

$e_1 = .03$

$AVLN = (WL-(P1)XLN)/15.0$

where

WL = weight of lean

$P1$ = the amount of essential lean a sheep must have, $1.0-(.35\ WM/WMA)$

XLN = the expected lean of a sheep, $WM-XFAT$.

The following series of equations depict how lean and fat tissue are catabolized. Once available lean and fat are calculated and summed, the fraction of available fat (FPC) is found.

$FPC = AVFAT/(AVFAT + AVLN)$

The total tissue that can be mobilized daily (WMBMAX) to meet a part of maintenance energy requirements is calculated as

$WMBMAX=FPC(MTE/KFM)+(1-FPC)(MTE/KLNM)$

With WMBMAX known the maximum fat (FMBMAX) and lean (LMBMAX) that can be mobilized daily in a fasting animal is:

$FMBMAX = (FPC)WMBMAX$

$LMBMAX = (1-FPC)WMBMAX$

In a nonfasting animal, these maximum amounts are reduced in direct proportion to the ratio of nutrient intake to the requirements for maintenance, fiber, gestation, lactation and essential growth by the equations:

$$\text{ERATO} = (1.0-\text{RE}/(\text{REQE}))^{2-\text{MOBXTR}}$$

$$\text{LRATO} = (1-\text{RP}/(\text{REQP}))^{2-\text{MOBXTR}}$$

For nonlactating sheep, MOBXTR = 1 and will be explained in the next paragraph. The ratio of energy intake to requirements is, of course, used for adjusting fat mobilization; whereas, the lesser of the energy or protein ratios is used for adjusting lean mobilization.

$$\text{FMBMAX} = \text{ERATO (FMBMAX)}$$

$$\text{LMBMAX} = \text{MAX (ERATO(LMBMAX),LRATO(LMBMAX))}$$

The immobilizable portion of essential lean and fat (3%) components of WM sets an additional upper limit on fat (AVFAT) and lean (AVLN) available for mobilization.

$$\text{AVFAT} = \text{MIN }((\text{AFAT}-e_1(\text{WM}))/15,\ \text{FMBMAX})$$

$$\text{AVLN} = \text{MIN }((\text{WL}-P_1(\text{XLN}))/15,\text{LMBMAX})$$

Due to the increase of nutritional requirements during lactation, ewes in poorer condition (EBW/WM) are not able to catabolize tissue at the same rate or amount as those in better condition. This concept was incorporated by the following equation:

$$\text{MOBXTR} = \frac{e^{2(\text{actual condition - expected condition})}{}_{-1}}{e^{2(1-\text{expected condition})}{}_{-1}}$$

The effects of this equation are shown in figure 9. To completely understand the influence of MOBXTR one must examine how lactating ewes of different conditions (EBW/WM) will mobilize tissue when the ratio of intake to requirements is varied (figure 10). Figure 9 demonstrates how mobilization would be reduced for ewes with various conditions, figure 10 represents the values calculated from either the LRATO or ERATO equations.

Lean For Protein. If REQP exceeds DP, lean is mobilized for protein and dietary energy is increased by the energetic value of the mobilized lean (MBLN).

$$\text{MBLN} = \text{MIN (REQP-RP)/GL, AVLN)}$$

$$\text{AVLN}' = \text{AVLN - MBLN}$$

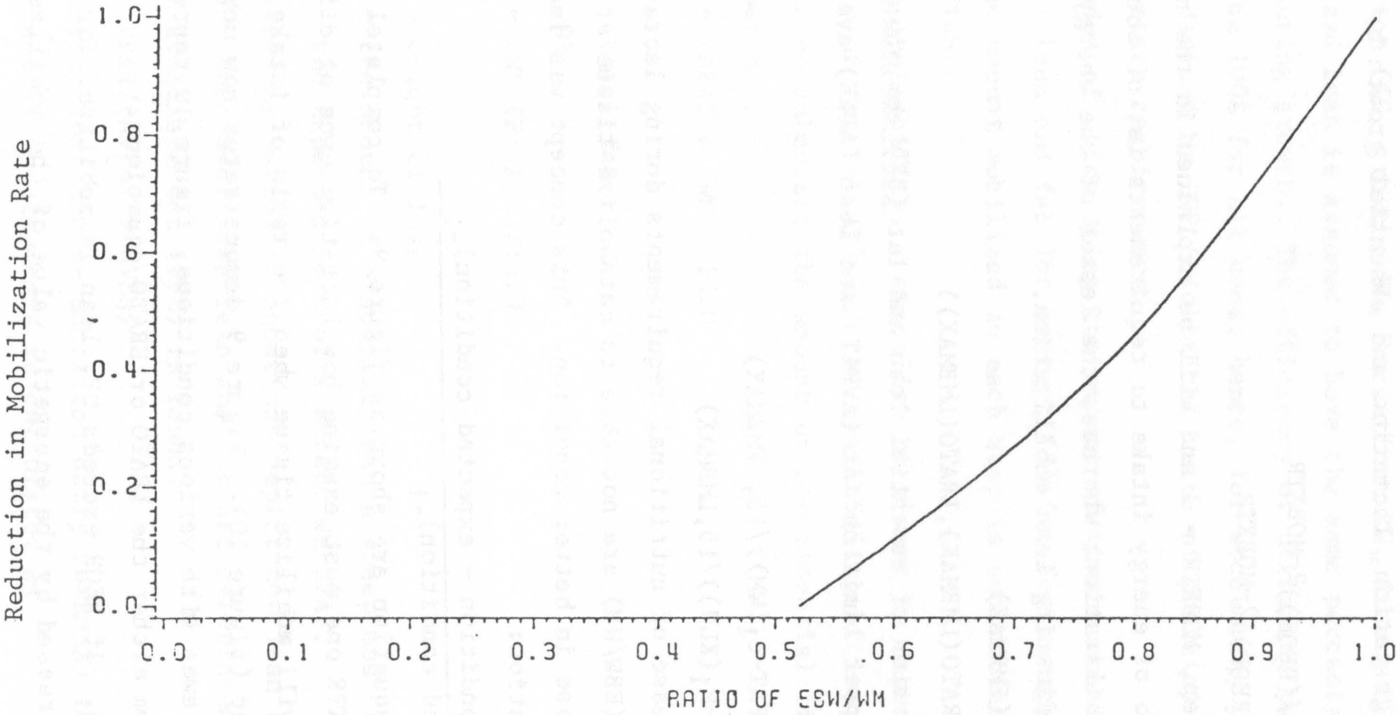

Figure 9. The reduction in tissue mobilization (MOBXTR) as a lactating female's body condition is lowered.

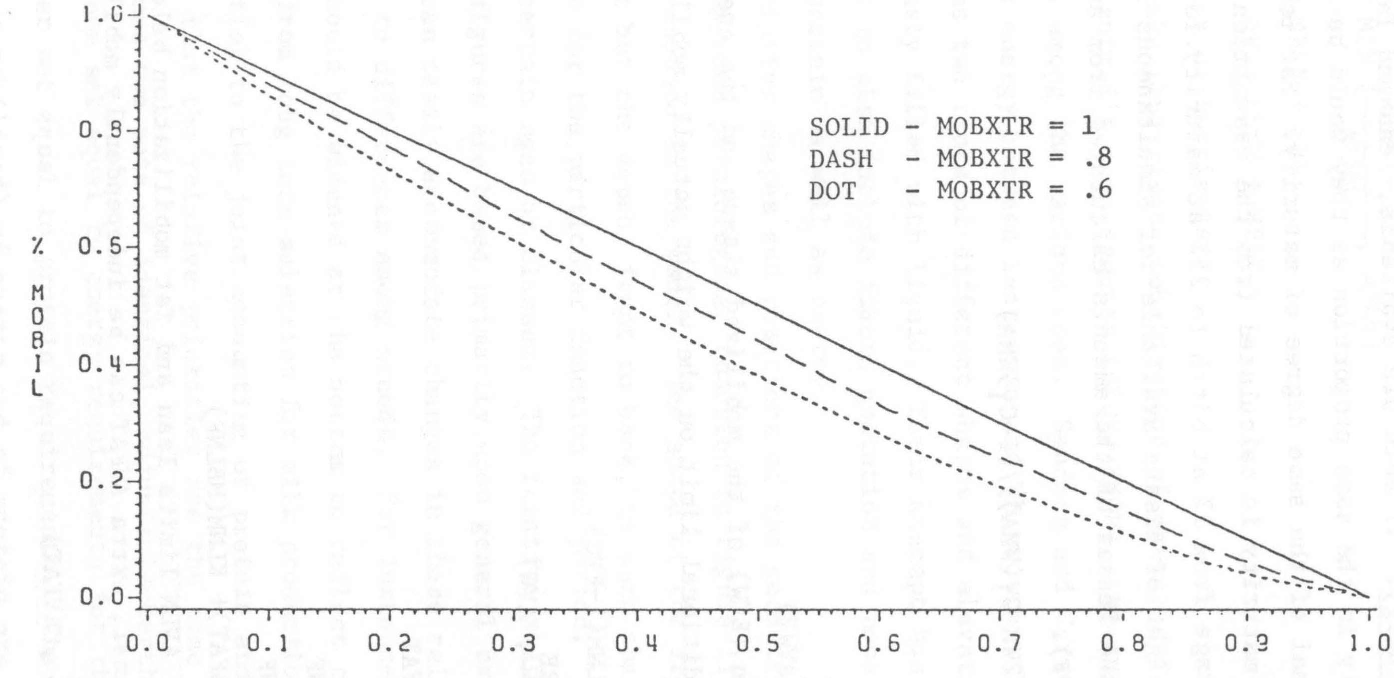

Figure 10. The intake/requirement ratio determining the percent of tissue mobilized to meet requirements of a lactating female. The different lines demonstrate how MOBXTR will influence mobilization rate.

$DP' = DP + GL(MBLN)$

$DME = KLNM(MBLN)$

Lean And Fat For Energy. If both are available, lean and fat may be mobilized simultaneously in the same proportion as they would be deposited in a normally growing animal of the same degree of maturity. Fat percentage (FPC) at any degree of maturity is calculated from the assumption of a linear increase in fat percentage from 3% at birth to 25% at maturity for animals in good condition. The weight of tissue available for simultaneous lean and fat mobilization (AVW) is the lesser of the amounts calculated from available lean (AVWL) or fat (AVWF).

$$FPC = .03 + .22((2WM-C_1(WMA))/(1-C_1)WMA)$$

$$AVWL = \frac{AVLN}{1-FPC}$$

$$AVWF = \frac{AVFAT}{FPC}$$

$$AVW = MIN\ (AVWL,\ AVWF)$$

The energy concentration (ECW) of the mobilized tissue and the energy deficit of the animal set an additional limit on the weight actually mobilized (MBW).

$$ECW = KFM(FPC)+KLNM(1-FPC)$$

$$MBW = MIN\ (\frac{REQE-RE}{ECW},\ AVW)$$

$$MBFAT = FPC(MBW)$$

$$AVFAT' = AVFAT - MBFAT$$

$$MBLNF = (1-FPC)MBW$$

$$AVLN = AVLN - MBLNF$$

$$MBLN = MBLN + MBLNF$$

$$RE' = RE + KFM(MBFAT)+ KLNM(MBLNF)$$

Fat For Energy. If AVLN limits lean and fat mobilization below that amount needed by the animal, extra AVFAT can be independently mobilized.

$$MBFX = MIN\ (\frac{REQE-RE}{KFM},\ AVFAT)$$

$$MBFAT' = MBFAT + MBFX$$

$$RE = RE + KFM(MBFX)$$

Protein For Energy. If AVFAT limits lean and fat mobilization below that amount needed by the animal, extra AVLN can be independently mobilized.

$$MBLX = MIN\left(\frac{REQE - RE}{KLNM}, AVLN\right)$$

$$MBLN = MBLN + MBLX$$

$$RE' = RE + KLNM + MBLX$$

i. Partition of Nutrients

If intake plus tissue mobilization of energy and protein (DME, DP) fail to meet an animal's requirements (REQE, REQP), the available nutrients are partitioned among the various uses. Sanders and Cartwright (1979a) partitioned energy between lactation and WM growth. They depicted this partition as two tanks of different shapes and elevations that are simultaneously filled with liquid. Their concept has been extended for the sheep model to also include fiber, gestation and nonessential growth and to partition protein as well as energy.

The relative shapes and positions of the geometric figures (containers) representing each physiological function in figure 11 depict the relative priorities assumed in the model. The shape of the front face of a container is constant but the depth, front to back, is such that the volume equals the requirement for the particular function and period. Containers may have zero depth for certain ages or classes. The relative shapes and positions of the different figures are based primarily upon general experience and intuition. The model can easily accommodate changes in these relative priorities to correspond to differences among breeds. For instance, the container for lactation could be widened at the bottom to reflect characteristics of breeds resulting from long term selection for milk production.

Essential to the joint accounting of protein and energy effects is the assumption that the relative priorities are the same for both. Hence, the model assumes two sets of identical, adjustable-depth containers with the volume of one set equal to energy requirements for that period and the volume of the other set equal to protein requirements. The total availability (intake plus mobilized) of energy and of protein are "poured" into the respective container sets. The set filled to the lowest level identifies the limiting nutrient. The fraction of the volume filled for each container in

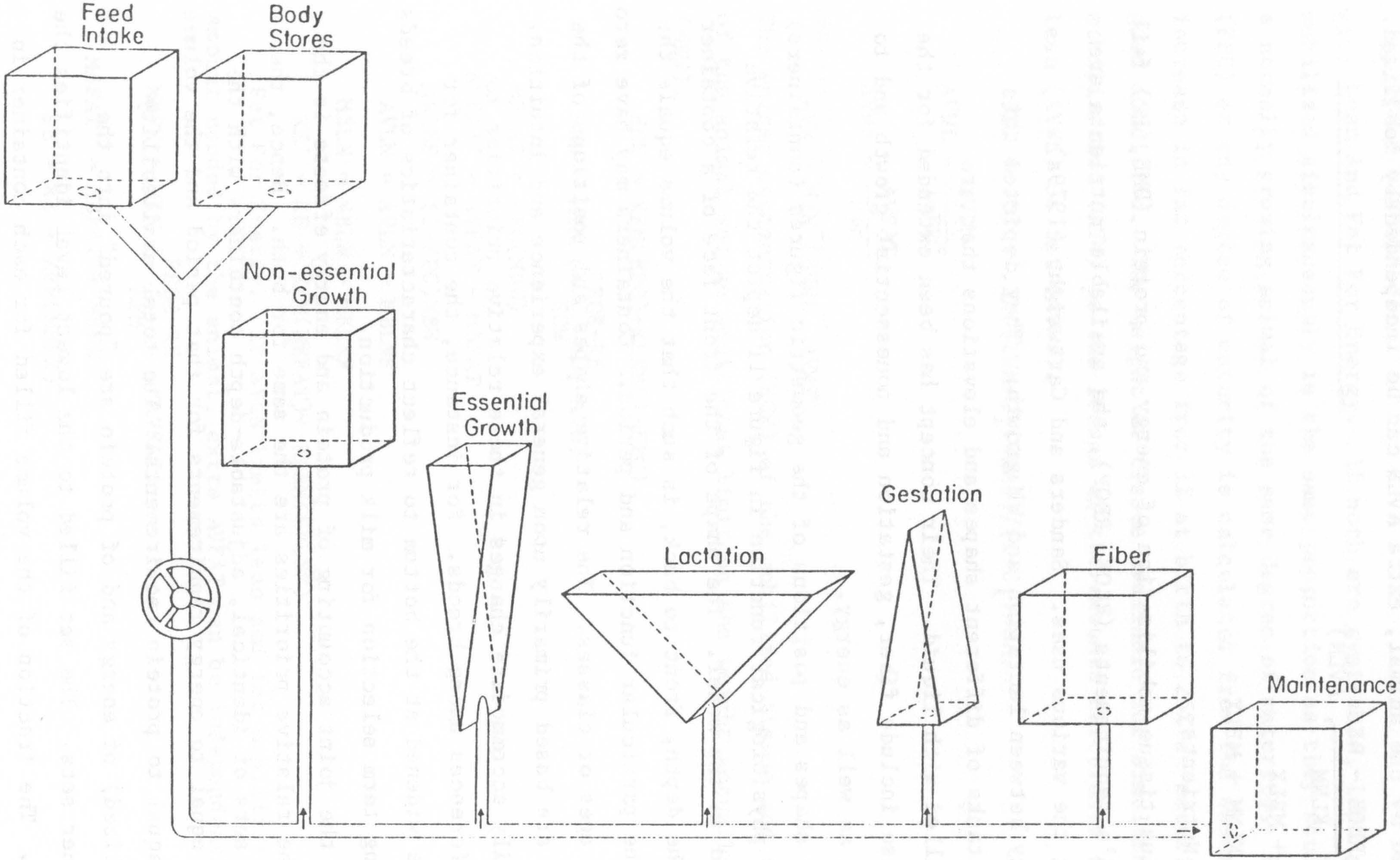

Figure 11. Partition of nutrients among different requirements.

this set determines the fraction of potential productivity attained for that function. If protein is the limiting nutrient, the energy above the level limited by protein is deposited as fat. The proportion of this extra energy that came from mobilized fat is redeposited with the same efficiency with which it had been mobilized (i.e., as if it had never been mobilized).

j. Update Phenotype

Protein and energy requirements are recalculated based upon actual levels of production and amount of essential growth and subtracted from the amounts available from intake and/or tissue mobilization. The remaining amounts are used for nonessential growth and fat deposition. The ratio of nonessential lean gain to nonessential fat gain can not be greater than the expected ratio of the "normal" components of gain (LGN:FGN) based upon the degree of maturity of the animal. Energy in excess of the amount required for this proportional lean and fat gain, is stored as fat.

Net gain or loss equals essential plus nonessential gain minus mobilized tissue. Weight, EBW, WM and WL are updated at the end of each 15-day period.

k. Reproduction

Research in the area of reproductive physiology has made it apparent that the reproductive process of the ewe is influenced by many factors. Numerous papers have been written on the effects of breed, nutrition, management and environmental stress on reproduction in sheep. From these results we can conclude that the reproductive process is a sequence of component events, each of which must occur at a particular level of intensity for a successful completion of the reproductive cycle. If one of these components falls below a critical level, then the level of reproduction will be reduced or, in severe cases, the reproductive processes will be terminated.

The general approach in modeling reproduction has been to account for many of the components which exert an influence on reproduction. Once these components were identified, mathematical functions were developed which described their effects. The functions developed depict the dynamic properties of the component by establishing the range of values and the rate of change between values within the range. These equations are each designed to demonstrate the behavior of a component independent of all other components assuming that the covariance between these components is zero, or that it is possible to disassociate the effects of one component from the other.

The fertility subroutine deals with two aspects of the reproductive process. First, it calculates the probability that a ewe may exhibit estrus, and if she has, the probability of conceiving. Secondly, provided the ewe has conceived, the ovulation rate is determined.

Estrus. The basic equations used to describe reproduction are expressed as the ewe's functional capability of exhibiting estrus for a current period. A series of equations determine if a given ewe exhibits estrus and is able to conceive. The equation

$$PEST = .85(CFW)(CFDW)(CFT)(CFM)(CFL)(CFS)$$

represents the probability of estrus (PEST) in ewes that did not exhibit estrus during the preceding 15-day period. The constant .85 sets the upper limit on the probability of a ewe initiating estrus which can occur when every factor equals 1.0, the maximum value. These remaining factors are correction factors each of which range from 0.0 to 1.0 but is usually less than 1.0, especially for stressing conditions (see below). The probability of estrus in animals that exhibited estrus during the preceding 15-day period is calculated as:

$$CCYC = (CFW^{.1})(CFDW^{.1})(CFS)$$

Conception. The probability of conception given estrus and breeding:

$$PCON = .75(CFT^{.5})(CFW^{.2})(CFDW^{.2})(MB)(CFS^{.2})$$

where:

MB = The specified management breeding season, with values of 0.0 or 1.0.

Combining the probabilities of CCYC and PEST for an open ewe, the form becomes:

$$ACC = CYCC(ACC + PEST)(1 - ACC)$$

where

ACC = ACC from the previous period

The rate at which animals mature influences the initiation and cessation of their body functions. A sheep's maturing rate can influence the time at which it attains puberty. In American and British breeds, ewe lambs reach puberty when they reach 60 to 65% of their WMA or mature weight (Southam et al., 1971; Cedillo et al., 1977). However, Hawker and Kennedy (1978) indicated that Merinos reached puberty at 55% of their mature weight.

The purpose of incorporating the CFM is to prevent young ewes which are physiologically immature from cycling. Sanders (1974) showed how the age and weight related to a heifer attaining puberty. In sheep, within a breed, age and weight are factors influencing the age at puberty, but in addition, seasonality may be influential in determining when this event is initiated (Hulet and Price, 1974).

Dufour (1975) indicated that ewe lambs reached puberty more as a function of season than of a specific age. Furthermore, shortening day length may trigger estrus at a relatively constant calendar time, but, at varying ages and weights. This would cause lambs born late in the season to cycle at younger ages and lighter weights, than older and heavier contemporaries (Cedillo et al., 1977). Land (1978) proposed two genetic effects that control sexual maturation; one controls the response to a given photoperiodic change, given that an individual is sufficiently mature to respond, and a second that determines whether she is able to respond.

Age is an important component in attaining puberty. An animal's age provides an individual an opportunity to express its inherent potential for growth and maturation within its particular environment (Fitzhugh, 1976). Estimates of age at puberty were collected from a variety of sources. It was apparent from these data that breed and environmental effects influence the time when ewe lambs attain puberty. Estimates of age at puberty ranged from 157 to 400 days (Wiggins et al., 1970; Southam et al., 1971; Dickerson et al., 1975; Evans et al., 1975; Cedillo et al., 1977). Estimates which are close to the upper boundary of this range may be due to ewe lambs being born immediately prior to or during the breeding season. Ewe lambs which are born in the spring and early summer have been shown to display estrus between 160 and 250 days of age.

The third component of ewe lambs attaining puberty is weight. Estimates of weight at puberty are just as variable as estimates of age at puberty. They are subject to breed and environmental conditions. Reports by Foote et al. (1970) and Southam et al. (1971) exemplify these differences, in their reports, Rambouillet ewe lambs reached puberty at 41.8 kg and 55 kg, respectively.

The literature reviewed indicates that ewe lambs reach puberty from 40 to 60% of their mature weight. These estimates are within the ranges given by Sanders (1974). Using degree of a maturity as a basis, the following equation was derived:

$$\mathrm{CFM} = \frac{((\mathrm{WM}/.6\mathrm{WMA}) - .67)}{(1-.67)}$$

WM/WMA is the degree or fraction of maturity of the ewe lamb. The graph of this equation is shown in figure 12.

Correction Factor For Weight (CFW). The CFW is an adjustment for body condition of the ewe. As she loses body tissue (both fat and lean) the ratio of EBW to WM decreases resulting in a lower level of fertility. The CFW is a reflection of past nutritional levels. The equation for this correction is:

$$\mathrm{CFW} = \frac{e^{-6((\mathrm{EBW}/\mathrm{WM})-(\mathrm{MIN\ WT}/\mathrm{WM}))}_{-1.0}}{e^{-6(1-(\mathrm{MIN\ WT}/\mathrm{WM}))}_{-1.0}}$$

where

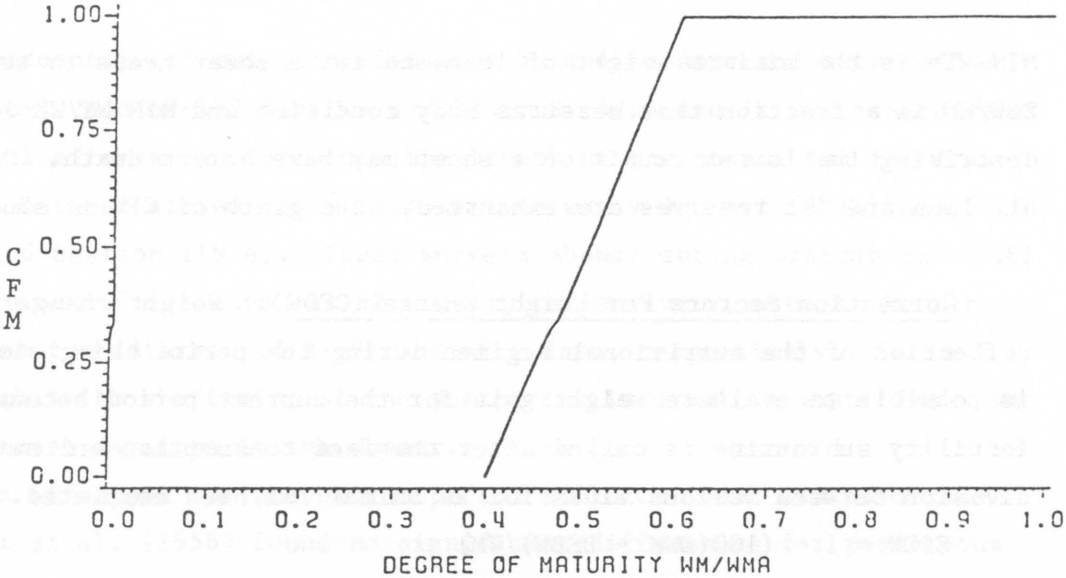

Figure 12. The change in CFM as an animal becomes more mature.

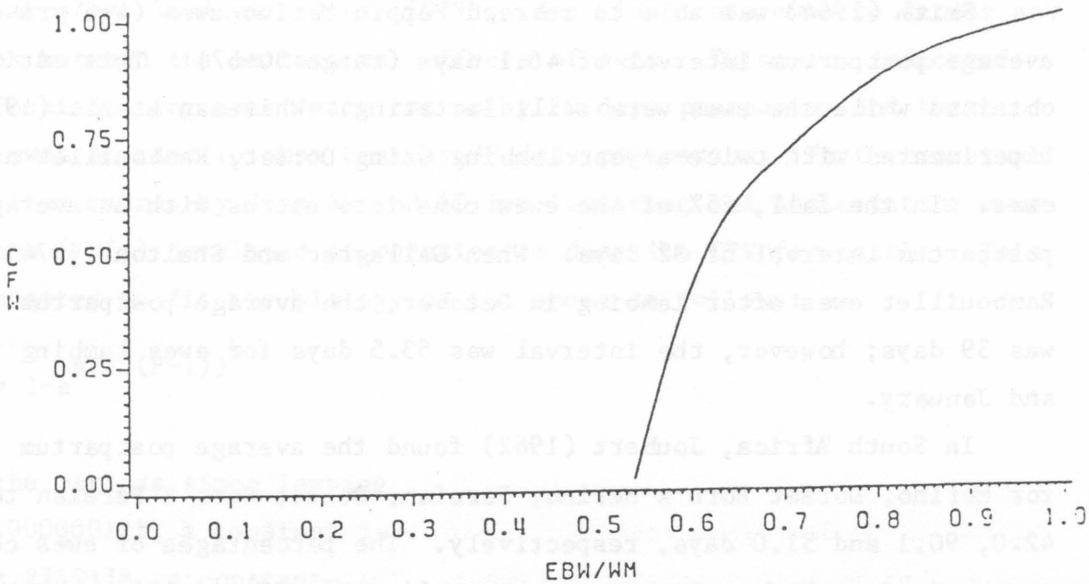

Figure 13. The change in CFW as the body condition of a female changes.

MIN WT= is the minimum weight of lean and fat a sheep needs to stay alive. EBW/WM is a fraction that measures body condition and MIN WT/WM is a fraction describing the lowest condition a sheep may have before death. At this point all lean and fat reserves are exhausted. The graph of CFW is shown in figure 13.

Correction Factors For Weight Change (CFDW). Weight change is a reflection of the nutritional regimen during the period being simulated. It is possible to evaluate weight gain for the current period because the fertility subroutine is called after the feed consumption and nutrient division between various sinks for an animal has been completed.

$$CFDW = 1 - (100(DWM - DEBW)/WM)$$

where

DWM = the change in WM for the current 15 day period

DEBW = the change in EBW for the current 15 day period.

Correction Factor For Time Since Parturition (CFT). This correction accounts for the length of time taken for the involution of the uterus in preparation for the next pregnancy.

Smith (1964) was able to rebreed Peppin Merino ewes (4-6 yrs old) at an average postpartum interval of 46.1 days (range 30-67). This estimate was obtained while the ewes were still lactating. Whiteman et al. (1972) experimented with twice-a-year lambing using Dorset, Rambouillet and D x R ewes. In the fall, 85% of the ewes came into estrus with an average postpartum interval of 32 days. When Gallagher and Shelton (1974) rebred Rambouillet ewes after lambing in October, the average postpartum interval was 39 days; however, the interval was 53.5 days for ewes lambing in December and January.

In South Africa, Joubert (1962) found the average postpartum interval for Merino, Dorset Horn x Merino, Persian, Dorset Horn x Persian to be 103.3, 42.0, 90.1 and 51.0 days, respectively. The percentages of ewes coming into estrus during the breeding season were 64, 100, 82 and 100, respectively. In a later study with Dorper sheep, it was found that after autumn lambing, the postpartum interval was 61.8 days (Joubert, 1972).

Attempts have been made to rebreed Karakul ewes (with lambs removed) during the peak of their breeding season. The reported average postpartum interval was 27.5 days (Nel, 1965). However, the conception rates remained low. The percentage of ewes conceiving at 30 and 40 days and between the ranges of 40-59 and 60-109 days were 7.7, 27.8, 42.9 and 72.2, respectively.

Seasonal effects can influence the length of the postpartum interval. Differences between spring and summer were shown by Joubert (1972) and Gallagher and Shelton (1974). These workers showed spring postpartum intervals to be 117-129 days and 62.8 days, respectively, with a shorter summer postpartum interval of 81-97 and 58.8 days, respectively. It is speculated that the shortening of the postpartum interval is most likely due to the decreased daylight in the summer.

A third effect on the postpartum period is lactational status of the ewe. Torell et al. (1956) found no significant differences for postpartum interval for Rambouillet x Merino ewes with or without lambs. These two groups had postpartum periods of 55.4 and 50.3 days, respectively. It should be noted that these ewes lambed in the spring, therefore it is likely that the effects of season and lactation are confounded. Restall (1971) found in fall lambing ewes that nonlactating ewes had a shorter postpartum period than lactating ewes. The nonlactating ewes exhibited behavioral estrus and ovulation at 17 vs 34 days. Ford (1979), used Finn cross ewes to detect any differences between the lactational effects of ewes. This work indicated that some nonlactating ewes reach estrus by 20 days postpartum and that lactating ewes started to show heat by 30 days postpartum. Furthermore, all ewes exhibited estrus by days 60 and 45 for lactating and nonlactating ewes.

Sanders (1974) developed an equation to describe CFT for cattle. This form was adapted to fit the biology of the sheep as follows:

$$\mathrm{CFT} = 1-e^{a(15(P-1))^{b}}$$

where

P = the periods since lambing

a =-.000000125, a constant

b =-5.2740378, a constant

This equation allows 45% of the ewes to cycle 30 days after parturition and all of the ewes to cycle at 45 days postpartum provided all other correction factors are 1.0 (figure 14).

Correction Factors For Lactation (CFL). As previously discussed, there is a lactational influence upon estrus. The correction factor for lactation

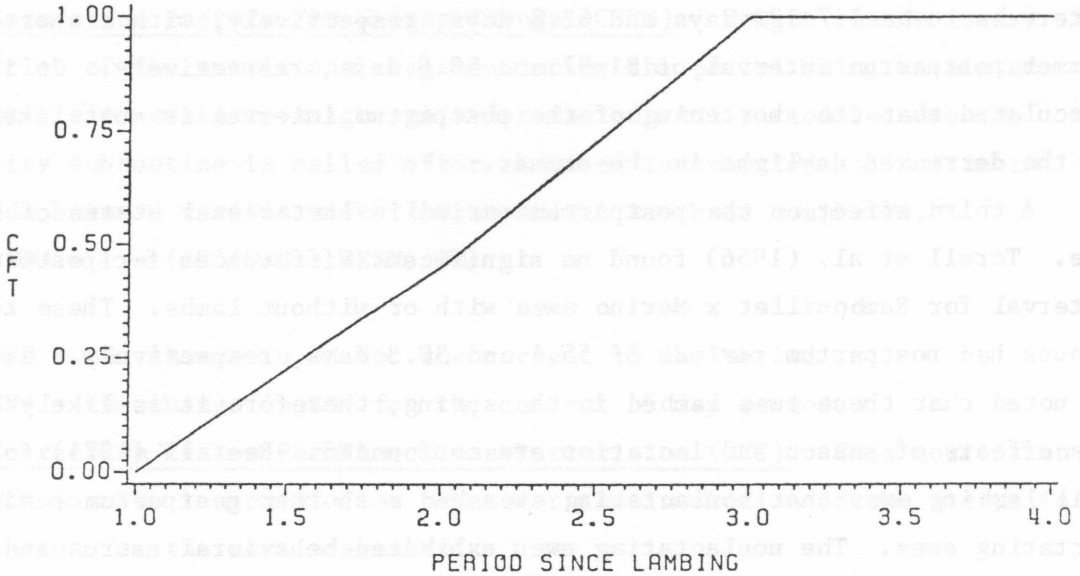

Figure 14. The correction factor for postpartum interval (CFT).

(CFL) has been accounted for in the model as a constant of .95 for all lactating ewes. For nonlactating ewes this value is 1.0. At the present time a functional relationship for CFL has not been developed for the sheep model. This is, in part, due to a paucity of data. Boyd (1983) has recently developed a function to describe this event in beef cattle and perhaps this equation can be incorporated into the sheep and goat models.

Correction Factors For Season (CFS). For many breeds of sheep the cyclic change in photoperiod (seasonality) is the main determinant keying estrus activity. Breeds vary not only in breeding season length but also in the intensity of their cycles. The photoperiodic response within a breed will also be altered with a change in latitude or the light/dark ratio; these responses were discussed in the comprehensive review by Hafez (1952).

As stated earlier, Land (1978) proposed that the response of ewes to photoperiodic changes are genetically controlled. This response is believed to be mediated via the pineal gland and its secretion of melatonin (Rollag et al., 1978; Barrell and Lappwood, 1979). CFS is therefore a genetic parameter specified in the model as input as a characteristic of the cyclic pattern of the breed in the environment that is being simulated. The input required for a breed is a set of 24 values (one for each period of the year) each of which ranges from 0 to 1.0. This method provides the capability to specify the exact cyclic pattern for the sheep or goats simulated. As an example of how photoperiod influences breeding season, the response of two sets of Rambouillet ewes in different latitudes is given in figure 15. The CFS array which could be constructed from these data is presented in table 1. These values would then be used in calculating PEST and CCYC.

Ovulation Rate. Prolificacy in sheep has been shown to be genetically mediated (Turner, 1969; Land, 1981; Piper and Bindon, 1982). A major component in the chain of physiological responses resulting in multiple births is ovulation rate. The sheep model utilizes the genetic differences in ovulation rate to simulate breed differences in prolificacy. In the development of a method to assign an ovulation rate (OVR), as a genetic parameter for the breed being simulated, several factors were considered. One important consideration was embryonic mortality. In 1969, Edey reviewed the literature on embryonic mortality. Basal embryonic losses were found to

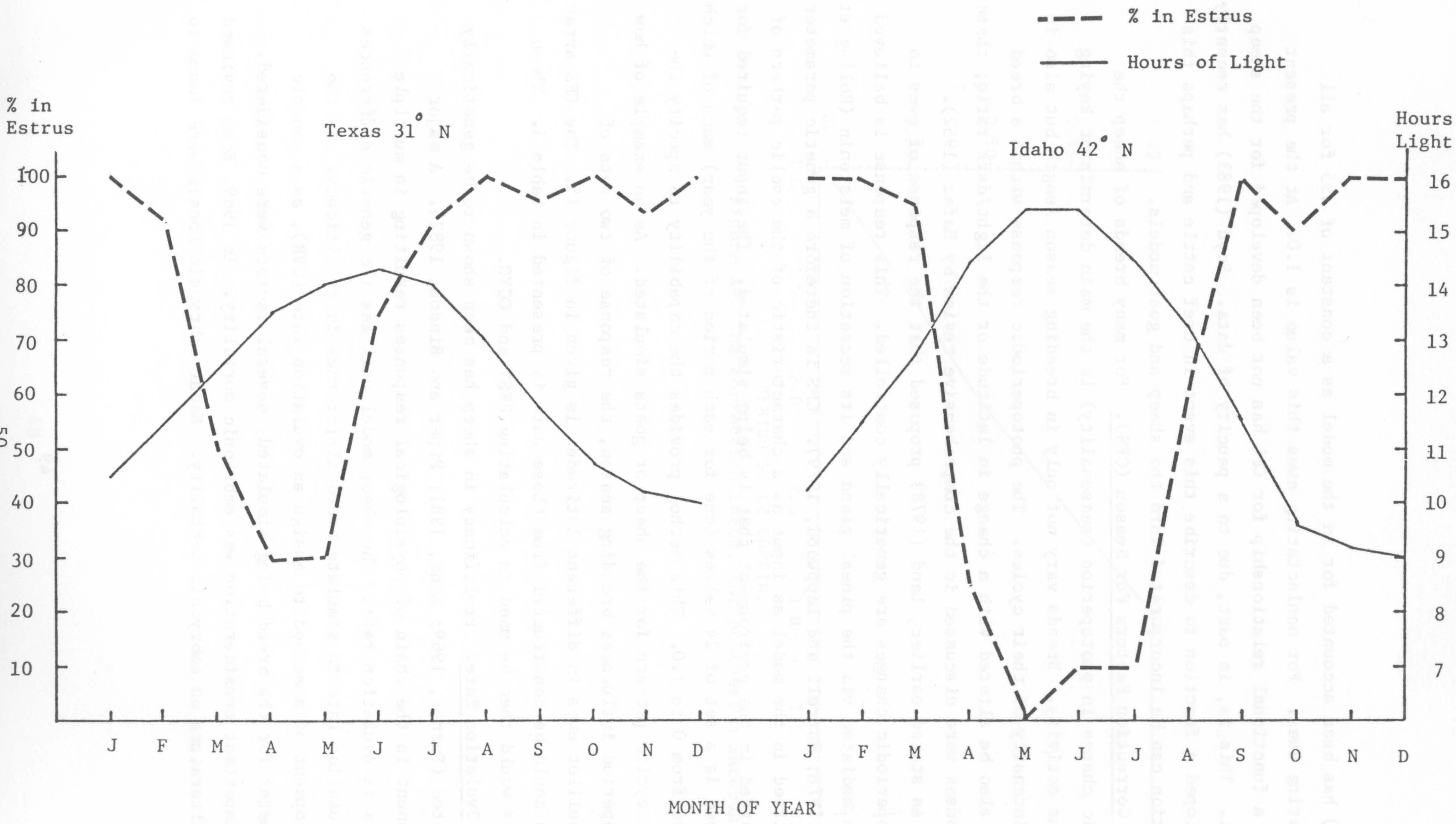

Figure 15. The estrus response of Rambouillet ewes to 2 different photoperiods (Shelton et al., 1973).

TABLE 1. THE ARRAY OF VALUES FOR THE CORRECTION FACTOR FOR SEASON.

	MONTH											
Lactation	J	F	M	A	M	J	J	A	S	O	N	D
Texas	1.0	.9	.5	.3	.3	.78	.95	1.0	1.0	1.0	1.0	1.0
Idaho	1.0	1.0	.95	.2	0.0	.1	.1	.98	1.0	1.0	1.0	1.0

range from 20 to 30%. The greatest loss of embryos was found to occur in the first month of pregnancy. These losses were attributed to genetic abnormalities. Further experimentation was conducted to determine when embryonic loss was at its peak. The results revealed that one-half of all losses were before day 13 with most of the remainder occurring by day 18 (Edey, 1976). Work by Coop and Clark (1969) confirmed Edey's results in that the majority of embryonic loss was before day 18 of pregnancy.

Because the sheep model uses a 15-day time step it was not feasible to directly model this important reproductive loss. However, the loss was accounted for by considering the genetic parameter of ovulation rate as an effective ovulation rate; that is, the value used as OVR is adjusted downward by 20% to compensate for the mortality of unimplanted embryos.

Two approaches can be taken to estimate OVR. First, if the actual ovulation rate of the breed to be simulated is known, this value may be reduced by 20% and then used as a model input. Second, if lambing rates (lambs born/ewes pregnant) for the breed are known and there has been no environmental stress on the ewes, this value may be used directly as OVR. In the case where environmental conditions are harsh, the lambing rate should be adjusted upward to account for additional embryonic deaths and abortions.

Calculating the ovulation rate in the model (RATE) is, like other components of reproduction, an interactive process. The manner in which ovulation rate is calculated represents this concept:

$$\mathrm{RATE} = \mathrm{OVR}(\mathrm{CFW}^{.7})(\mathrm{CFDW})^{(1.0-\mathrm{CFS})}\mathrm{CFS}^{.7})(\mathrm{CFC}^{.5})(\mathrm{CFM}^{.5})$$

The RATE equation combines the effects of breed, seasonal variation, body condition and maturity. Periodic environmental (nutrition) changes are mediated through the CFDW portion of the equation. The effects of current weight change (CFDW) can be over-ridden when photoperiod effects are optimum; i.e., CFS = 1.0.

Edey (1968) showed how increases in body weight (therefore condition) increased ovulation rate. However, this response was sigmoidal in shape and not linear as reported by Coop (1962). Gunn and Doney (1975) reported significant differences in ovulation rate for ewes which had three different condition scores. Earlier work by Gunn et al. (1969) led the authors to conclude that there was a threshold of body condition above which the level of food intake has no effect on ovulation rate and below which food intake is important.

Reeve and Robertson (1953) reported that maturity, measured as age, influenced ovulation rate. With four breeds of sheep, they showed how there is a curvilinear response in ovulation rate as ewes grow older. Not only is there an increase in ovulation rate to approximately 5 years of age, but thereafter there is a decrease in ovulation rate at a slower progression than the increase.

Gunn et al. (1969) found an interaction between age and condition for ovulation rate. They stated that the ovulation rate of young ewes was more sensitive to the influence of body condition than of older groups of ewes.

Reeve and Robertson (1953) showed that season influenced ovulation rate. As the middle of the breeding season is approached, the percentage of twins born from ewes bred at this time increases; at the extremes of the breeding season the percentage of multiple births declined.

Once RATE has been calculated the following equations are used to determine the actual ovulation rate:

$TRP = (e^{.7(RATE-1.0)}-1)/(e^{2(.7)}-1)$

$TWN = (RATE - 1) - 2\ TRP$

$SNG = (1 - TRP) - TWN$

where

$TRP = 3$ ova

$TWN = 2$ ova

$SNG = 1$ ovum

These equations generate numbers between 0.0 and 1.0. The values for TRP, TWN and SNG are then compared to a random number (RI) which is generated from a uniform distribution ranging from 0 to 1.0. The following IF statements show the final steps in calculating ovulation rate:

```
IOVR = 1
IF (RI > SNG),IOVR = 2
IF (RI > (1-TRP)),IOVR = 3
```

From this point the subroutine CONCV is called to initiate body parameters for the number of fetuses conceived.

1. Fiber Production

Potential. The model simulates wool production for breeds which grow wool. The genetic potential for wool growth (GWOOL) is similar to other genetic parameters used in the model in that it specifies maximum (or potential) wool growth per day for the simulated breed when all other factors influencing wool growth are at an optimal level.

Photoperiod Effect. Fleece growth is adjusted or modified by photoperiod (SCR) and age and degree of maturity (UCR). Nagorcka (1979) derived an equation describing the photoperiodic effect. For this equation, amplitude (AMP) of seasonal differences (distance from the equator), frequency (FREQ) of day light pattern (once/year) and time of peak growth (PHAS, mid-June in Northern Hemisphere, day 165; and mid-December in Southern Hemisphere, day 345) must be specified:

$$SCR=AMP(\cos(120(FREQ\ (DAY-PHAS))))$$

where

AMP=.35GWOOL; for 35 degree latitude

$FREQ=2\pi/360$ $\pi = 3.1416$

DAY=day of the year

PHAS=165 FREQ

Using the photoperiod reported by Shelton et al. (1973) the following example of wool growth for Rambouillet sheep in Texas and Idaho may be generated. The parameters used are:

GWOOL = .0076 kg given that a ewe shears 5.45 kg of grease fleece which has a yield of 50% thus producing 2.725 kg of clean wool which is divided by 360 to put wool growth on a per day basis.

AMP = .31(.0076) for Texas and .42(.0076) for Idaho; 31°N and 42°N are the latitudes, respectively.

$FREQ = 2\pi/360 - .0174533$

PHAS = 165 FREQ = 2.8797933

Figure 16 illustrates how photoperiod may affect wool growth. The effect on the same breed is illustrated for 3 latitudes: 15°N, 31°N and 42°N.

Age And Degree Of Maturity. The influence of age and degree of maturity are calculated by the following equation;

$$UCR = (1+e^{-.165(AGEP)-1})(WM/WMA)^{.67}$$

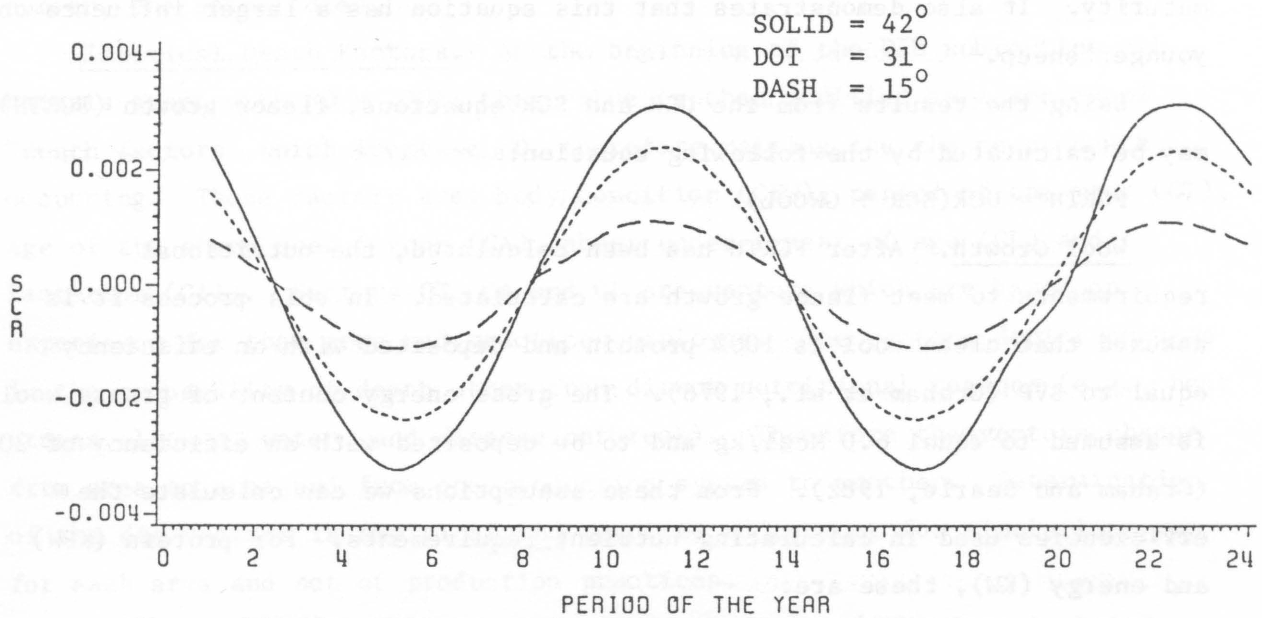

Figure 16. The influence of photoperiod on wool growth.

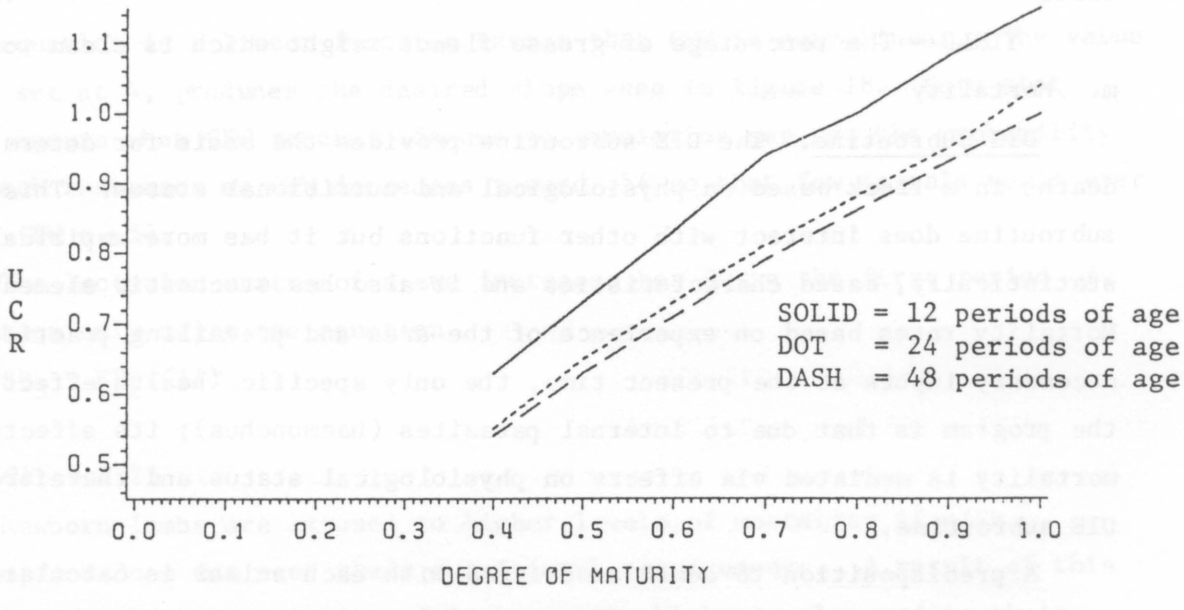

Figure 17. Age and maturity effects on wool growth.

Figure 17 shows how wool growth is adjusted for various ages and degrees of maturity. It also demonstrates that this equation has a larger influence on younger sheep.

Using the results from the UCR and SCR equations, fleece growth (FGRTH) may be calculated by the following equation:

FGRTH = UCR(SCR + GWOOL)

Wool Growth. After FGRTH has been calculated, the nutritional requirements to meet fleece growth are calculated. In this process it is assumed that clean wool is 100% protein and deposited with an efficiency equal to BVP (Graham et al., 1976). The gross energy content of grease wool is assumed to equal 6.0 Mcal/kg and to be deposited with an efficiency of 20% (Graham and Searle, 1982). From these assumptions we can calculate the efficiencies used in calculating nutrient requirements. For protein (KPW) and energy (KW), these are:

KW = 6.0/.20

KPW = 1.0/BVP

The nutritional requirements for energy (FIBRQE) and protein (FIBRQP) are calculated as:

FIBQRE = KW(FGRTH/YIELD)

FIBQRP = KPW(FGRTH)

where

YIELD = The percentage of grease fleece weight which is clean wool.

m. Mortality

DIE Subroutine. The DIE subroutine provides the basis for determining deaths in a flock based on physiological and nutritional status. This subroutine does interact with other functions but it has more empirically, or statistically, based characteristics and it also has stochastic elements. Mortality rates based on experience of the area and prevailing practices are necessary inputs at the present time, the only specific "health effect" in the program is that due to internal parasites (haemonchus); its effects on mortality is mediated via effects on physiological status and therefore the DIE subroutine.

A predisposition to death associated with each animal is calculated; this variable, FD (fraction dead), ranges from 0.0 to 1.0. To calculate if death occurs the variable FD is compared to a random number drawn from a uniform distribution between 0.0 and 1.0. If FD is greater than the random number, the animal dies.

Empirical Death Factors. At the beginning of the DIE subroutine all animals start with FD = .001; this value is then modified by a series of "death factors" which increase FD, therefore raising the chance of death occurring. These factors are: body condition (CFW), period of the year (CT), age of the sheep over 1 year (CA), sheep under 1 year of age (CL) and lactation (C11). Factors CT, CA and CL are vectors which are based on experience for that area and practices employed. The vectors depict changes in the probability of death other than direct nutritional reasons (e.g., heat stress, lack of water, and disease outbreak). Therefore the vectors change from area to area and from one production system to another. Determination of the die vectors is empirical and requires adjustment for simulations run for each area and set of production practices.

Interacting Correction Factors. Body condition (CFW) is calculated within the DIE subroutine by the same equation used to calculate body condition in reproduction (EBW/WM). Body condition alters FD ($FD_1 = FD$) by the equation:

$$FD_2 = FD_1\ (A-(A-1)\ CFW)$$

where

$A = 4$

This equation is a linear function except that CFW is curvilinear. The value of A, set at 4, produces the desired slope seen in figure 18. Note that death occurs when CFW reaches .54 due to emaciation per se; the probability of death increases as CFW decreases toward .54 so that few animals would ever reach CFW = .54.

The lactation status of a ewe increases her FD in the first period of lactation only using the equation

$$FD_3 = FD_2(C11)$$

where

$C11 = 1.25$

Newborn lambs are exposed to higher levels of mortality if milk consumption does not meet their nutritional requirements. A result of this situation would be a stunting of lamb growth which may also reduce their

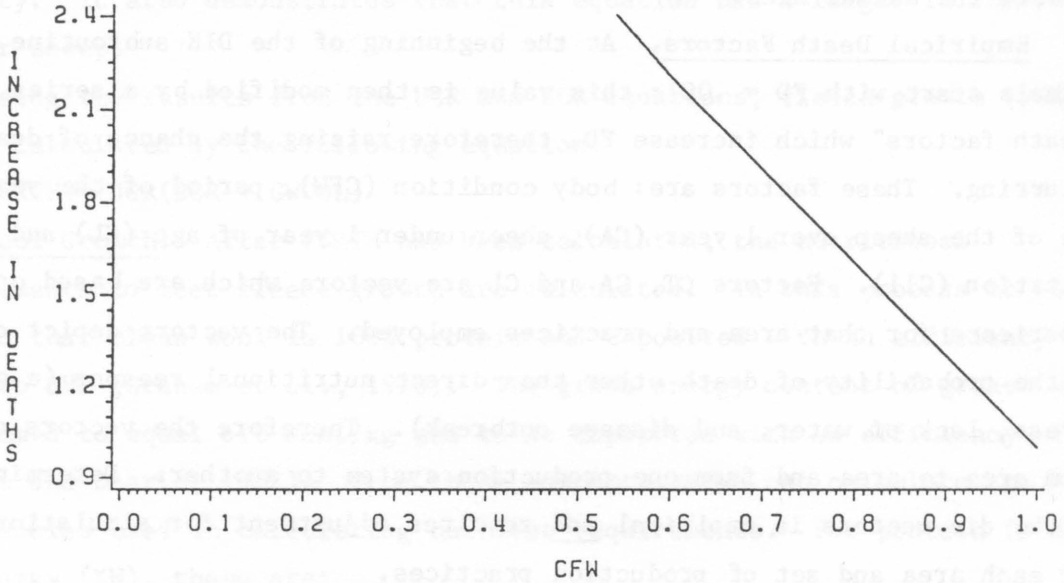

Figure 18. The increase in FD as body condition worsens.

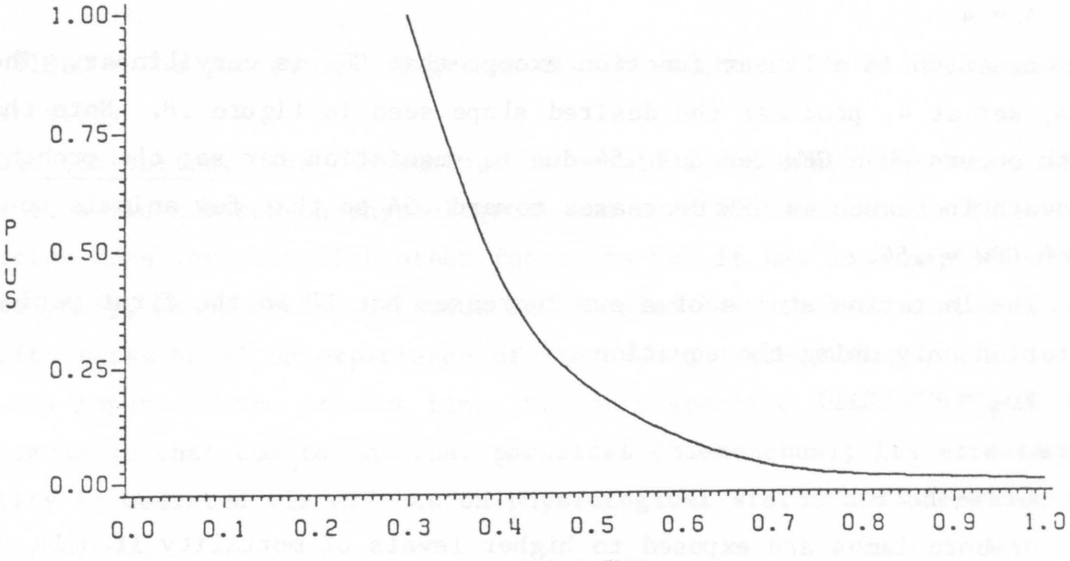

Figure 19. The increase in FD as stunting becomes more severe in young lambs.

survivability. This concept was modeled by using an equation to increase the likelihood of death, FD, for lambs which have not grown in WM. The equation compares the expected WM (EWM) to the actual WM for lambs between 1 and 4 periods of age. The PLUS equation is defined as follows:

$$PLUS = 1-((e^{-8(WM/EWM-.3)}-1)/(e^{-8(.7)}-1)$$

where

$$EWM = BW + 15EDW(AGEP)$$

and

EDW=expected growth in WM and is calculated as (WMP-BW)/TI

The PLUS curve is shown in figure 19. PLUS is added to FD where all other factors are multiplied (FD+PLUS).

The subroutine LMDIE calculates the probability of a lamb being stillborn or dying within the first 24 hr after parturition (PROBD). The probability is calculated as:

$$PROBD = CB(CBA)$$

where

CB = A vector containing probabilities of death in newborn lambs due to the time of year.

CBA = A vector containing probabilities of death in newborn lambs due to the age of its dam.

PROBD is then compared to a random number, uniformly distributed ranging from 0.0 to 1.0, if PROBD is greater than the drawn number the lamb dies.

Abortion. Situations arise where pregnant ewes are severely undernourished. In such an instance fetal growth is reduced or halted. When this happens the chance of abortion is increased. The model monitors this situation by accounting for and storing the potential and actual conceptus weight. When the ratio of actual conceptus weight to potential conceptus weight is less than .5 the ABORT subroutine is called and the ewe aborts her lamb. Abortion may be triggered at a higher ratio and, if this is the case, the .5 base can be appropriately increased.

Early embryonic mortality is part of the PCON subroutine. Additional abortion may be specified at an empirical rate.

n. Health

Limitations. The interactive health component of the model is currently limited to the effects of internal parasites, more specifically the helminth.

The important impact that helminths have on sheep and goats is of major importance on a worldwide basis (Preston and Allonby, 1979).

The functions in the parasite subroutine are developed around concepts for which there is less basis in the literature and less experience-based knowledge than for any other equations used in the model. The equations developed depict animal response to parasitic load and, although a considerable amount of biology is known by parasitologists, experimental quantification of the effects parasites have on the biology of sheep and goats is limited. Therefore, the cooperation of consulting parasitologists was paramount in developing the approach and methodology. However, the subroutine developed does provide the opportunity of quantitatively assessing the effect of health regimens and, perhaps more importantly, it provides parasitologists an opportunity (incentive) and basis to further investigate the interaction between parasite and host; i.e., it "... throws information gaps into sharp relief, thus guiding future data collection exercises towards the most critical areas" (Hallam et al., 1983).

Population. An overview of the health component is presented in figure 20. The program first establishes the worm population of an animal, which is a summation of previously acquired worm count and the larvae intake for the current period. The existing population may be reduced by the administration of anthelmintics which have varying levels of efficacy, where this level is an input parameter. Larvae intake is also an input parameter (based on data or experience) which varies as the situation (e.g., season) dictates.

The effective worm population count is also conditioned by the animal's immune status that determines its resistance to the parasite. The modeled immune response is a function of age, body condition, pregnancy status, lactational status and genotype. The effective worm population is the number of worms surviving and having an influence upon the animal.

Several avenues are utilized in the model to express the effect of the parasites on the individual. The physiological limit of feed intake is reduced as the worm burden becomes heavier. Also, there is a reduction in energy absorbed due to damage to the gut. This effect is small with haemonchus; however it is programmed in a form such that it may be increased

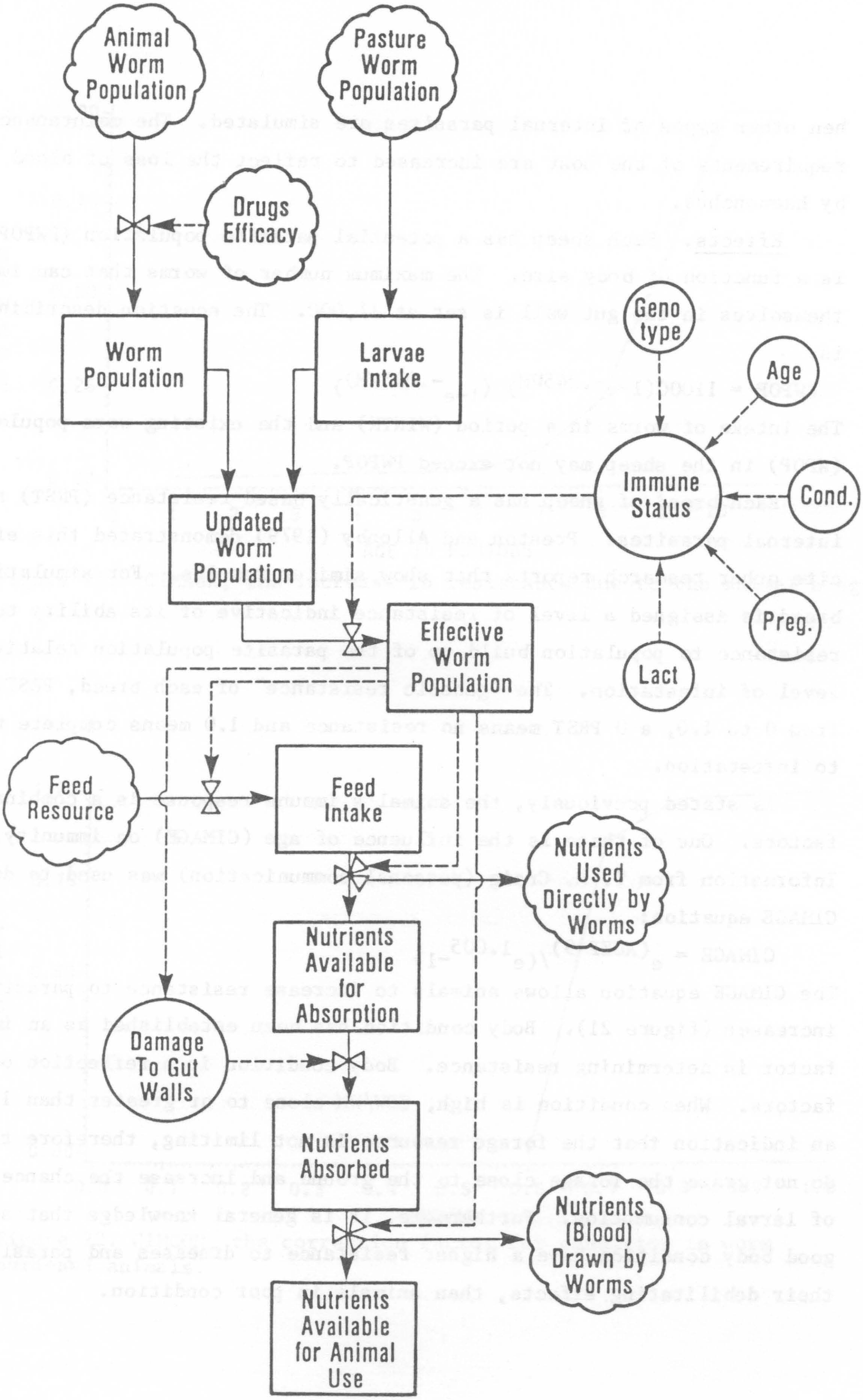

Figure 20. A flow chart of the effects of parasites on productivity.

hen other types of internal parasites are simulated. The maintenance requirements of the host are increased to reflect the loss of blood absorbed by haemonchus.

Effects. Each sheep has a potential parasite population (PWPOP) which is a function of body size. The maximum number of worms that can implant themselves in the gut wall is set at 11,000. The equation describing PWPOP is:

$$PWPOP = 11000(1-e^{-.045WM})\ (1-e^{-.045WM})$$

The intake of worms in a period (WINTK) and the existing worm population (WPOP) in the sheep may not exceed PWPOP.

Each breed of sheep has a genetically based resistance (PRST) to internal parasites. Preston and Allonby (1979) demonstrated this effect and cite other research reports that show similar results. For simulation, a breed is assigned a level of resistance indicative of its ability to maintain resistance to population build up of the parasite population relative to level of infestation. The "genetic resistance" of each breed, PRST, ranges from 0 to 1.0, a 0 PRST means no resistance and 1.0 means complete resistance to infestation.

As stated previously, the animal's immune response is a combination of factors. One of these is the influence of age (CIMAGE) on immunity. Information from T. M. Craig (personal communication) was used to develop the CIMAGE equation:

$$CIMAGE = e^{(AGEP-9)}/(e^{1.005}-1)$$

The CIMAGE equation allows animals to increase resistance to parasites as age increases (figure 21). Body condition has been established as an important factor in determining resistance. Body condition is a reflection of several factors. When condition is high, EBW/WM close to or greater than 1.0, it is an indication that the forage resource is not limiting, therefore the sheep do not graze the forage close to the ground and increase the chance or rate of larval consumption. Furthermore, it is general knowledge that animals in good body condition have a higher resistance to diseases and parasites, and their debilitating effects, than animals in poor condition.

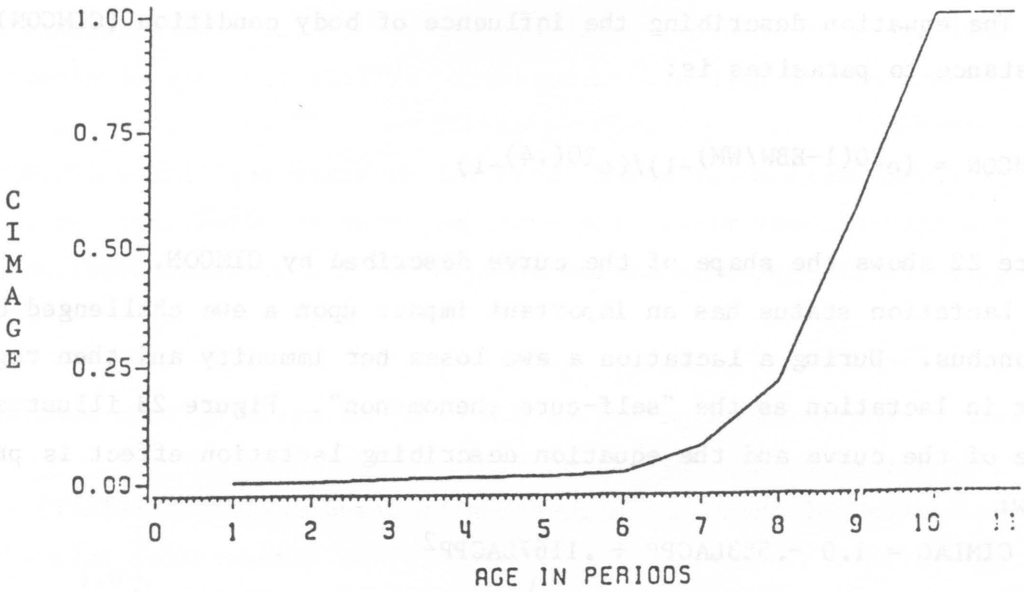

Figure 21. CIMAGE, the increase in resistance due to the animal's age.

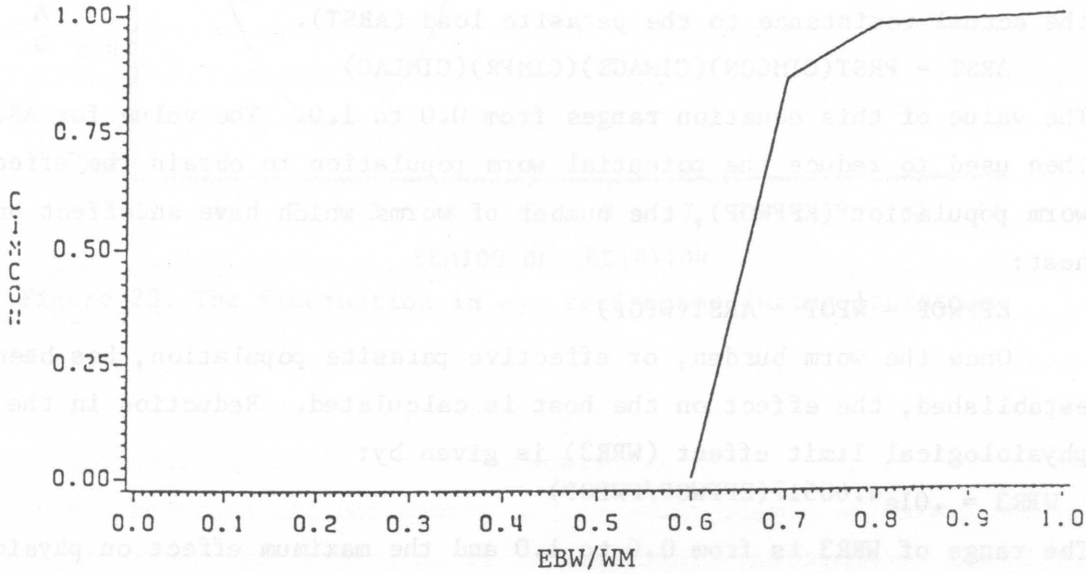

Figure 22. CIMCON, the correction factor for condition in worm burdened animals.

The equation describing the influence of body condition (CIMCON) on resistance to parasites is:

$$CIMCON = (e^{20(1-EBW/WM)}-1)/(e^{20(.4)}-1)$$

Figure 22 shows the shape of the curve described by CIMCON.

Lactation status has an important impact upon a ewe challenged by haemonchus. During a lactation a ewe loses her immunity and then regains it later in lactation as the "self-cure phenomenon". Figure 23 illustrates the shape of the curve and the equation describing lactation effect is presented below:

$$CIMLAC = 1.0 -.583LACPP + .1167LACPP^2$$

where:

LACPP = the period of lactation.

The final adjustment made to the immune status of a ewe is for pregnancy (CIMPR). As a ewe reaches the last period of gestation her immunity drops from 1.0 to 0.60.

The product of the mediating factors previously described are used as the actual resistance to the parasite load (ARST).

$$ARST = PRST(CIMCON)(CIMAGE)(CIMPR)(CIMLAC)$$

The value of this equation ranges from 0.0 to 1.0. The value for ARST is then used to reduce the potential worm population to obtain the effective worm population (EFFWOP), the number of worms which have an effect on the host:

$$EFFWOP = WPOP - ARST(WPOP)$$

Once the worm burden, or effective parasite population, has been established, the effect on the host is calculated. Reduction in the physiological limit effect (WRR3) is given by:

$$WRR3 = .01e^{4.60517(EFFWOP/PWPOP)}$$

The range of WRR3 is from 0.0 to 1.0 and the maximum effect on physiological limit is 20% (figure 24a).

Another effect of internal parasites is damage to the gut wall which decreases the host's ability to absorb energy (WRRE figure 24b). This effect is represented by the following equation:

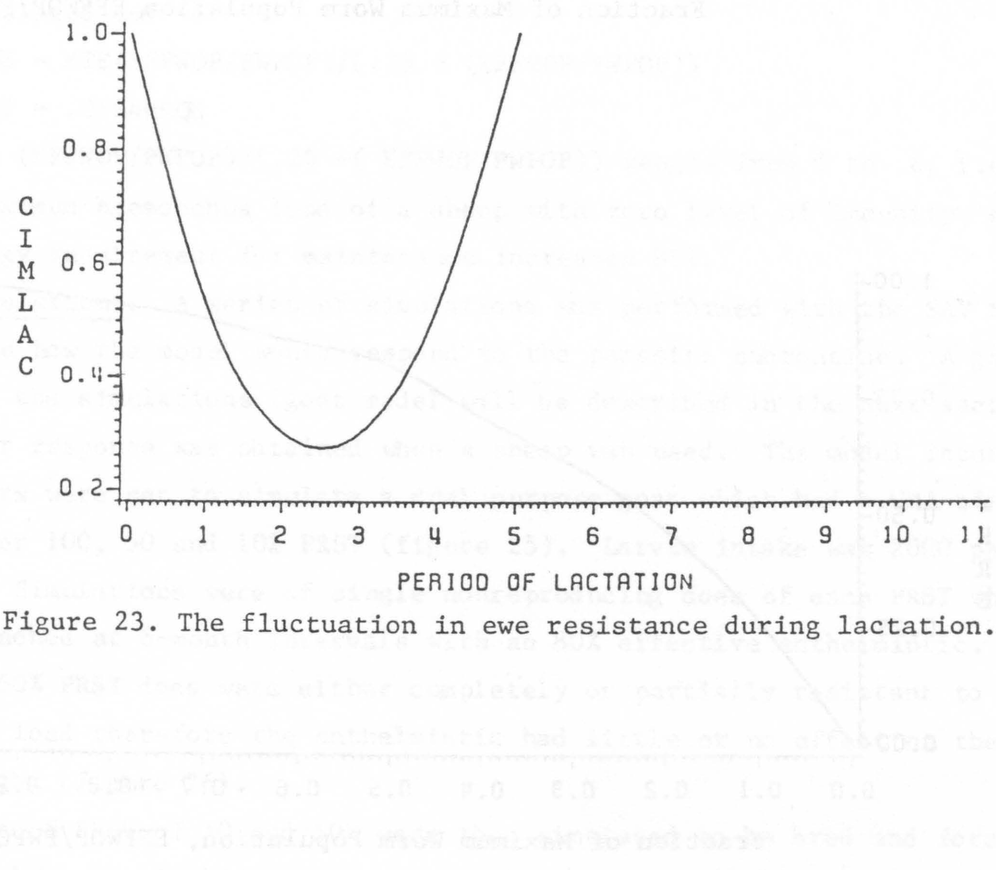

Figure 23. The fluctuation in ewe resistance during lactation.

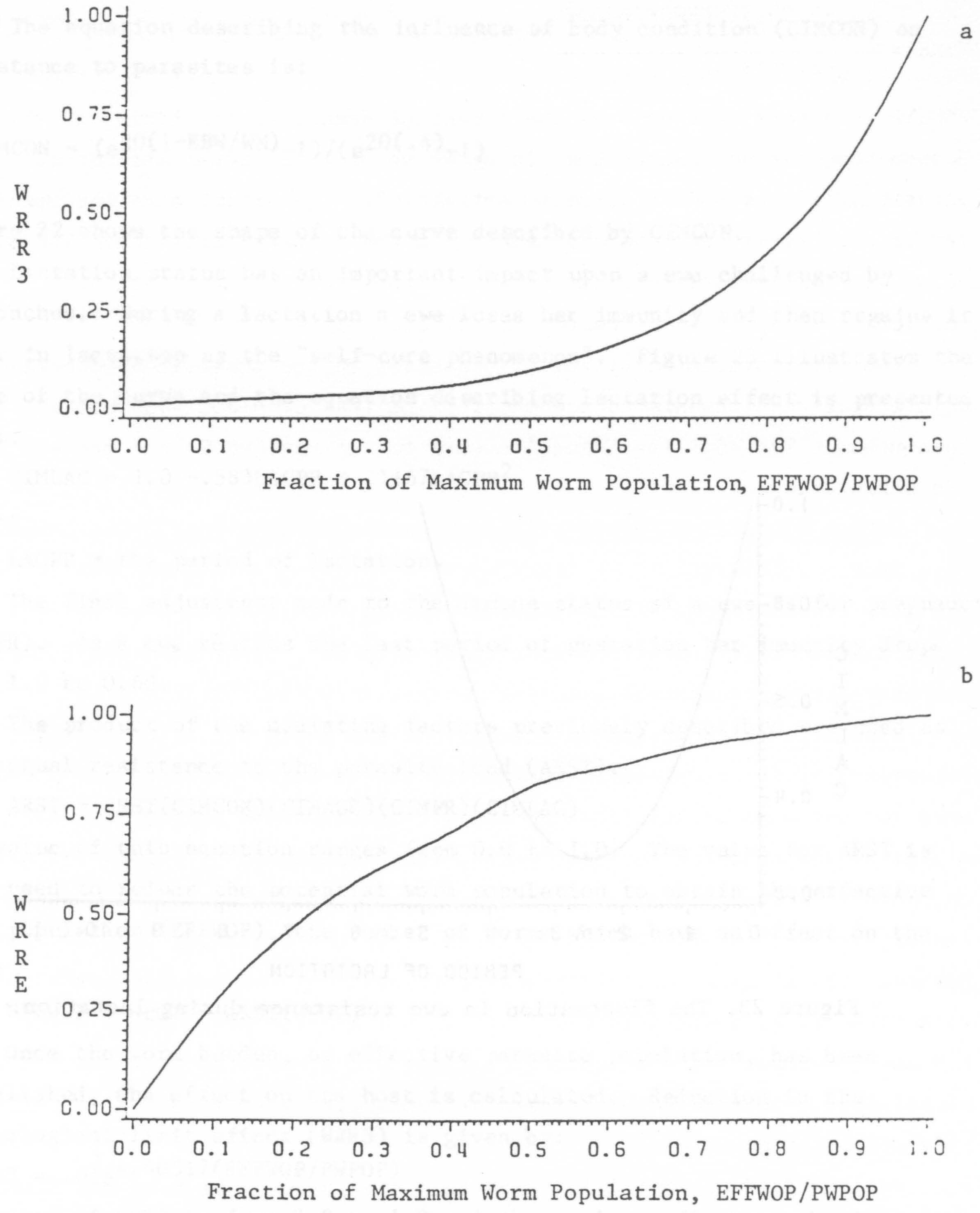

Figure 24. The influence of parasites on feed consumption, (a). The fractional reduction in energy utilization as worm burden increases, (b).

$$\text{WRRE} = \frac{1-e^{-3.0543(\text{EFFWOP}/\text{PWPOP})}}{1-e^{-3.0543}}$$

WORTYP is a term that denotes the extent of damage to the lining of the gut. Haemonchus does not damage the lining as severely as other species of parasites and the WORTYP value is set at .02. The effect of other species may be set higher (or lower) depending on their characteristics. The maximum value of WRRE is therefore .02; that is, the digested nutrients of a particular sheep could be reduced by 2% due this effect.

The final simulated effect of parasites on the sheep is an increase in maintenance requirements to account for the loss of blood absorbed by haemonchus. The additional requirements for energy (WRQE) and protein (WRQP) are calculated as:

$$\text{WRQE} = \text{MTE}(\text{EFFWOP}/\text{PWPOP})/(.25 + (\text{EFFWOP}/\text{PWPOP}))$$

$$\text{WRQP} = .0164\text{WRQE}$$

The term (EFFWOP/PWPOP)/(.25 +(EFFWOP/PWPOP)) ranges from 0 to .8; i.e., under maximum haemonchus load of a sheep with zero level of immunity, etc., the energy requirement for maintenance increases 80%.

<u>Simulations</u>. A series of simulations was performed with the SAV to determine how the model would respond to the parasite subroutine. A goat was used for the simulations (goat model will be described in the next section). A similar response was obtained when a sheep was used. The model input parameters were set to simulate a dual purpose goat which had a WMA of 45 kg and either 100, 50 and 10% PRST (figure 25). Larvae intake was 2000 per period. Simulations were of single nonreproducing does of each PRST which were drenched at 6-month intervals with an 80% effective anthelmintic. The 100 and 50% PRST does were either completely or partially resistant to the parasite load therefore the anthelmintic had little or no effect on their body weight (figure 26).

Does of PRST of 10 and 50% were then simulated to be bred and forced to have single and twin kids to determine the influences of pregnancy and lactation on doe weight (figures 27 and 28). These results show that the "50%" doe was able to regain some weight while the "10%" doe continued to lose weight and would have a high probability of dying (condition decreased to 70%; i.e., EBW/WM = .7). Further simulations involving similar does giving birth to singles and being wormed at 3-month intervals with a drug effectiveness of 80% were performed (figure 29). Under this health management, both "10%" and "50%" does were able to maintain sufficient body weight and remain in reasonable body condition.

The changes in the host's worm population are plotted in figure 30. The graph illustrates the genotypic difference in PRST and how the anthelmintic reduces the worm population.

These simulations can not be taken as validations since they are not compared with real data; nonetheless, they do appear to represent the form and magnitude of effects expected by experienced small ruminant parasitologists. Currently, experiments with the TAMU/SR CRSP Breeding Project in Kenya have been designed to provide feedback information to refine this component of the model.

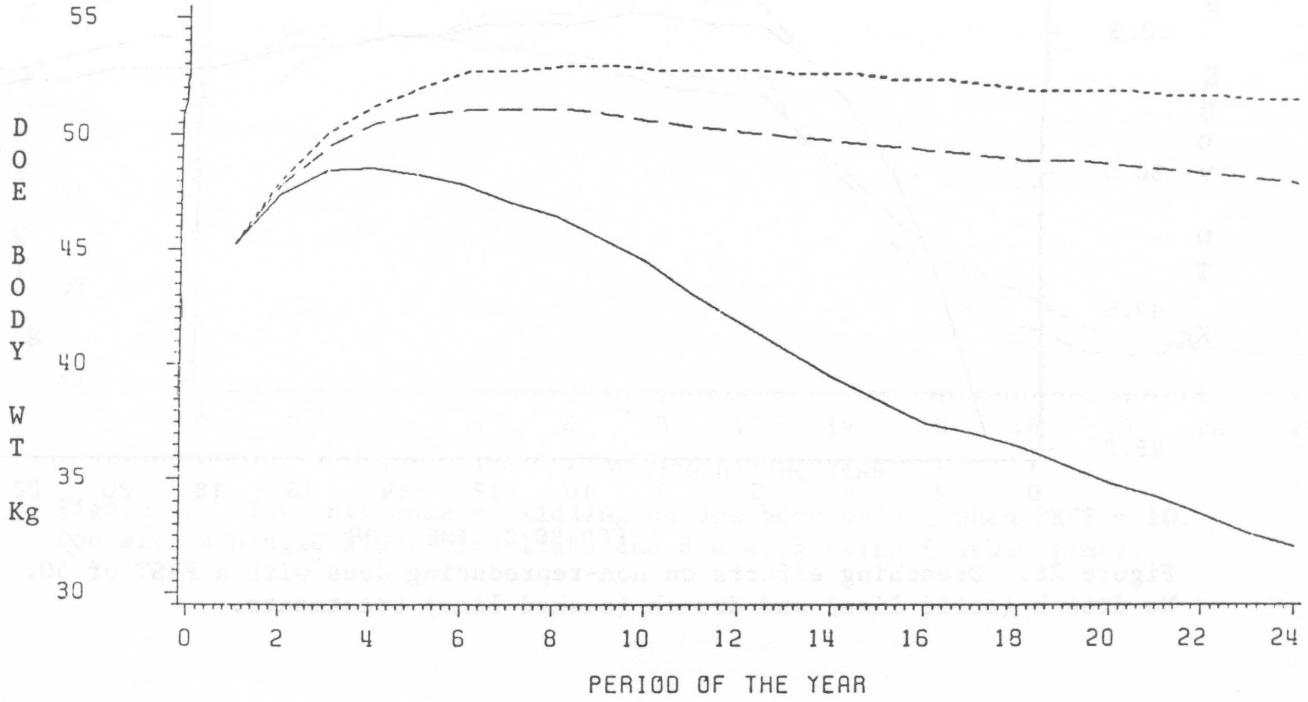

Figure 25. Non-reproducing doe body weights with no drenching. Genetic resistance (PRST) levels of 10 (solid line), 50 (dashed line) and 100 (dotted line).

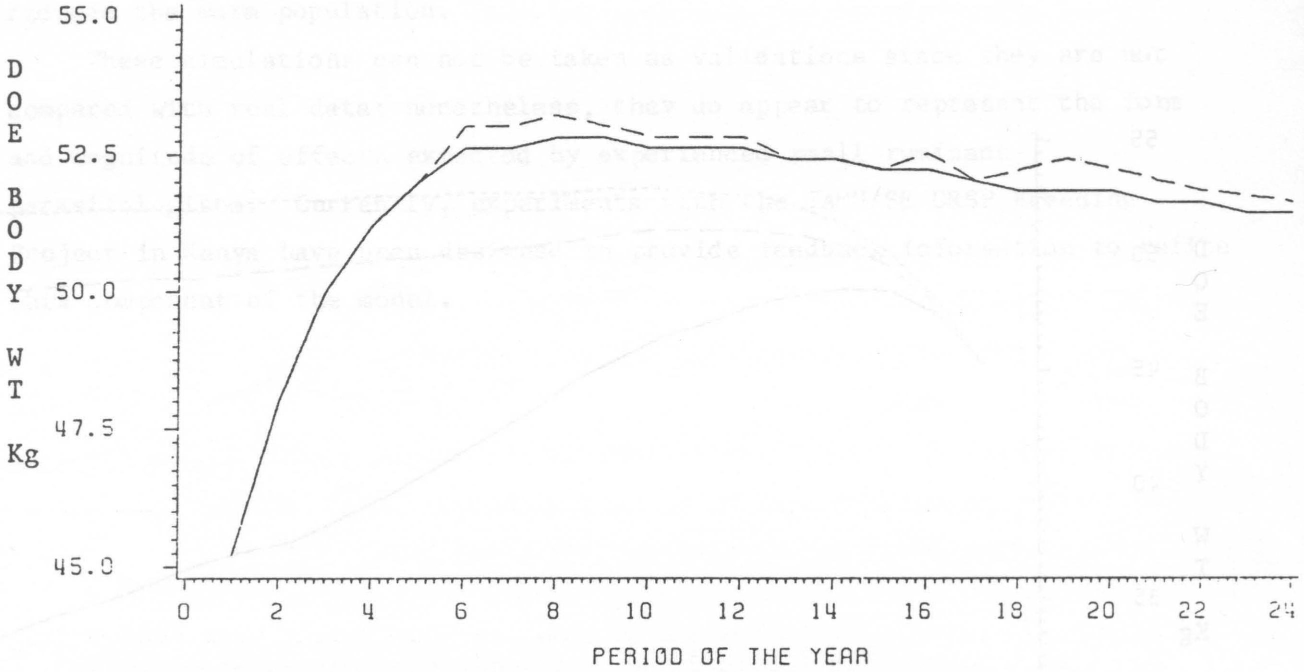

Figure 26. Drenching effects on non-reproducing does with a PRST of 50. No drench (solid line) and drench (dashed line) treatments.

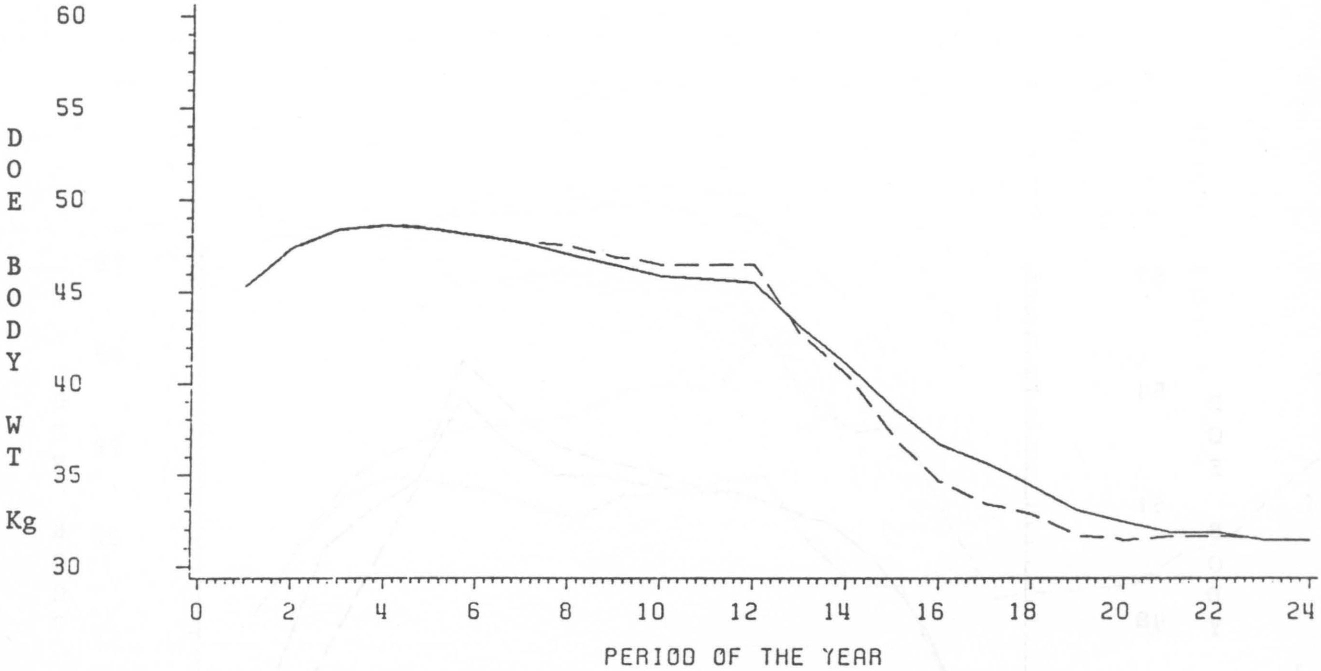

Figure 27. The influence of kidding on doe body weight when PRST = 10. Doe with a single kid (solid line) and doe with twins (dashed line).

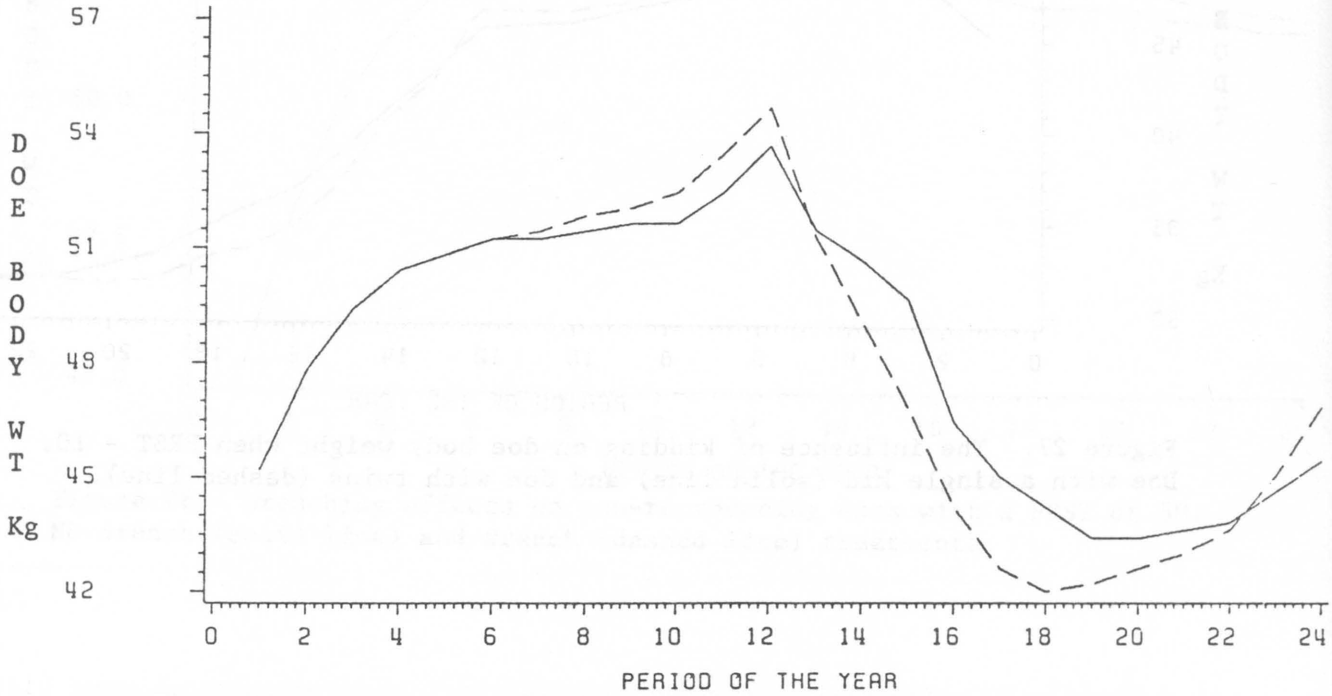

Figure 28. The influence of kidding on doe body weight when PRST = 50. Doe with a single kid (solid line) and a doe with twins (dashed line).

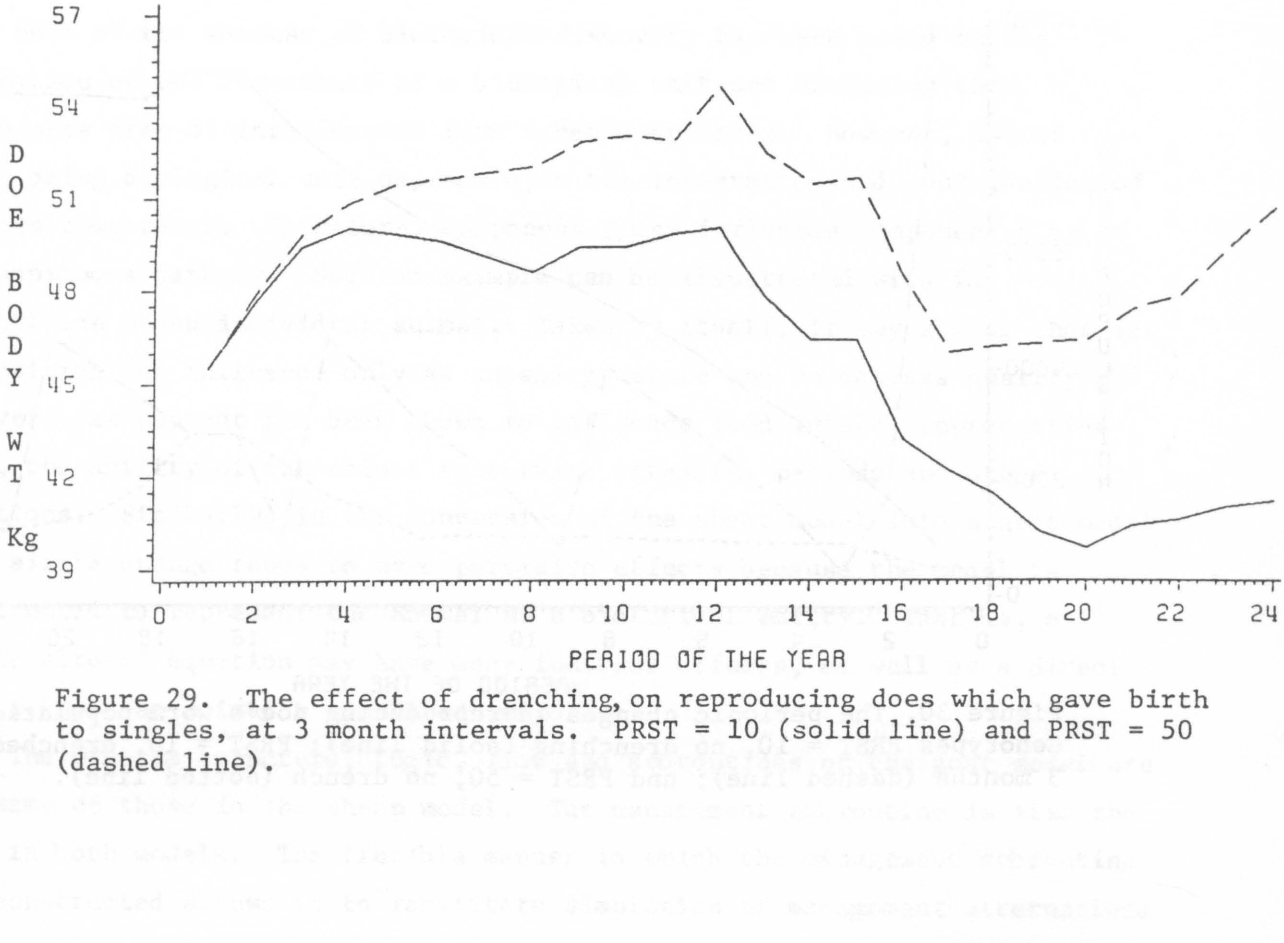

Figure 29. The effect of drenching, on reproducing does which gave birth to singles, at 3 month intervals. PRST = 10 (solid line) and PRST = 50 (dashed line).

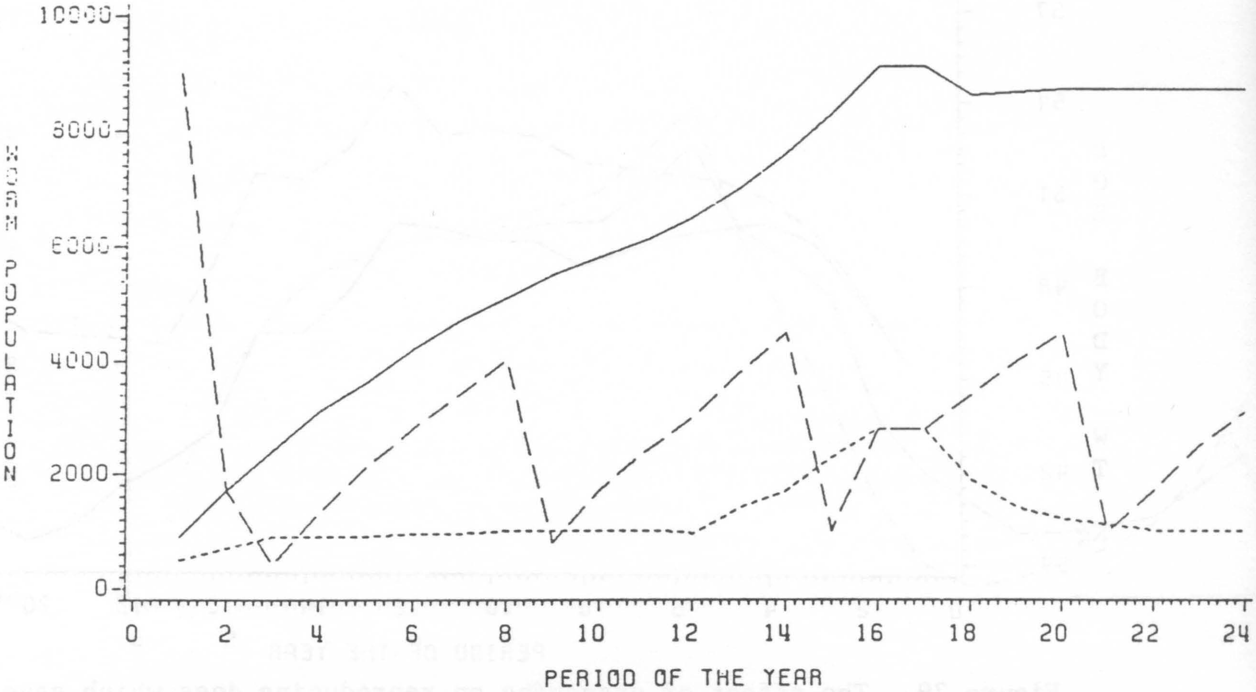

Figure 30. The periodic changes in reproducing doe's worm population. Genotypes PRST = 10, no drenching (solid line); PRST = 10, drenched every 3 months (dashed line); and PRST = 50, no drench (dotted line).

3. GOAT MODEL

The production resources utilized by sheep and goats and the variability of production systems (e.g., extensive vs intensive) for sheep and goats are similar. In many situations these species are treated as one production unit. The literature indicates that there are biological similarities between the two species, but recent experimental results have more clearly identified biological differences. The following section describes these primary differences and how they were incorporated into the construction and functions of the goat model.

Much of the success of biological discovery has been based on the separation of the components of a biological unit and examining the components free of interference from other components. However, a functioning biological unit depends upon the integration and contribution of all its components. Therefore, component A may influence component C by an inconspicuous pathway. Such an example can be illustrated with fat composition of an individual animal. Taken by itself, it may appear that fat composition has influence only as an energy store and on carcass quality. However, fat content has been shown to influence feed intake, reproductive rate, the ability of the animal to survive stressful periods and other functions. Similarly, in the conversion of the sheep model into a goat model each single change tends to have pervasive effects because the model is constructed to represent the animal as a biological entity. That is, a single altered equation may have many indirect effects, as well as a direct effect, upon an animal's simulated response.

The program structure, logic, flow and subroutines of the goat model are the same as those in the sheep model. The management subroutine is also the same in both models. The flexible manner in which the management subroutine was constructed allows it to facilitate simulation of management alternatives which can occur in either species. Anticipating production systems where sheep and goats are maintained as one flock, the model structure and programming were designed to allow simulation of both species simultaneously in the same computer run.

The reproductive processes of sheep and goats have many similarities. Shelton (1978) reported average estrus cycle length from 19 to 21 days which is similar to the 16 to 17 day cycle of sheep. In the same report, an average gestation length of 149 days was given. As with sheep, seasonality (photoperiod effects) and breed affect a doe's cycle. In equatorial regions goats display year-round sexual activity. Goats in temperate regions display a restricted breeding season for a portion of the year (Doney et al., 1981). Breed effects have been shown to influence breeding season; e.g., Sengar (1976) reported that Jamnapari does were more seasonal than Beetal, Barbari and Black Bengal does.

Does often have a high rate of multiple ovulations. Ovulation rate is genetically mediated but is also influenced by environmental effects. Ricordeau (1981) summarized breed differences in litter size, an indicator of ovulation rate minus embryonic death and abortions. Mean litter size ranged from 2.45 to 1.11 kids. Ovulation rate may be affected by body condition and maturity of the doe (Shelton, 1978; Shelton and Groff, 1974).

From the information reviewed it is apparent that the same environmental factors influence estrus and ovulation rate in sheep and goats. Therefore, the general method used to simulate reproduction in sheep can be used for the goat. It is assumed that the equations used in the sheep model fertility subroutine are applicable to the goat. Further simulations may indicate that some of the assumptions do not hold within close limits. If this occurs, the model will help identify the knowledge voids for which experiments can be designed to answer specific questions about reproductive processes or provide more definitive quantitative values.

Morand-Fehr (1981) discussed growth in the goat. He stated that there have been no systematic studies of fetal development. However, the information that does exists indicates that fetal growth is very similar in both species. Eighty percent of fetal kid growth was reported to occur in the last 8 weeks of gestation (Morand-Fehr, 1981) which is in agreement with the report on fetal lamb growth by Rattray et al. (1974).

As with other livestock species, birth weight is highly variable and influenced by genetic and environmental factors. The primary influence on birth weight of kids is related to the form and size of adults of the breed to which it belongs (Morand-Fehr, 1981). Morand-Fehr (1981) stated that, on average, birth weight was 1/15 (6.7%) of adult weight. The sheep and goat model uses 6% of WMA (base adult weight) to establish the target birth weight. Simulated kid birth weight varies according to sex, number of litter siblings and nutrition of the dam.

The growth and development of body tissues in goats are similar to those observed in other ruminants. The proportion of lean weight as a fraction of empty body live weight is similar to sheep (Morand-Fehr, 1981) but definite differences exist for fat deposition. Morand-Fehr (1981) stated that kids deposit fat earlier in the loin of the carcass and slower in the leg when compared to lambs. When comparing fat deposition to empty live weight it is apparent that fat development of goats is lower than that of lambs. However, it tends to increase linearly with empty live weight but at a slower rate of increase when compared to lambs (Morand-Fehr, 1981).

Naude' and Hofmeyr (1981) reported that Boer goats at approximately 250 days of age and weighing 41 kg had 12.9% fat. Gaili et al. (1972) demonstrated that Sudan Desert sheep had a larger percentage of fat in their carcass when slaughtered at "young", yearling and mature ages than goats (8.9, 16 and 24.5% in sheep and 5.5, 10.7 and 19.1% in goats, respectively).

In converting the sheep model to a goat model, body composition and growth have a key differentiating role. Fat composition of a goat in an average, "normal" (nonstressed) condition is assumed to be 3% at birth and to increase to 15% at maturity with a maximum fat content attainable of 25%. In the sheep model, fat is assumed to be 3% at birth and increases to 25% at maturity with a maximum of 40%. As with the sheep model, 3% fat is the minimum level required to sustain life at any age.

As discussed earlier, growth rates of goats are slightly less than sheep. This difference is at least partially a result of slower (less) fat deposition. The lower growth rate of a goat was modeled by reducing the maximum daily rate of energy gain from .0125 Mcal/kg/day to .00625 Mcal/kg/day, a reduction of 1/2. The effect of this reduction is expressed in the equation for maximum energy gain (MXEG):

$$MXEG=CFI1(.0125)(EBW)(WM/WMA)^{.45}(3(WM-.882\ EBW))/WM$$

where

$$CFI1 = .5$$

The calculated value for MXEG is used to calculate the physiological limit (PSOL). The influence of MXEG on PSOL is to lower the satiety level in the goat.

Another major difference incorporated into the goat model is an increase in the physical limit for feed intake. This increase is facilitated in the goat by having a faster passage rate of intake through the digestive system. The faster passage rate in goats is associated with a smaller rumen and reticulum. In synchrony with their gut size, goats have evolved as highly selective grazers (Kothmann, personal communication). Singleton (1961) measured the flow of digesta through the duodenum of goats and sheep. He reported that goats had a flow rate of 12-15 l/day vs 11 l/day for sheep for the diet used in his study. Information from Geoffray (1974) showed that goats have a higher frequency of eating than sheep; however the dry matter intake and organic matter digestibility were not significantly different. The increased frequency of feeding implies that the goats were feeding to their physical limit but were not meeting their nutritional requirements; therefore they were only partially digesting the consumed feed (compared with sheep), thus allowing them rumen space to consume more forage. Huston (1978) also found that goats have a greater passage rate that results in a capacity for greater food consumption at more frequent intervals.

In the goat model the physical limit (R2) for feed intake is adjusted upward by the variable CFI2:

$$R2 = CFI2\ (.12\ WM^{.75})\ e^{-5.8(.85-DIG)^2}$$

where

CFI2 = 1.4; In the sheep model this variable is set at 1.0.

The protein and energy requirements are calculated essentially the same in both models, but the results differ due to the alterations previously described. The NRC requirements of goats (1981) repeatedly refer to the similarity between sheep and goat data for maintenance, pregnancy and growth. This precedent is currently accepted as the soundest basis for designing the nutritional component. As more nutrition research with goats is reported, model modifications which are indicated and supported by data will be made. Also, as simulations and validations proceed, more precise indications of nutritional differences between sheep and goats as well as the nature of the differences, will become evident and may be incorporated into the model.

Similarities between the goat model simulations and reports from the literature of basal metabolic requirements of a doe, are illustrated in the following example where the maintenance requirement for energy for a 50 kg doe consuming feed of 60% digestibility was calculated.

Method source	ME Requirement	Location
NRC (1981)	1.91 Mcal/day	U.S.A.
Sengar (1980)	1.757 Mcal/day	India
Morand-Fehr (1981)	1.76 Mcal/day	France
Goat Model	1.72 Mcal/day	

Although direct comparison between ME requirements should not be made, due to differences in breed of goats, type of feed and the age of goats used, it is interesting to see how closely these values are grouped. Also, it should be noted that the goat model has more refined provisions to account for differences in physiological status (e.g., pregnancy and lactation) and activity (e.g., greater distance traveled to grazing or water).

Important differentiations between the sheep and goat models are contained in the specification of input parameters. The values used as input parameters are equally as important as the model equations for they specify characteristics of the breed being simulated and take into account the goat's feeding behavior. The genetic parameters are specified to reflect inherent differences between breeds; e.g., maturing rate potential independent of size potential is characteristically slower in tropically adapted breeds and must be properly specified for the breed simulated.

Differences between sheep and goats in diet quality and quantity have been shown to exist (Bryant et al., 1979; Bryant et al., 1980). It is important that these differences be taken into account when specifying forage input vectors for either species.

Limited research and general experience indicate that goats are more agile and active than sheep (Huston, 1978). Therefore their activity factor, expressed as distance walked, should be higher than the factor used for sheep. The higher activity factor of the goat indicates that they have a higher maintenance cost than sheep. On the other hand, goats are more agile allowing them a larger more diverse foraging range; the effects of these grazing behavior characteristics are reflected in the forage availability vector. For a "cut and carry" confinement system, a differential selectivity is often observed but has not been sufficiently quantified for inclusion as an interactive component of the model (or inclusion in NRC requirements or other objective considerations of goat nutrition), but may be accommodated in simulations through input vectors to the extent that observations are available.

4. PARAMETER SPECIFICATION

a. Forage Parameters

Three sets of data must be specified as input parameters in order to perform simulations. These are forage, animal and management parameters. The forage parameters are crude protein, digestibility and availability. Crude protein and digestibility estimates are of the forage plus any supplements in the diet. These are usually obtained from forage research reports or forage scientists experienced in the geographic area. Availability is the amount of forage, measured in kg/head/day, that is of the given quality of the diet for that period, which is available for an animal to consume. The estimation of availability is difficult because measures of the total biomass or stratified layers of biomass estimates are not directly useable. These tend to overestimate the forage availability because the actual diet selected from the total does not include the lower quality plant components. In addition these estimates do not include the effects of selective grazing on diet quality. One method used to adjust forage availability for free-grazing animals has been to collaborate with persons experienced in the production environment and have them identify critical times of the year, such as the last month of a dry season. When the critical times of forage production have been identified the input availability is adjusted downward to correspond with the level of severity.

b. Genetic Parameters

The genetic parameters provided vary with the breed being simulated. The genotype of each animal has been set equal to the mean of its breed. The components of genotype are mature size (WMA), milk production (GMLKL), ovulation rate (OVR), seasonality of estrus (SEAEST), wool growth (GWOOL) and resistance to parasites (PRST). These genetic potentials are estimated as the values for mature females in good condition that have never been restricted by nutrition or health. These values are estimated at the location in question if possible but may be obtained from the literature, unpublished or other data, or estimates of knowledgeable persons (actually, usually a combination of these sources).

c. Management Parameters

Management options are the third set of input parameters. These parameters specify breeding season, weaning date or weight, feed supplementation, sale policy, culling policy, pasture rotation and flock assignments. Age, weight or time of year can be used to determine when the previously mentioned parameters are implemented.

d. Example Of Parameters Specification

An example of how input parameters are established is given for a series of simulations in northern Kenya. The genetic parameters were initially established from general literature values and fine tuned based on more relevant information sources. The breed simulated was the Somali Blackhead. Mason and Maule (1960) describe this breed as a fat-rumped hair sheep, with a mature ewe weight ranging from 33 to 52 kg and milk production ranging from 200 to 300 g per day.

Field (1979) studied the characteristics of this breed in northern Kenya. She reported that mature pregnant ewes weighed 35.3 kg in the wet season and 31.7 kg in the dry season. It was estimated that ewes produced 58.8 l of milk in 5 months. Season and sex effects appeared to be present. Rams born in the rains or in the dry season had a preweaning weight gain of 107.1 and 91.9 g/day, respectively. Ewe lambs gained 91.9 and 86.5 g/day in the respective seasons. Carles (personal communication) has recorded weights of Somali Blackhead ewes at Kabete, Kenya and found them to have an average mature weight of 35 kg.

The seasonal factors which affect the productivity of East African Blackhead sheep were examined in western Uganda (Trail and Sacker, 1966a). Lambs born to ewes exposed to dry conditions during the last 2 months of pregnancy had mean birth weights of 2.61 vs 2.63 kg for those born in the remainder of the year ($P>.05$). At two months of age those lambs which suckled during the dry season weighed 9.64 kg compared to 10.25 kg ($P<.05$) for lambs not nursing in the dry season. If lambs were born before the dry season but were still nursing during the dry season (age 2 to 5 mo), seasonality was nonsignificant. Sacker and Trail (1966a) provided estimates of the growth rates for the same group of lambs. Single born lambs had a range in weight gain from birth to eight weeks of age of .095 to .136 kg/day.

Mortality rates from birth to 5 months of age of single lambs from ewes lambing for the first time was 21.6% with 6.5% occurring from birth to 21 days of age (Trail and Sacker, 1966b). The mortality rate for single lambs from aged ewes was 15.8%, with 4.6% occurring from birth to 21 days. Those ewes producing twins had a 27.5% loss of which 10.2% came before day 21. Lamb mortality was higher in the dry season than in the remainder of the year (31 vs 20%).

The Somali Blackhead or varied strains of it have been used outside of Africa. Estimates of mature ewe weights from South America range from 27.6 to 31.3 kg (Butterworth et al., 1968; Fitzhugh and Bradford, 1983). Birth weights were reported to range from 1.9 to 3.0 kg. Butterworth et al. (1968) reported that the milk production of ewes on a high and low nutritional plane was 67.9 and 37.8 kg for a 12-week lactation.

The literature reviewed indicated that the genetic parameters for mature size (WMA) and the genetic potential for milk (GMLKL) should be set at 35 kg and 1.30 kg, respectively. The value used for WMA agrees with Carles (personal communication) whose sheep were under very little stress allowing them to express their genetic potential. The 1.30 kg level for GMLKL (which is the peak milk production level) would produce an average milk production within the range of reported values. The ovulation rate for the Somali Blackhead was set at 1.1, which would result in very few multiple births. The seasonality of reproduction in the Somali Blackhead is not influenced by photoperiod. Therefore, seasonality of estrus in the model is set to 1.0 for 24 periods which allows the sheep to breed year around.

The forage parameters used in the simulations were provided by the IPAL staff. They hand plucked the plant species that sheep and goats were observed foraging. The crude protein and digestibility levels of those plants are given in table 2. As stated previously, obtaining forage availability estimates were difficult. In situations where the exact availability is unknown, several steps can be used to construct these parameters. Of primary importance is the input from on-site personnel who know, in general terms, what month, or combination of months, forage quantity may be limiting. An indirect indicator is the fluctuation of mature ewe weight. Ideally these two sources coincide. Rainfall pattern and amount, and stocking rate may also be valuable in fine tuning forage estimates. The availability of forage for the IPAL runs were derived by using a combination of all the factors listed (table 3).

The inputs for the management subroutine were obtained from the IPAL staff. These inputs comprise the management practices used on the IPAL flock. They included year-round breeding, weaning all lambs at 10 periods of age (150 days), utilizing 1/4 of the ewes milk for dairy production and setting the minimum age for breeding ewe lambs at 1 year. Model stipulations placed upon milk extraction for dairy purposes were: the ewe must be at least 1 year of age, the lamb's body condition (EBW/WM) must be .85 or greater and the maximum amount of milk to be extracted was set at 1/4 of the total amount produced. These stipulations reflect the basis on which herdsmen make decisions about whether to milk a ewe.

The management subroutine can transfer animals to other classes when deemed necessary by the simulator. In the IPAL simulations there are several classes that both sexes can go through (figure 31). The transfers are determined by either age, weight, or a proportion of total flock size. Setting culling and sales policies are important in simulating the production situation, but also they provide a means of establishing a flock in steady state. A flock in steady state is defined as one where there is very little fluctuation in the number of mature ewes. It is necessary to simulate a flock in steady state for validation against actual results. More importantly, the effects of alterations in management practices or other simulated effects can be more clearly compared with the baseline (validation run) when a steady state is simulated unless, of course, the effect of interest is the process of change.

With the IPAL input data in the model, simulations for that production system may be run. The first computer runs will be a validation or comparison of model results with the actual results.

TABLE 2. Weighted Average of Crude Protein and Digestibility for Sheep Diets

	1979			1980		
Month	C.P. %	DIG %	% Diet accounted for	C.P. %	DIG %	% Diet accounted for
Jan	9.46	50.90	87.0	12.14	56.57	56.0
Feb	14.53	54.35	87.0	8.87	42.57	61.0
Mar	10.25	39.89	83.0	5.66	40.59	34.0
Apr	11.61	48.38	74.0	14.40	56.71	42.0
May	10.36	43.43	80.0	13.66	64.71	51.0
Jun	9.86	46.53	76.0	7.47	54.07	47.0
Jul	7.34	42.50	31.0	6.65	47.52	62.0
Aug	6.60	43.97	37.0	6.09	50.32	40.0
Sep	---	---	---	6.50	54.90	73.0
Oct	8.25	45.77	91.0	5.90	54.46	68.0
Nov	12.50	56.50	65.0	4.67	50.49	80.0
Dec	---	---	---	12.65	47.36	25.0

TABLE 3. FORAGE AVAILABILITY FOR IPAL SHEEP kg/hd/day.

Month	1979[a]	1980
January	1.1	1.7
February	7.5	.4
March	7.5	3.7
April	7.5	4.0 -.9[c]
May	7.5	.7
June	7.5	8.0
July	7.5	2.1
August	3.9	.5
September[b]	1.9	.1
October	2.7	1.0
November	1.0	12.0
December	1.0	9.3

[a] Values greater than 2.0 indicate availability is unlimited.

[b] September availability values were increased by .25 kg to represent the consumption of Acacia tortilis pods.

[c] .9 is the availability for the second period of April.

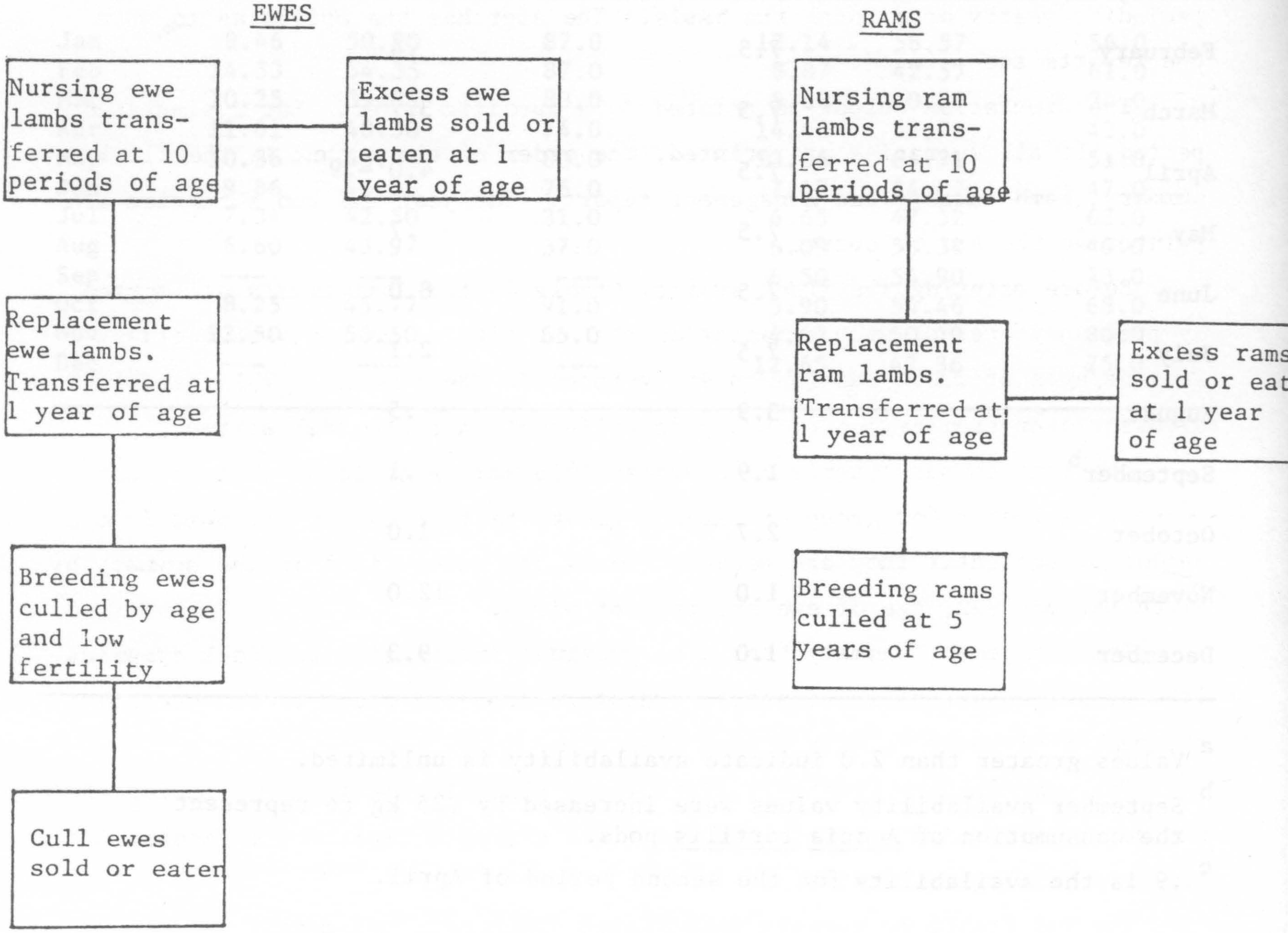

Figure 31. The age transfer of animals through the flock.

5. SUMMARIES OUTPUT - SUMMARIES

Summaries of the results from a simulation are printed in the run summary, the flock summary, the lamb summary, the management report and the year summary. These summaries allow the user to examine output on a periodic, yearly or a total run basis. The user has the option as to when the reports are printed.

The simulation output is printed in a specific order. For a simulated period, if all summaries are printed, the order of the output is the flock summary, lamb summary and management report. The year and run summaries are printed at the end of output.

Before printing the flock summary (table 4) the individuals are sorted by pregnancy status, within lactation status, within age and within class. The averages of these subclasses are printed in the summary. This grouping allows closer examination of sheep in different physiological states.

The lamb summary (table 5) provides information on lambs that are not weaned. A lamb's (or group of lambs') growth pattern can be followed from a period of age until they are weaned. Lambs are categorized in the summary by birth period, sex, age of ewe and type of birth.

The management summary (table 6) provides information on flock dynamics (the number of births and deaths), transfers from one class to another and the number of sheep sold from each class.

The year summary (table 7) lists every class in the flock by period of the year. All animals within the class are averaged together, regardless of age or physiological status.

The run (table 8) summary accumulates flock data and prints it out yearly. This summary provides the user with an overview of total flock performance. Printed are total births, deaths, animals marketed and feed consumed. This information can be used for evaluating biological efficiency (total kg of liveweight and milk harvested/total kg of dry matter consummed) of the flock.

The data printed in the summaries are intended to meet the information requirements of most users. However, more information can be placed in these summaries as the user desires. For example, the total weight of lean and fat for all sheep sold can be included in the run summary. Furthermore, shortages of energy and protein for particular body functions (i.e.

TABLE 4. FLOCK SUMMARY

```
          ***************  SUMMARY FOR FLOCK 1 BY GESTATION W/I LACTATION W/I AGE W/I CLASS IN PERIOD  6 YEAR  3 ***************
                ②                   ⑦   ⑧           ⑩         ⑪         ⑫           ⑬           ⑭                        ⑱         ⑲     ⑳        ㉑
--------------------------------------------------------------------------------------------------------------------------------------------------
     ①        AG  ③  ④   ⑤    ⑥    STL  LIV  ⑨   ----W---  ---WM---  ---WL---   FLEECE WT   EMPTY WT  ⑮  ⑯      ⑰  --NO PREG--   %    --MILK-  -DAIRY-
 CLASS       GR  LC  GT  NUM  DTH   BIR  BIR AGE  AVG   ADG AVG   ADG AVG   ADG  AVG    ADG  AVG   ADG DM DME   TPR SNG TWN TRP  CYC   NO AVG   NO AVG
--------------------------------------------------------------------------------------------------------------------------------------------------
BR EWE 13   1   0    1    0     0     0 116   44-0.61  44 0.05  30-0.24  0.0 0.000   39 -0.6 0.7 1.1 0.03   0   0   0    0    1 0.1    1 0.0
BR EWE 13   2   0    1    0     0     0 116   45-0.90  44 0.05  31-0.50  0.0 0.000   40 -0.9 0.8 1.1 0.03   0   0   0    0    1 0.1    1 0.0
BR EWE 13   4   0    3    0     0     0 116   45-1.80  45 0.05  32-0.46  0.0 0.000   41 -0.9 0.8 1.2 0.03   0   0   0    0    3 0.1    3 0.1
BR EWE 13   8   6    1    0     0     0 116   45-0.73  44 0.05  31-0.73  0.0 0.000   41 -1.2 0.7 1.0 0.02   1   0   0    0    1 0.0    1 0.0
BR EWE 13   9   4    1    0     0     0 116   44-0.81  45 0.05  31-0.60  0.0 0.000   41 -1.1 0.7 1.0 0.02   1   0   0    0    1 0.0    1 0.0
BR EWE 13   9   5    1    0     0     0 116   44-0.81  44 0.05  31-0.70  0.0 0.000   40 -1.2 0.7 1.0 0.02   1   0   0    0    1 0.0    1 0.0
BR EWE 13   9   6    4    0     0     0 116   45-0.80  44 0.05  31-0.82  0.0 0.000   40 -1.3 0.7 1.0 0.02   4   0   0    0    4 0.0    4 0.0
BR EWE 13   9   7    1    0     0     0 116   46-0.45  45 0.05  30-1.37  0.0 0.000   40 -1.8 0.7 1.0 0.02   1   0   0    0    1 0.0    1 0.0
BR EWE 13  10   6    1    0     0     0 116   44-0.87  45 0.05  31-0.87  0.0 0.000   40 -1.4 0.6 0.9 0.02   1   0   0    0    1 0.0    1 0.0
BR EWE 13  26   6    4    0     0     0 116   45-0.74  44 0.05  31-0.79  0.0 0.000   40 -1.3 0.6 0.9 0.02   4   0   0    0    0 0.0    0 0.0
BR EWE 13  26   7    6    0     0     0 116   45-0.42  44 0.05  30-1.32  0.0 0.000   39 -1.7 0.6 0.9 0.02   6   0   0    0    0 0.0    0 0.0
BR EWE 13  26   8    4    0     0     0 116   46-0.28  44 0.05  30-1.41  0.0 0.000   39 -1.8 0.6 0.9 0.02   4   0   0    0    0 0.0    0 0.0
BR EWE 13  27   9    1    0     0     1 116   44-0.53  45 0.05  29-1.69  0.0 0.000   39 -2.0 0.6 0.9 0.02   0   0   0    0    0 0.0    1 0.0
BR EWE 13*AGE**     29    0     0     1 116   45-0.72  44 0.05  31-0.97  0.0 0.000   40 -1.4 0.7 1.0 0.02   0   0   0    0   14 0.0   15 0.0
BR EWE**CLASS**     29    0     0     1 116   45-0.72  44 0.05  31-0.97  0.0 0.000   40 -1.4 0.7 1.0 0.02  23   0   0    0   14 0.0   15 0.0
RP EWE  7  22   0    1    0     0     0  13    7-0.13   3 0.00   3-0.00  0.0 0.000    4 -0.1 0.2 0.3 0.00   0   0   0    0    0 0.0    0 0.0
RP EWE  7*AGE**      1    0     0     0  13    7-0.13   3 0.00   3-0.00  0.0 0.000    4 -0.1 0.2 0.3 0.00   0   0   0    0    0 0.0    0 0.0
RP EWE**CLASS**      1    0     0     0  13    7-0.13   3 0.00   3-0.00  0.0 0.000    4 -0.1 0.2 0.3 0.00   0   0   0    0    0 0.0    0 0.0
N E LB  1   0   0    2    0     0     0   1    3 0.17   3 0.00   3-0.00  0.0 0.000    3  0.0 0.1 0.2 0.00   0   0   0    0    1 0.0    0 0.0
N E LB  1*AGE**      2    0     0     0   1    3.0.17   3 0.00   3-0.00  0.0 0.000    3  0.0 0.1 0.2 0.00   0   0   0    0    1 0.0    0 0.0
N E LB**CLASS**      2    0     0     0   1    3 0.17   3 0.00   3-0.00  0.0 0.000    3  0.0 0.1 0.2 0.00   0   0   0    0    1 0.0    0 0.0
WETHER 15   0   0    1    0     0     0  23    6-0.11   3 0.00   3-0.00  0.0 0.000    3 -0.1 0.2 0.3 0.00   0   0   0    0    0 0.0    0 0.0
WETHER 15*AGE**      1    0     0     0  23    6-0.11   3 0.00   3-0.00  0.0 0.000    3 -0.1 0.2 0.3 0.00   0   0   0    0    0 0.0    0 0.0
WETHER**CLASS**      1    0     0     0  23    6-0.11   3 0.00   3-0.00  0.0 0.000    3 -0.1 0.2 0.3 0.00   0   0   0    0    0 0.0    0 0.0
N W LB  1   0   0    1    0     0     0  10    6 0.20   3 0.00   3-0.00  0.0 0.000    3 -0.1 0.2 0.3 0.00   0   0   0    0    1 0.0    0 0.0
N W LB  1*AGE**      1    0     0     0  10    6 0.20   3 0.00   3-0.00  0.0 0.000    3 -0.1 0.2 0.3 0.00   0   0   0    0    1 0.0    0 0.0
N W LB**CLASS**      1    0     0     0  10    6 0.20   3 0.00   3-0.00  0.0 0.000    3 -0.1 0.2 0.3 0.00   0   0   0    0    1 0.0    0 0.0
N R LB  1   0   0    1    1     0     03995    3 0.35   3 0.01   3-0.05  0.0 0.000    3  0.1 0.1 0.3 0.00   0   0   0    0    1 0.1    0 0.0
N R LB  1*AGE**      1    1     0     03995    3 0.35   3 0.01   3-0.05  0.0 0.000    3  0.1 0.1 0.3 0.00   0   0   0    0    1 0.1    0 0.0
N R LB**CLASS**      1    1     0     03995    3 0.35   3 0.01   3-0.05  0.0 0.000    3  0.1 0.1 0.3 0.00   0   0   0    0    1 0.1    0 0.0
```

1. Class of individuals simulated
2. Age group
3. Lactation status
4. Period of gestation
5. No. in groups
6. No. of deaths in group
7. Stillbirths
8. Live births
9. Age in periods
10. AVG weight and ADG for a group, kg.
11. AVG WM and ADG of WM, kg.
12. AVG weight of lean and ADG of lean, kg.
13. AVG fleece weight and ADG of wool, kg.
14. AVG empty body weight and ADG of EBW, k
15. Dry matter intake, kg.
16. Energy contained in DM, Mcal ME/day
17. Digestible crude protein, kg/day
18. No. of pregnant ewes and number of fetuses.
19. Percent of ewes in estrus.
20. No. of ewes lactating and total amount of milk produced.
21. No. of ewes lactating and the amount used for dairy.

TABLE 5. Lamb Summary

```
************** LAMB SUMMARY BY BIRTH PERIOD, SEX, EWE AGE AND TYPE BIRTH FOR FLOCK 1 IN PERIOD  6 YEAR  3**************

-------------------------------------------------------------------------------------------------------------------------------------
BTH S ①---1.0---  ---1.5---  ---2.0---  ---2.5---  ---3.0---  ---4.0---  ---5.0---  ---6.0---  ---7.0---  ---8.0---  ---AVG---
PRD X ②SNGL MLTP  SNGL MLTP  SNGL MLTP  SNGL MLTP  SNGL MLTP  SNGL MLTP  SNGL MLTP  SNGL MLTP  SNGL MLTP  SNGL MLTP  SNGL MLTP
-------------------------------------------------------------------------------------------------------------------------------------
③MR1 ④PM   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.1  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.1  0.0  ⑧
 ⑤  E NO     0    0     0    0     0    0     0    0     0    0     0    0     1    0     0    0     0    0     0    0     1    0
    ⑥  W   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   3.3  0.0   0.0  0.0   0.0  0.0   0.0  0.0   3.3  0.0
  ⑦    WM  0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   2.6  0.0   0.0  0.0   0.0  0.0   0.0  0.0   2.6  0.0

 NV1    PM  0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0
      W NO    0    0     0    0     0    0     0    0     0    0     0    0     1    0     0    0     0    0     0    0     1    0
         W  0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   6.3  0.0   0.0  0.0   0.0  0.0   0.0  0.0   6.3  0.0
        WM  0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   2.8  0.0   0.0  0.0   0.0  0.0   0.0  0.0   2.8  0.0

⑨AVG    PM  0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0  ⑩
      E NO    0    0     0    0     0    0     0    0     0    0     0    0     1    0     0    0     0    0     0    0     1    0
         W  0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   3.3  0.0   0.0  0.0   0.0  0.0   0.0  0.0   3.3  0.0
        WM  0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   2.6  0.0   0.0  0.0   0.0  0.0   0.0  0.0   2.6  0.0
      W NO    0    0     0    0     0    0     0    0     0    0     0    0     1    0     0    0     0    0     0    0     1    0
         W  0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   6.3  0.0   0.0  0.0   0.0  0.0   0.0  0.0   6.3  0.0
        WM  0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0   2.8  0.0   0.0  0.0   0.0  0.0   0.0  0.0   2.8  0.0
```

1. Ewe age groups
2. Designation of single or multiple births
3. Birth period
4. Milk produced by the ewe for the lamb, kg.
5. No. and sex of lambs within type of birth and ewe age group
6. AVG body weight, kg.
7. AVG WM, kg.
8. AVG of lambs born in the same period
9. AVG across period of birth and within type of birth and ewe age group, kg.
10. Grand av. of lamb AVG across period of birth and ewe age groups and within type of birth, kg.

TABLE 6. Management Summary

```
******************************* MANAGEMENT SUMMARY FOR PERIOD  6 YEAR   3 *******************************

                                 ⑥        ⑦
-------------------------------------------------------------------------------------------------------------
                         ⑤  ---TRANSFERS---    ⑧            ⑪    ⑫   ⑬  ⑭  ⑮  ⑯  ⑰  ⑱  ⑲   ⑳      ㉑
①②③        ④         INTL  BTW FLK W/I FLK LIVE  ⑨   ⑩    END  SHRN  -----------EWES-----------  DEAD  --HEADERS--
YR F PER  CLASS        NO.   IN OUT  IN OUT BTHS DTH MRT    NO.   NO. PRG EXP MAT CCV ABR LMB PRG BRTH  FIRST  LAST
-------------------------------------------------------------------------------------------------------------
83 1 MR2 S E LB         0    0   0   0   0    0   0   0     0     0   0   0   0   0   0   0   0    0     3     3
83 1 MR2 S EWE          0    0   0   0   0    0   0   0     0     0   0   0   0   0   0   0   0    0     4     4
83 1 MR2 BR EWE        29    0   0   0   0    0   0   0    29     0  25   5   0   0   0   1  24    0     5   166
83 1 MR2 RP EWE         1    0   0   0   0    0   0   0     1     0   0   1   0   0   0   0   0    0     6   217
83 1 MR2 N E LB         1    0   0   1   0    1   0   0     2     0   0   0   0   0   0   0   0    0     7   246
83 1 MR2 MUTTON         0    0   0   0   0    0   0   0     0     0   0   0   0   0   0   0   0    0     8     8
83 1 MR2 WETHER         1    0   0   1   0    0   0   0     2     0   0   0   0   0   0   0   0    0     9   211
83 1 MR2 N W LB         1    0   0   0   1    0   0   0     0     0   0   0   0   0   0   0   0    0    10    10
83 1 MR2 S R LB         0    0   0   0   0    0   0   0     0     0   0   0   0   0   0   0   0    0    11    11
83 1 MR2 BR RAM         0    0   0   0   0    0   0   0     0     0   0   0   0   0   0   0   0    0    12    12
83 1 MR2 RP RAM         0    0   0   0   0    0   0   0     0     0   0   0   0   0   0   0   0    0    13    13
83 1 MR2 N R LB         1    0   0   0   1    0   1   0     0     0   0   0   0   0   0   0   0    0    14    14

   1 BIRTHS      1 DEATHS      0 STILL BIRTHS      1 WEANED      0 SALES IN PERIOD      6
-------------------------------------------------------------------------------------------------------------
```

1. Year of simulation
2. Flock number
3. Period of the simulated year
4. Class of sheep
5. Initial number
6. Transfer of individuals between flocks
7. Transfer of individuals within the same flock.
8. Live births for the period
9. No. of deaths per class
10. No. of sheep marketed per class
11. No. of sheep per class at the end of the period.
12. No. of sheep shorn
13. No. of pregnant ewes at the beginning of the period
14. No. of ewes exposed to rams for breeding
15. No. of ewes mated in the current period
16. No. of ewes conceiving in the current period
17. No. of abortions occurring in the current period
18. No. of ewes lambing
19. No. of pregnant ewes at the end of the period
20. No. of stillbirths
21. Headers that identify the first and last numbers in the linked lists.

TABLE 7. Yearly Summary

```
                   ***************************SUMMARY FOR YEAR  2 BY CLASS W/I FLOCK W/I PERIOD ***************************
①②  ③
-------------------------------------------------------------------------------------------------------------------------------------
    F              STL LIV      ----W--- ---WM--- ---WL--- FLEECE WT  EMPTY WT                  --NO PREG--  %   --MILK- -DAIRY-
PER L  CLASS NUM DTH BIR BIR AGE AVG  ADG AVG  ADG AVG  ADG AVG    ADG AVG  ADG  DM DME  TPR SNG TWN TRP CYC  NO AVG  NO AVG
-------------------------------------------------------------------------------------------------------------------------------------

④JA1 1 BR EWE  10   0   0   0  87  38 0.18  34 0.11  25 0.00  0.0 0.000  34 -0.0 0.9 1.6 0.05   8   1   1   0   0 0.00  0 0.00

JA2 1 BR EWE  10   0   0   0  88  38 0.37  34 0.10  25 0.06  0.0 0.000  35  0.1 0.9 1.6 0.05   8   1   1   0   0 0.00  0 0.00

FB1 1 BR EWE  10   0   0   0  89  39 0.71  34 0.09  26 0.13  0.0 0.000  35  0.3 1.0 1.9 0.07   8   1   1   0   0 0.00  0 0.00

FB2 1 BR EWE  10   0   0   0  90  40 1.16  34 0.09  26 0.10  0.0 0.000  35  0.2 1.0 1.9 0.07   8   1   1   0   0 0.00  0 0.00

MR1 1 BR EWE  10   0   0   0  91  38-1.75  34 0.08  24-2.16  0.0 0.000  32 -3.0 0.5 0.8 0.01   8   1   1   0   0 0.00  0 0.00

MR2 1 BR EWE  10   0   0   0  92  36-0.53  34 0.06  22-1.43  0.0 0.000  30 -1.9 0.5 0.7 0.01   3   0   0  70   0 0.00  7 0.00
MR2 1 N E LB   7   0   0   0   0   2 0.00   2 0.00   2 0.00  0.0 0.000   2  0.0 0.0 0.0 0.00   0   0   0   0   0 0.00  0 0.00
MR2 1 N R LB   3   0   0   0   0   2 0.00   2 0.00   2 0.00  0.0 0.000   2  0.0 0.0 0.0 0.00   0   0   0   0   0 0.00  0 0.00

AP1 1 BR EWE  10   0   0   4  93  34-0.95  34 0.03  21-0.75  0.0 0.000  29 -1.4 0.8 1.4 0.04   1   0   0  90   7 0.61  7 0.11
AP1 1 N E LB   8   4   0   01975   3 1.10   2 0.75   2 0.68  0.0 0.000   3  0.8 0.0 0.3 0.02   0   0   0   0   7 0.32  0 0.00
AP1 1 N R LB   4   2   0   01975   3 1.20   3 0.88   3 0.79  0.0 0.000   3  1.0 0.0 0.4 0.02   0   0   0   0   3 0.42  0 0.00
```

1. Period of the year
2. Flock number
3. Class of sheep simulated
4. Class average within flock and period

Note: All other columns in yearly summary are the same as those in the flock summary.

TABLE 8. Run Summary

```
                          ................................ RUN SUMMARY ................................
①② ③         ④     ⑤     ⑥    ⑦      ⑧         ⑨          ⑩        ⑪        ⑫    ⑬          ⑭              ⑮ ⑯  ⑰     ⑱    ⑲
------------------------------------------------------------------------------------------------------------------------------
                                                ----------------SALES----------------
      INTL NO.         DEATHS      TRANSFR  END NO.  MKT LAMBS  --CULLS  TOTAL                ----FEED INTAKE----  LAMBING LMB SWT/EWE MLK
YR F TOT   EWE BRTH PRN PSN SLD  IN OUT  TOT  EWE  NO      WT  NO    WT    WT  FIBER  MILK   D.M.   DME   PROT  %  RATE SUR LMB TOT AVE
------------------------------------------------------------------------------------------------------------------------------

 1 1  10   10    0   0   0   0   0   0   10   10   0       0   0     0     0     0  0.00     47    95      0   0    0   0   0   0  0.0
 1 2   0    0    0   0   0   0   0   0    0    0   0       0   0     0     0     0  0.00      0     0      0   0    0   0   0   0  0.0
 1 3   0    0    0   0   0   0   0   0    0    0   0       0   0     0     0     0  0.00      0     0      0   0    0   0   0   0  0.0
 1 4   0    0    0   0   0   0   0   0    0    0   0       0   0     0     0     0  0.00      0     0      0   0    0   0   0   0  0.0
 1 5   0    0    0   0   0   0   0   0    0    0   0       0   0     0     0     0  0.00      0     0      0   0    0   0   0   0  0.0
 1 6   0    0    0   0   0   0   0   0    0    0   0       0   0     0     0     0  0.00      0     0      0   0    0   0   0   0  0.0
 1 7  10   10    0   0   0   0   0   0   10   10   0       0   0     0     0     0  0.00     47    95      0   0    0   0   0   0  0.0
```

1. Simulation year number
2. Flock number, where 7 is the total of all six flocks
3. Initial total no. of sheep and ewes for the year
4. No. of births
5. Prenatal (PRN) and postnatal (PSN) deaths
6. No. of sheep sold
7. No. of transfers in and out of the flock
8. Total no. of sheep and the total no. of ewes at the end of the year
9. No. and weight of lambs sold, kg.
10. No. and weight of culls sold, kg.
11. Total weight sold, kg.
12. Total fiber produced in a year, kg.
13. Total milk produced for dairy purposes, kg.
14. Dry matter, energy and protein intake for the entire flock, kg.
15. Lambing percentage, no. of parturitions/no. of ewes at first of year
16. Lambing rate, no. of births per year/no. of parturitions
17. Lamb survival rate, no. of lambs weaned/no. of lambs born
18. Sale weight sold per ewe, by lamb weight and total weight
19. Av. milk produced per ewe in flock

lactation, growth and maintenance) may be printed out. Such information would be useful in planning feed supplementation policies.

6. MODEL VALIDATION

A critical area of systems analysis is validation. For use of the Texas A&M Sheep or Goat Production Systems Model, the validation process examines how closely simulated results match actual data thus testing both model structure and functions and input parameters. Closeness of correspondence establishes the level of confidence in the simulated results. When the simulation data match with reasonable closeness the actual production levels and fluctuations in those levels in every phase of the production system in the area of intended use, experimental simulations can be conducted with more confidence.

I. Single Animal Version - SAV

Before validating the flock model (FM), the SAV was tested to determine if the biological assumptions and equations are representative of a sheep's biology. One of the model components of the SAV least tested is the method used to calculate milk production. In the process of validating milk production, it was possible to also evaluate the model's response for ewe body weight, feed intake and lamb growth.

Two experiments were chosen to validate the basic structure and functions of the milk portion of the SAV model. These experiments were selected because they included information on milk production, ewe body weight, feed intake and feed quality.

Barnicoat et al. (1949a,b) reported a series of experiments involving the milk production of Romney ewes. The portion of this paper selected for simulation involved 42 five-year-old ewes. The experimental treatments consisted of placing the ewes in two groups on a high or low level of feed intake prior to and after lambing. The ration was composed of lucerne hay and a concentrate. The study started 51 days prior to lambing and lasted 84 days after lambing. After lambing, every alternate ewe in each group was transferred to the other treatment group. Lactation data were collected for 12 weeks. Milk production was measured 6 times in 24 hr, once every week, using the weigh- suckle-weigh technique.

The results from Barnicoat et al. (1949a) indicate that type of birth and ration had highly significant effects on milk production from 0 to 6 weeks. During the last half of lactation (7 to 12 weeks) differences were found for ration (P<.01). These workers concluded that feed level during pregnancy is second in importance for maintaining milk yield, that feed level during lactation is the primary factor influencing both initial and total milk yield, and that the maximum yield is obtained only by liberal feeding during late pregnancy and throughout lactation.

Treacher (1970) reported the second experiment used for validation. He utilized 32 Scottish half-breed ewes (Border Leicester x Cheviot) which were all pregnant for the third time and all of which were carrying twin fetuses. Three treatments were used to determine the effects of nutrition in late pregnancy on milk production. The treatments consisted of feeding ewes during the last six weeks of pregnancy so they would gain 20, 10, and 0% of their initial live weight. The ewes were individually fed during pregnancy and fed ad lib after parturition.

Milk production was measured by milking the ewes twice daily using a milking machine. Lambs were removed shortly after birth. The level of milk production for treatment groups ranked 20, 10, and 0% for peak milk production during the six-week lactation period.

a. Model Parameters

To simulate the experiments performed by Barnicoat et al. (1949 a,b) and Treacher (1970) genetic, management and forage parameters had to be specified. For Barnicoat et al. (1949a), digestible organic matter and crude protein were 57 and 17%, respectively. The WMA and genetic potential for milk were set at 60 kg and 2.2 kg/day at peak lactation. These levels were derived by examining other reports in the literature which involved Romney sheep (Jagusch et al., 1972; Geentry and Jagusch, 1974).

Treacher (1970) fed his ewes a ration which consisted of 60% digestible organic matter and 25% crude protein. Due to the breed type used in this experiment (Border Leicester x Cheviot) it was difficult to find corroborative values for mature size and peak milk production. Therefore the values used for WMA and GMLKL were set at 70 kg and 1.8 kg/day. These values appear to be reasonable when the mature weight and milk production of the parental breeds are considered. The availabilities of feed were set equal to the actual intakes of ewes reported in the respective papers by Treacher (1970) and Barnicoat et al. (1949a) (figures 32, 36, 37 and 38).

In both simulated sets, the ewes were bred and fed at nutritional levels so that they would be at the same stage of pregnancy and approximately the same weight at the beginning of the experiment.

b. Simulated Results.

The simulated results from the Treacher experiment generally indicate a close agreement with the actual data. For all treatments the simulated feed intakes mimicked the shape and the magnitudes of the actual changes in intake (figure 32). The largest difference occurred in the 20% treatment where the difference between simulated and actual intake is approximately 10% for the fourth through the seventh period of simulation. The remaining treatments had very close agreement between simulated and actual results.

The ewe body weights (figures 33 and 34) tend to parallel the reported results. The magnitude of differences averaged less than 10% across all treatments for the duration of the experiment.

After parturition there was close agreement between the actual and simulated body weights for the ewes of this experiment. There was a tendency for the simulated ewes on the 20% treatment to gain more weight on less feed than the actual ewes in the postpartum period (figure 34).

The simulated results for milk production were similar for all three treatment groups (figure 34 and 35). The closest agreement with actual data was in the 20% treatment. The differences between actual and simulated data increased as the percent body weight gain in pregnancy decreased. A possible explanation for the differences which exist in the 0% gain group is that Treacher's ewes were in poor condition and therefore partitioned a greater percentage of their nutrient intake to body reserves and less to milk production. However, the SAV does allow a ewe to redeposit lean and fat while producing a relatively large quantity of milk. Other discrepancies may be present due to the machine milking of the ewes, therefore depriving the ewes of the continuous suckling stimulus that they might otherwise have.

The feed intakes for the Barnicoat et al. (1949a) ewes are shown in figures 36, 37 and 38. Not shown are the intake of ewes on the L/L ration since the simulated and actual intakes of this group were equal and

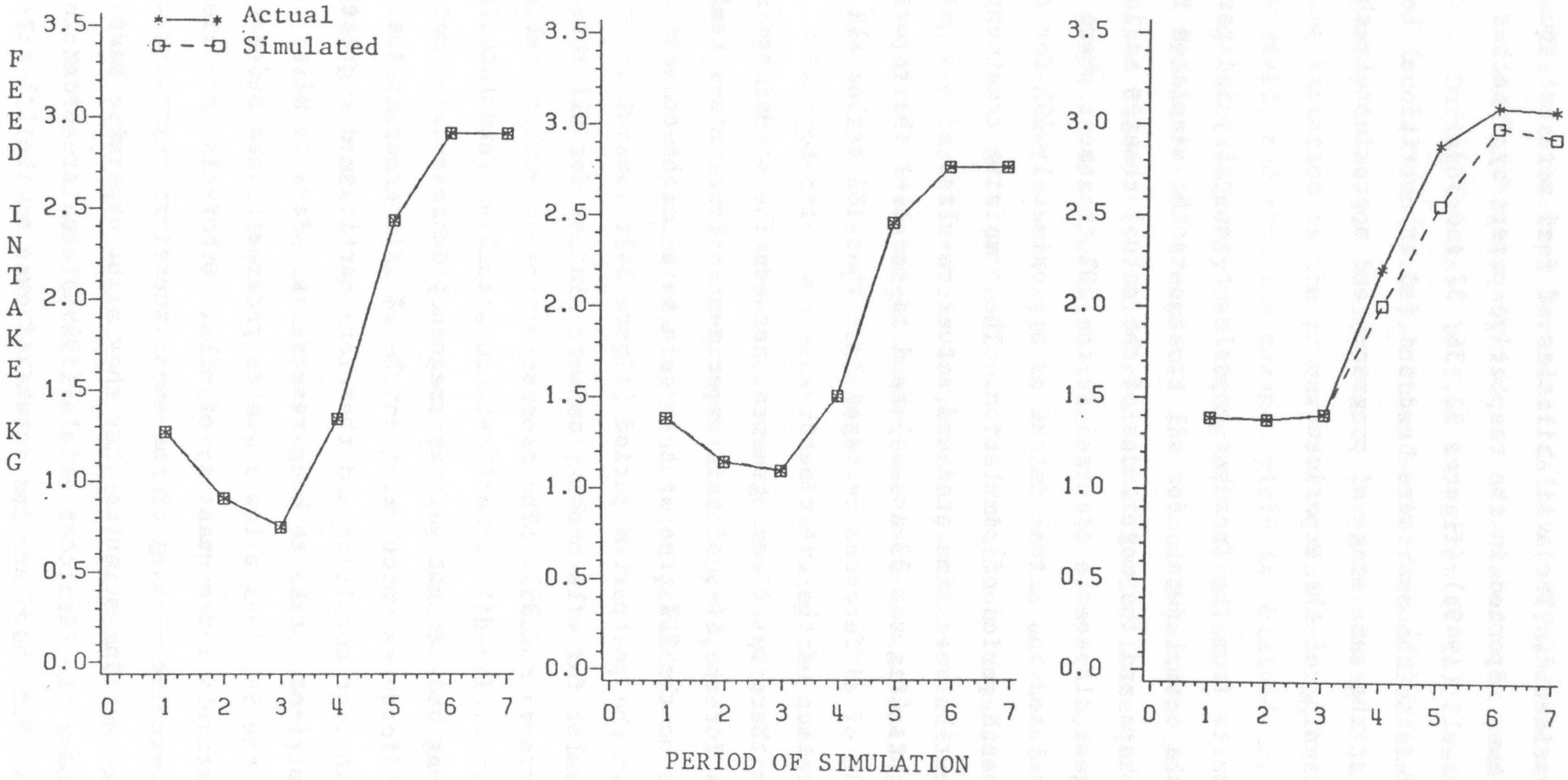

Figure 32. Feed intakes of ewes fed to gain 0, 10 and 20% of their body weight, repectively.

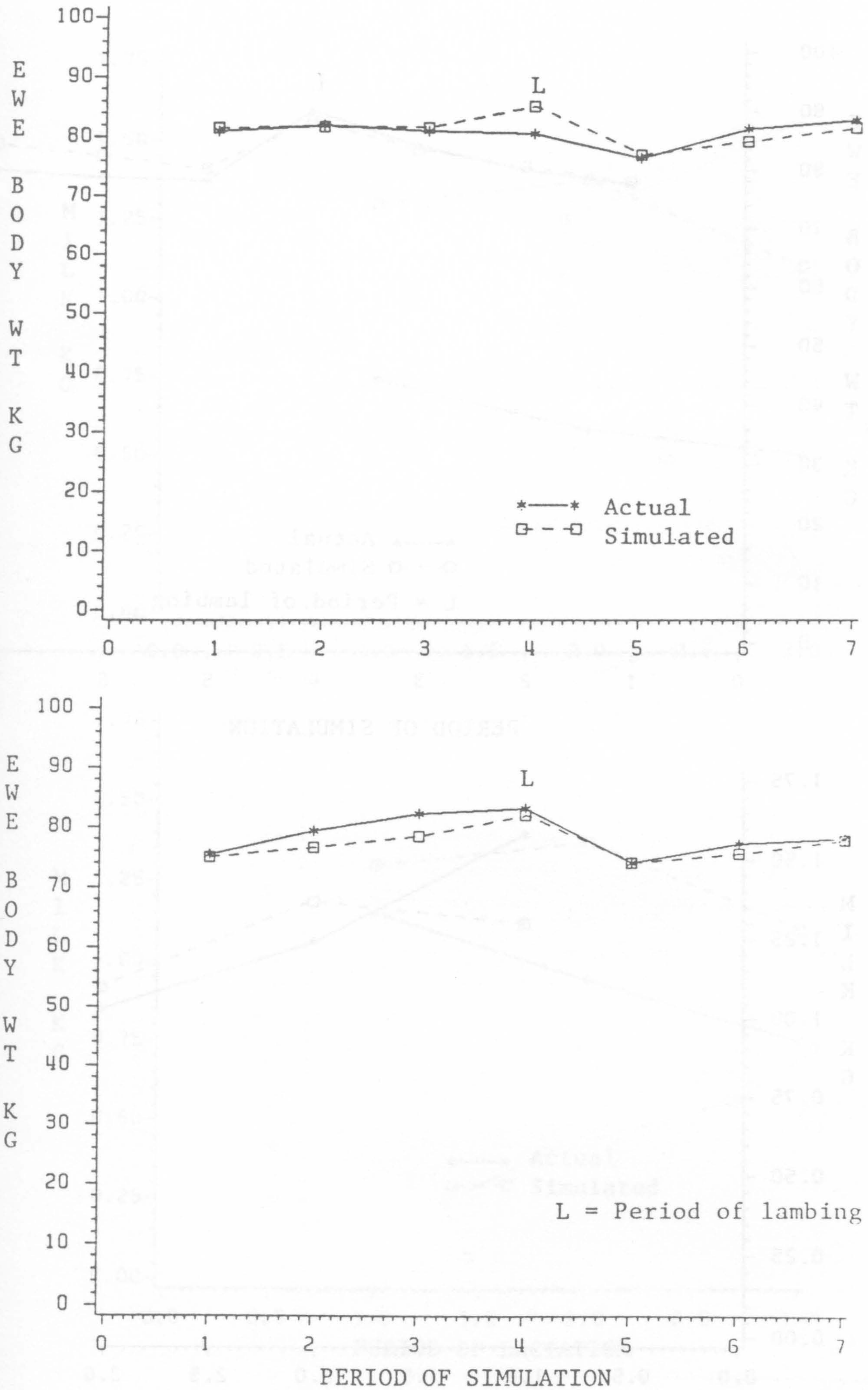

Figure 33. Actual and simulated body weights for ewes fed to gain 0 or 10% of their body weight, respectively.

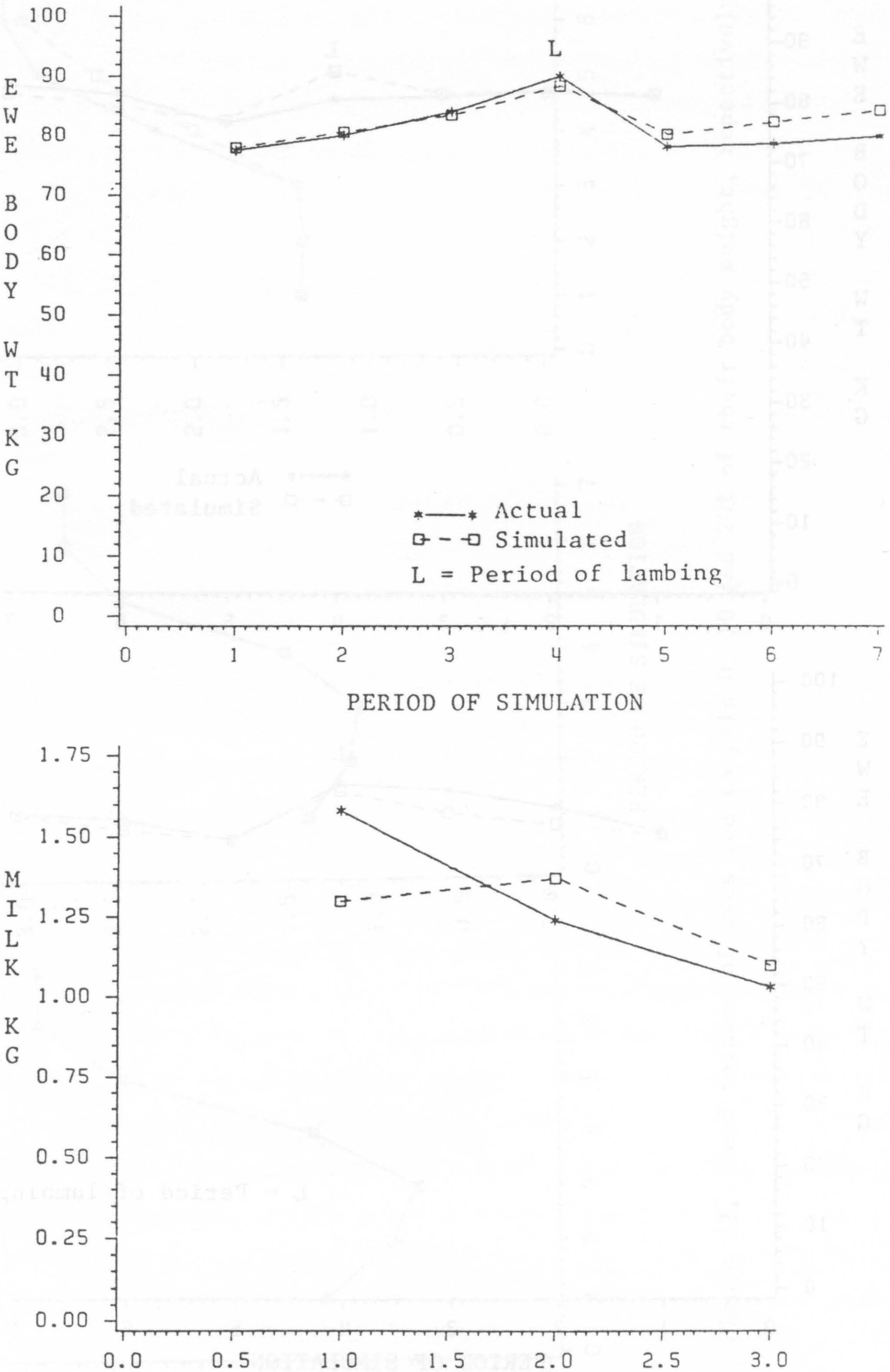

Figure 34. Actual and simulated ewe body weight and milk production for ewes fed to gain 20% of their body weight.

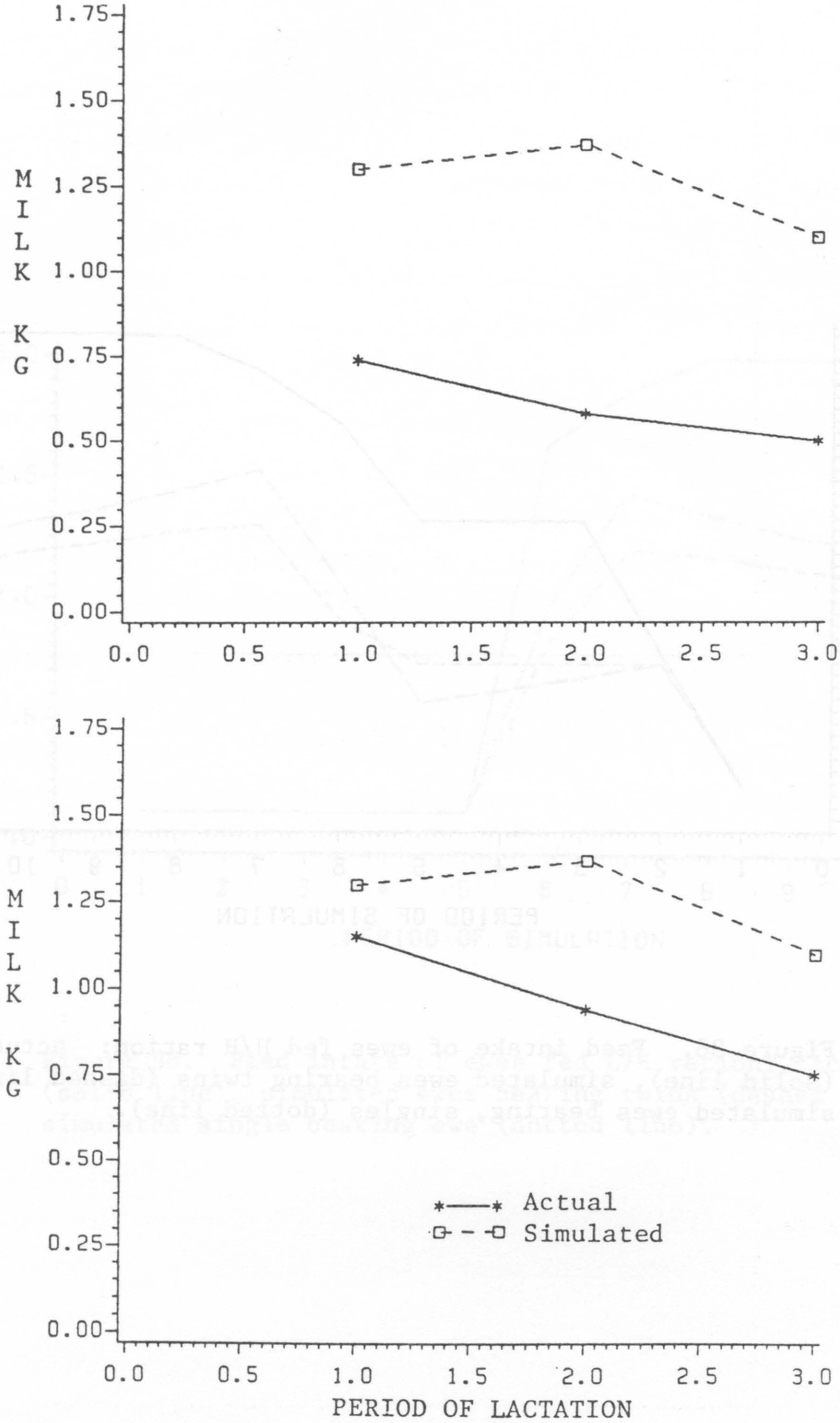

Figure 35. Actual and simulated milk production of ewes fed to gain 0 and 10% of their body weights, respectively.

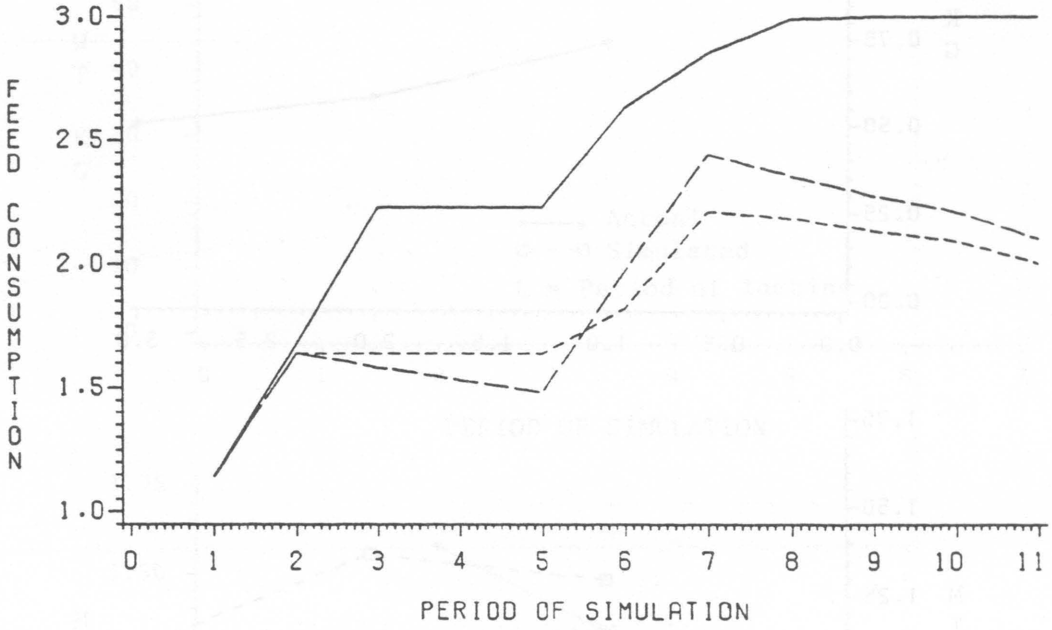

Figure 36. Feed intake of ewes fed H/H ration: actual intake (solid line), simulated ewes bearing twins (dashed line) and simulated ewes bearing, singles (dotted line).

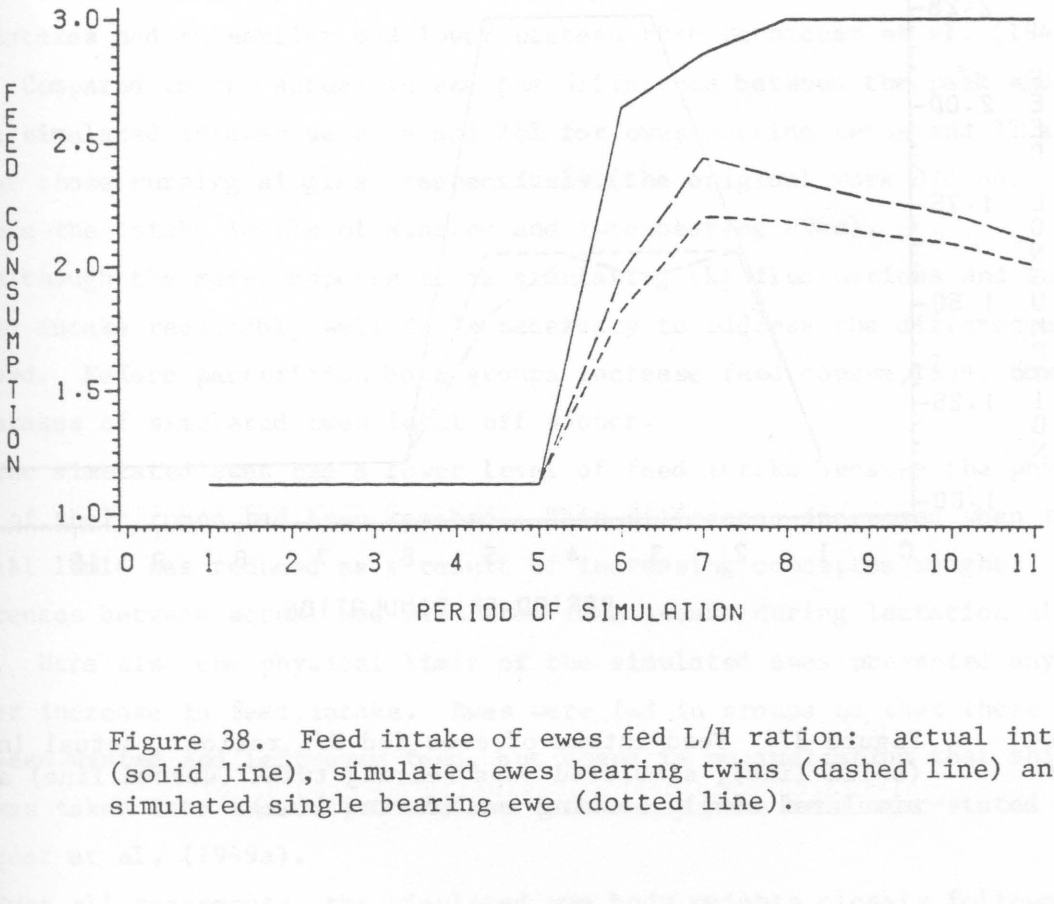

Figure 38. Feed intake of ewes fed L/H ration: actual intake (solid line), simulated ewes bearing twins (dashed line) and simulated single bearing ewe (dotted line).

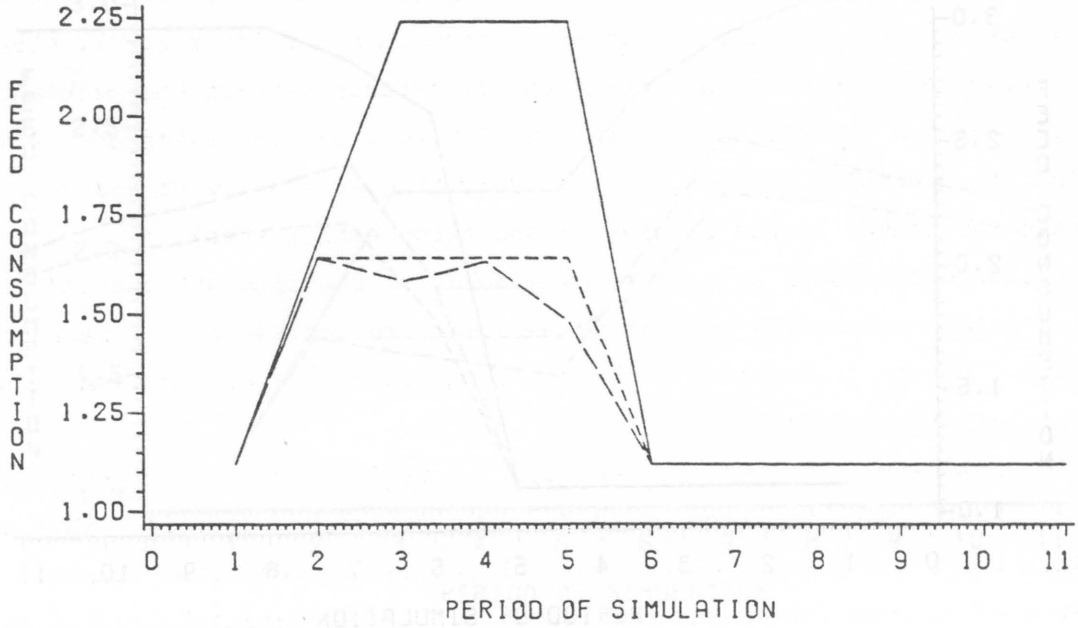

Figure 37. Feed intake of ewes fed H/L ration: actual intake (solid line), simulated ewes bearing twins (dashed line) and simulated single bearing ewe (dotted line).

consistent at 1.12 kg/day. The simulated intakes of the H/L, H/H and L/H ewes were in general agreement in shape and fluctuation of the actual data, but there were magnitude differences for all three groups. During the later stages of pregnancy, intake of the simulated H/L ewes carrying twin fetuses decreased. This is a programmed adjustment of the rumen capacity which increases during gestation to represent the decrease in rumen volume due to the increased conceptus size.

Before parturition the differences between actual and simulated intakes were 26 and 34% for single- and twin-bearing ewes. After lambing, simulated feed intakes had an earlier and lower plateau than Barnicoat et al. (1949a) ewes. Compared to the actual intake the difference between the peak and ending simulated intakes were 14 and 26% for ewes nursing twins and 22 and 30% for those nursing singles, respectively (the original work did not separate the intake levels of single- and twin-bearing ewes).

Although the model appears to be simulating the fluctuations and levels of feed intake reasonably well it is necessary to address the differences observed. Before parturition both groups increase feed consumption, however, the intakes of simulated ewes level off sooner.

The simulated ewes had a lower level of feed intake because the physical limit of their rumen had been reached. This difference increased when the physical limit was reduced as a result of increasing conceptus weight. Differences between actual and simulated feed intake during lactation also exist. Here also the physical limit of the simulated ewes prevented any further increase in feed intake. Ewes were fed in groups so that there must have been wasted and left-over feed, but there is no indication that this feed was taken into account; therefore intake may have been over-stated by Barnicoat et al. (1949a).

Over all treatments, the simulated ewe body weights closely followed the weight and weight fluctuations of the Romney ewes with mean differences of less than 10% (figures 39 and 40) at any time. Divergence of the simulated and actual results occurred during the later stages of gestation and in the later periods of lactation.

The H/H simulated ewes consistently gained more weight than the actual ewes as the postpartum interval lengthened. Comparing the single and twin simulations within a treatment, the effects of bearing and nursing twins are

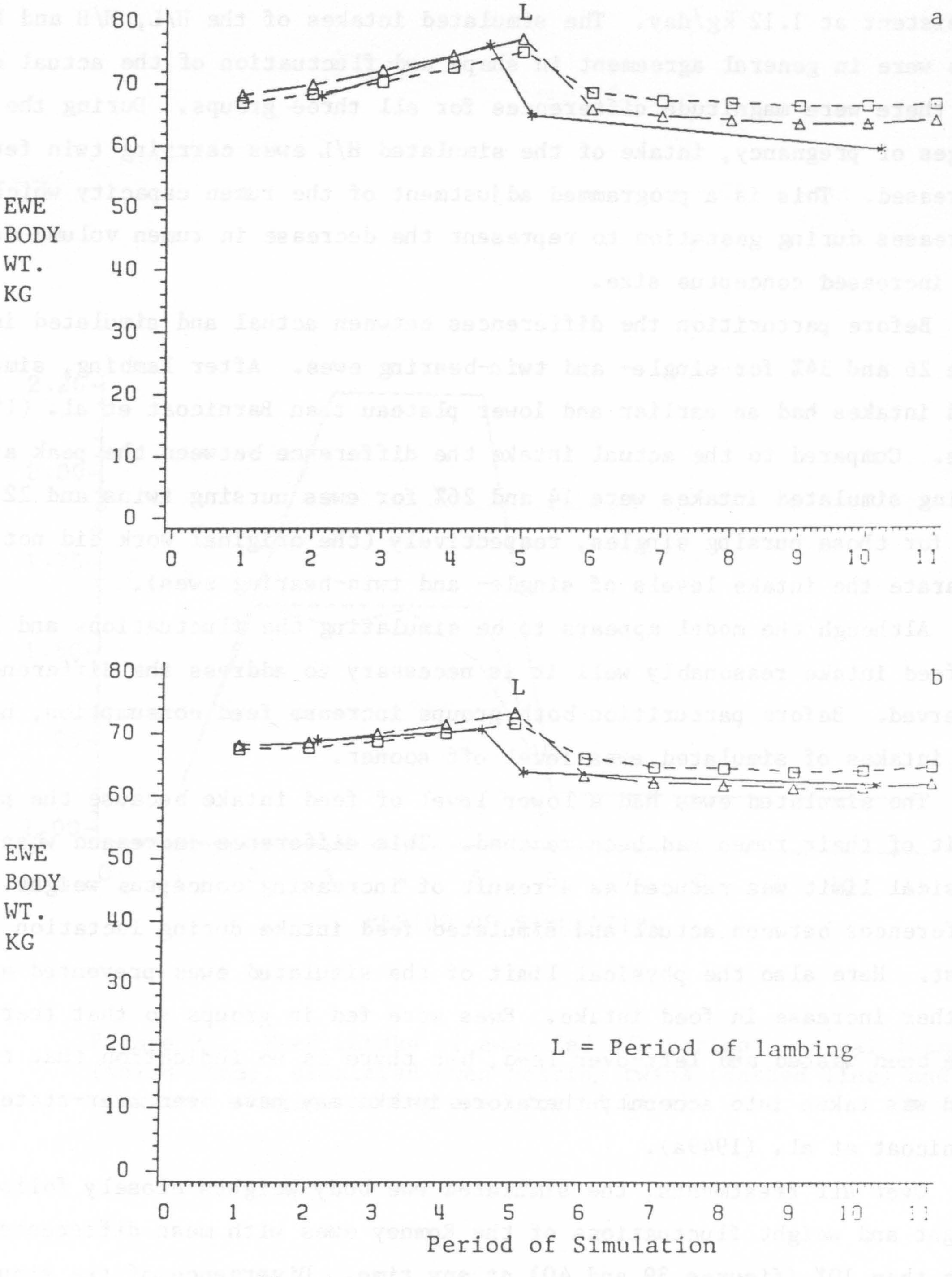

Figure 39. a) Ewe body weights for the H/H ration
b) Ewe body weights for the L/H ration. For each graph actual weight (*), ewe bearing twin lambs (Δ) and ewe bearing a single lamb (□).

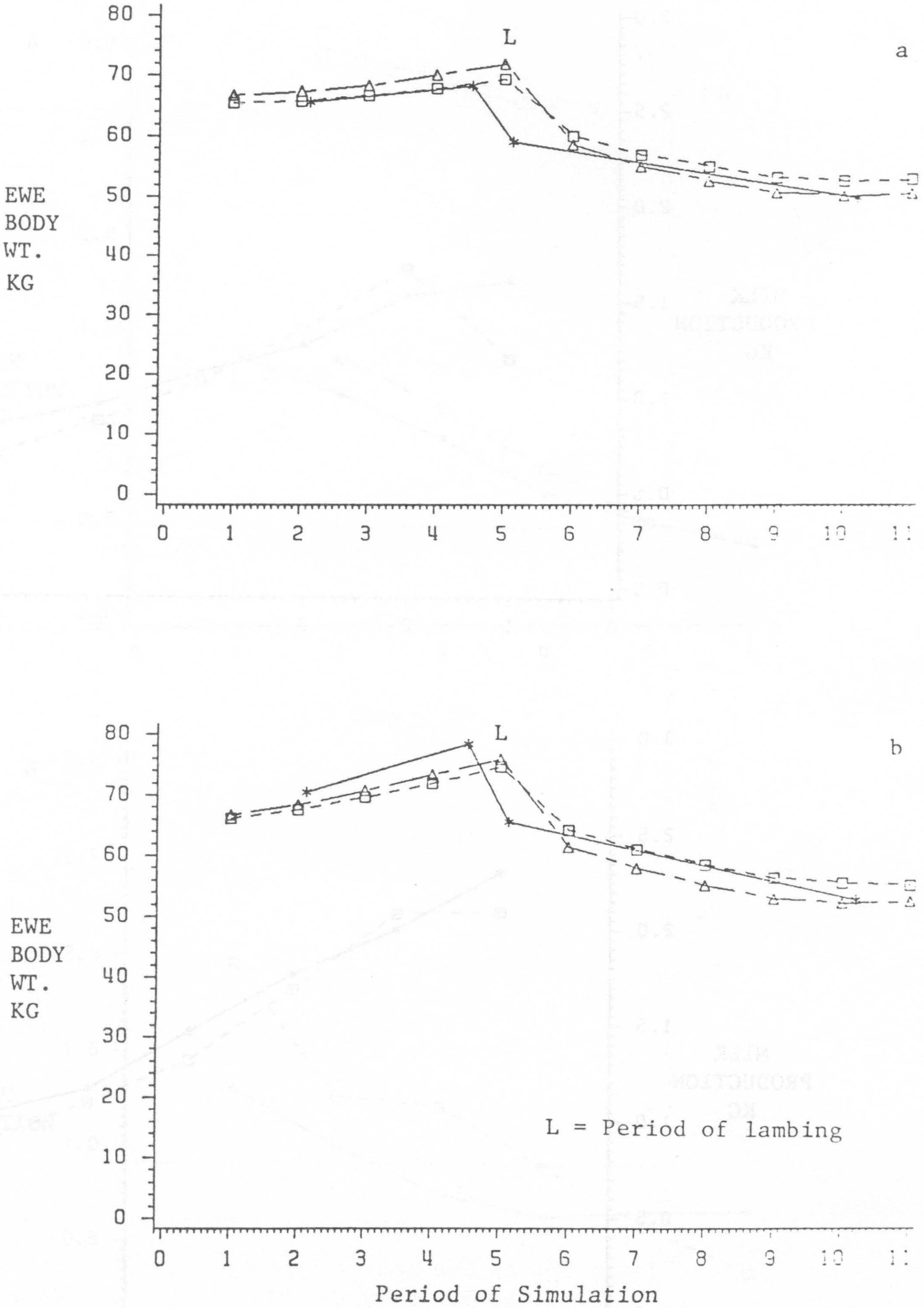

Figure 40. a) Ewe body weights for the L/L ration.
b) Ewe body weights for the H/L ration.
For each graph, actual weights (*), ewe bearing twin lambs (Δ) and ewe bearing a single lamb (□).

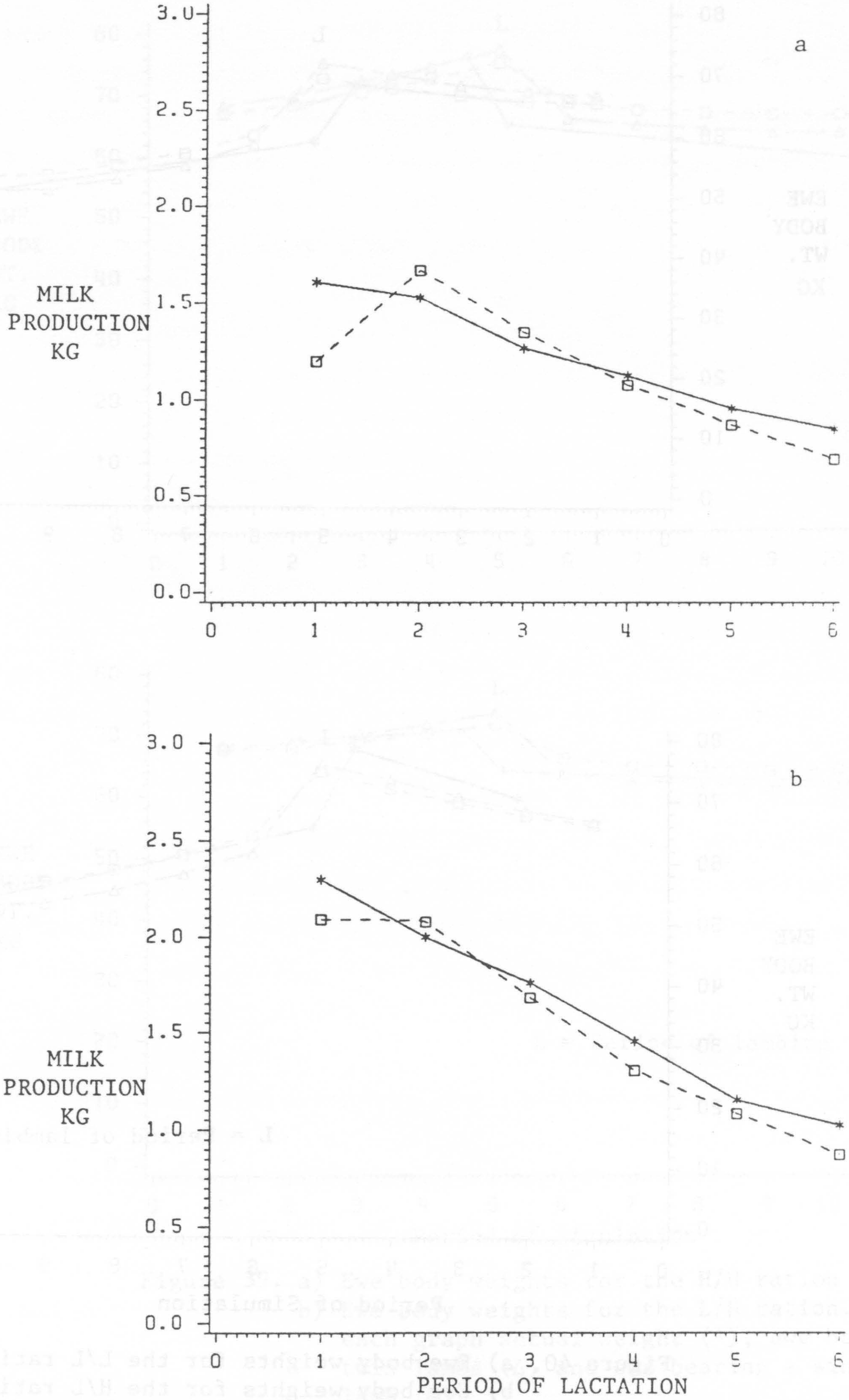

Figure 41. Milk production of ewes fed H/H ration, a) ewes nursing singles and b) ewes nursing twins. * Actual, □ Simulated

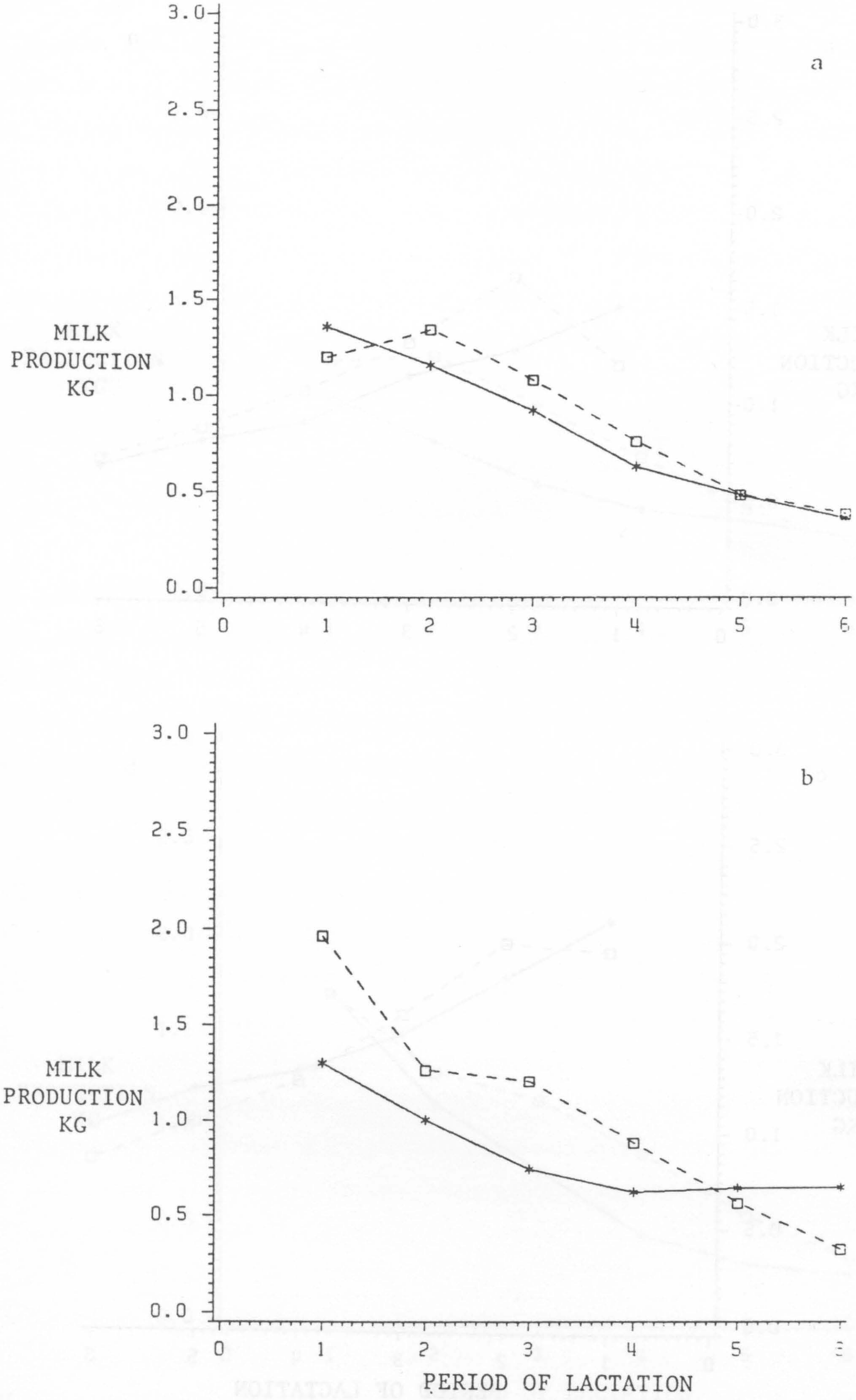

Figure 42. Milk production of ewes fed H/L ration a) ewes nursing singles and b) ewes nursing twins. * Actual, □ Simulated

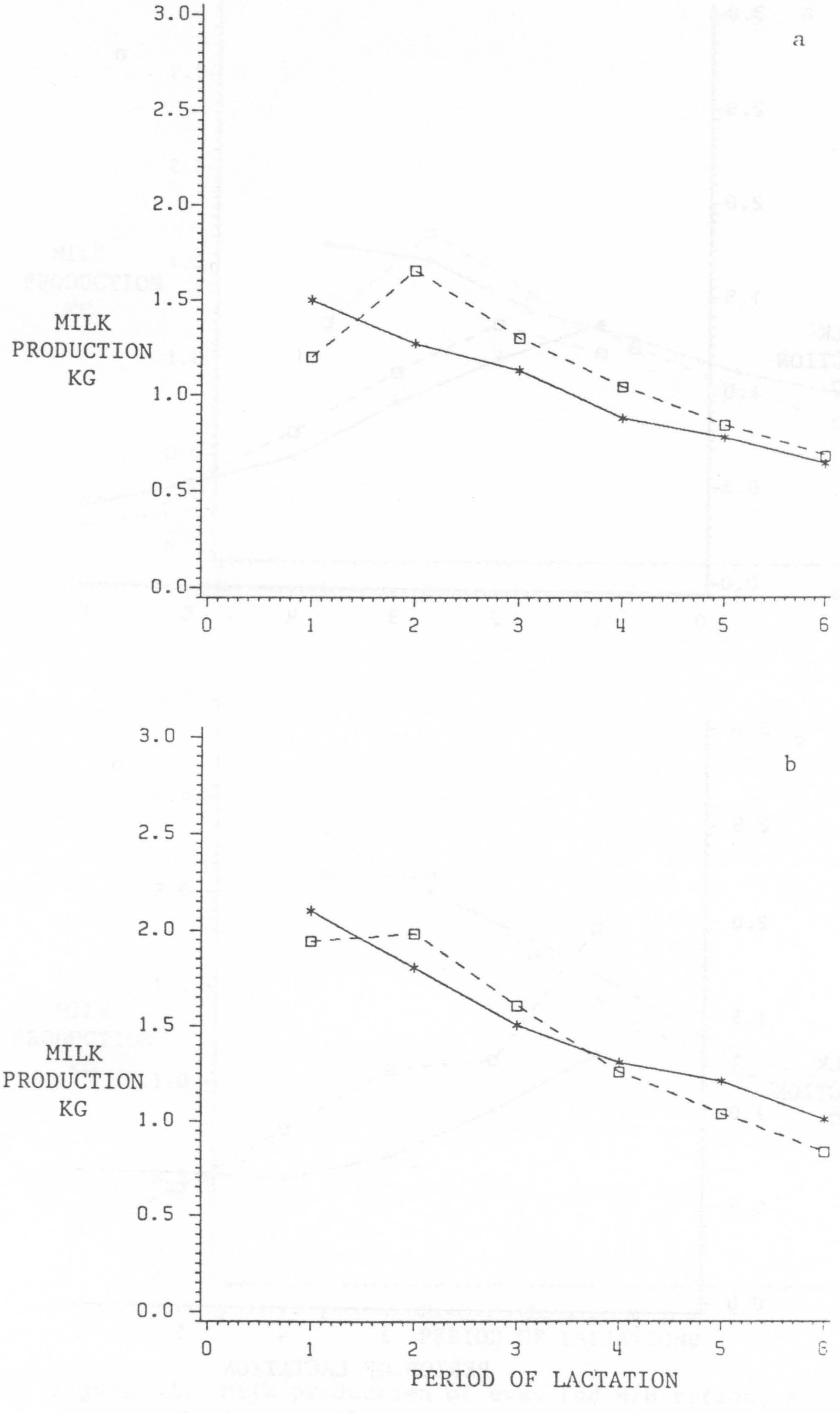

Figure 43. Milk production of ewes fed L/H ration a) ewes nursing singles and b) ewes nursing twins. * Actual, ◻ Simulated

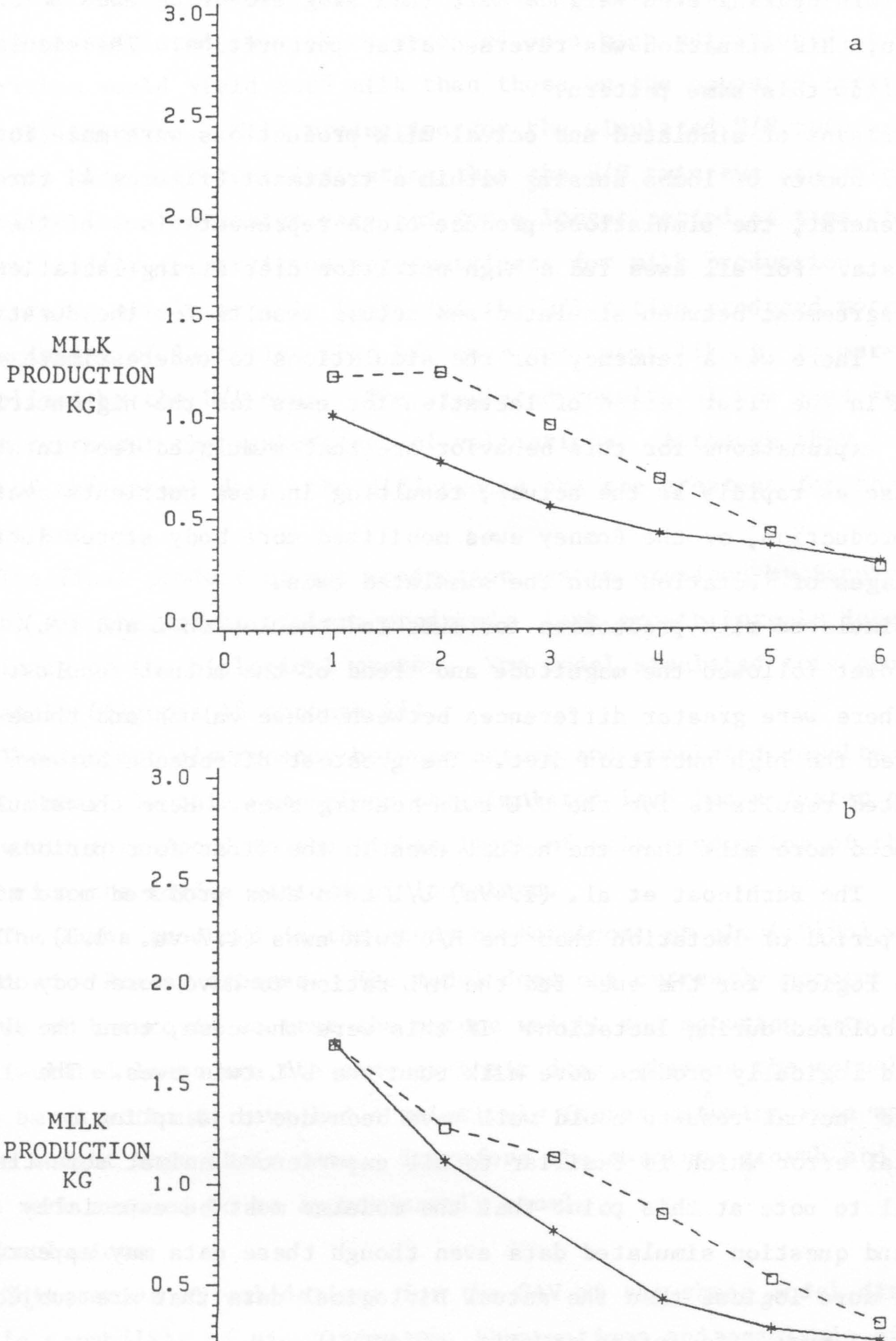

Figure 44. Milk production of ewes fed L/L ration a) ewes nursing singles and b) ewes nursing twins. * Actual, ◻ Simulated

evident. Twin-bearing ewes weighed more than single-bearing ewes prior to parturition, this situation was reversed after parturition. The simulated results follow this same pattern.

Comparisons of simulated and actual milk productions were made for each ration and number of lambs nursing within a treatment (figures 41 through 44). In general, the simulations produce close representations of the reported data. For all ewes fed a high nutrition diet during lactation there was close agreement between simulated and actual results for the duration of lactation. There was a tendency for the simulations to underestimate milk production in the first period of lactation for ewes fed the high nutrition diet. Two explanations for this behavior are that simulated feed intake did not increase as rapidly as the actual, resulting in less nutrients available for milk production, or the Romney ewes mobilized more body stores during the initial stages of lactation than the simulated ewes.

The simulated milk production for ewes fed the low (H/L and L/L) nutrition diet followed the magnitude and trend of the actual results. However, there were greater differences between these values and those for the ewes fed the high nutrition diet. The greatest difference between actual and simulated results is for the H/L twin-bearing ewes. Here the simulated ewes produced more milk than the actual ewes in the first four periods of lactation. The Barnicoat et al. (1949a) L/L twin ewes produced more milk in the first period of lactation than the H/L twin ewes (1.7 vs. 1.3). It would seem logical for the ewes fed the H/L ration to have more body stores to be catabolized during lactation. If this were the case, then the H/L twin ewes should logically produce more milk than the L/L twin ewes. The "unexpected" actual results could well have been due to sampling or experimental error which is familiar to all experienced animal scientists. (It is well to note at this point that the modeler must be especially cautious and question simulated data even though these data may appear, and often are, more logical than the actual biological data that are subject to a vast array of real life, often cryptic, effects.)

Comparing the simulations between different rations, the simulated output agrees with the conclusion of Barnicoat et al. (1949a) that the current level of feeding is more important than the previous level of feeding for the determination of total milk yield. However, it would be expected that those simulated ewes which were fed on a high nutrition diet before parturition would yield more milk than those on the opposite treatment due to more body reserves. Milk production for the simulated H/H twin and the L/H twin ewes were different indicating that the H/H twin ewe was able to catabolize fat at a faster rate and for a longer period of time than the L/H twin ewe and/or to partition more nutrients for milk production. Simulated ewes nursing single or twin lambs fed the H/L ration produced more milk at the beginning of lactation than L/L ewes due, most likely, to more fat being catabolized by the H/L ewes. The simulated results of the ewes fed the L/L ration represent the weakest set of validations. Although they follow the trend of the actual data, the differences are the greatest for these simulations.

The final product of the production system examined by Barnicoat et al. (1949b) was the weight of lamb produced. Lamb growth largely determines the efficiency of the biological system. The model simulated this growth accurately (figures 45 through 48).

The largest discrepancy between actual and simulated results was for L/L single lamb. In this comparison the simulated lamb had a faster growth rate. This would correspond to the higher level of milk production of the simulated ewe during the middle periods of lactation.

The lambs produced in the study by Barnicoat et al. (1949b) were Southdown x Romney crosses. The model does not currently account for the effects of heterosis so that the mature weight and maturing rate functions of the simulated lambs are the same as their dams, whereas the actual lambs would be expected to have had a relatively faster maturing rate and a lighter mature weight than their dams. Therefore the absolute growth and maturing rates were assumed to be approximately equal.

c. Conclusions

This series of validations for the SAV of the sheep model displayed the model's capability of simulating the fluctuations and magnitude of changes of real data sets. It was evident from these simulations that the end product of the system (lamb growth) was simulated accurately, as were the intermediate steps and components (feed intake, ewe body weight and milk production) that influence lamb growth.

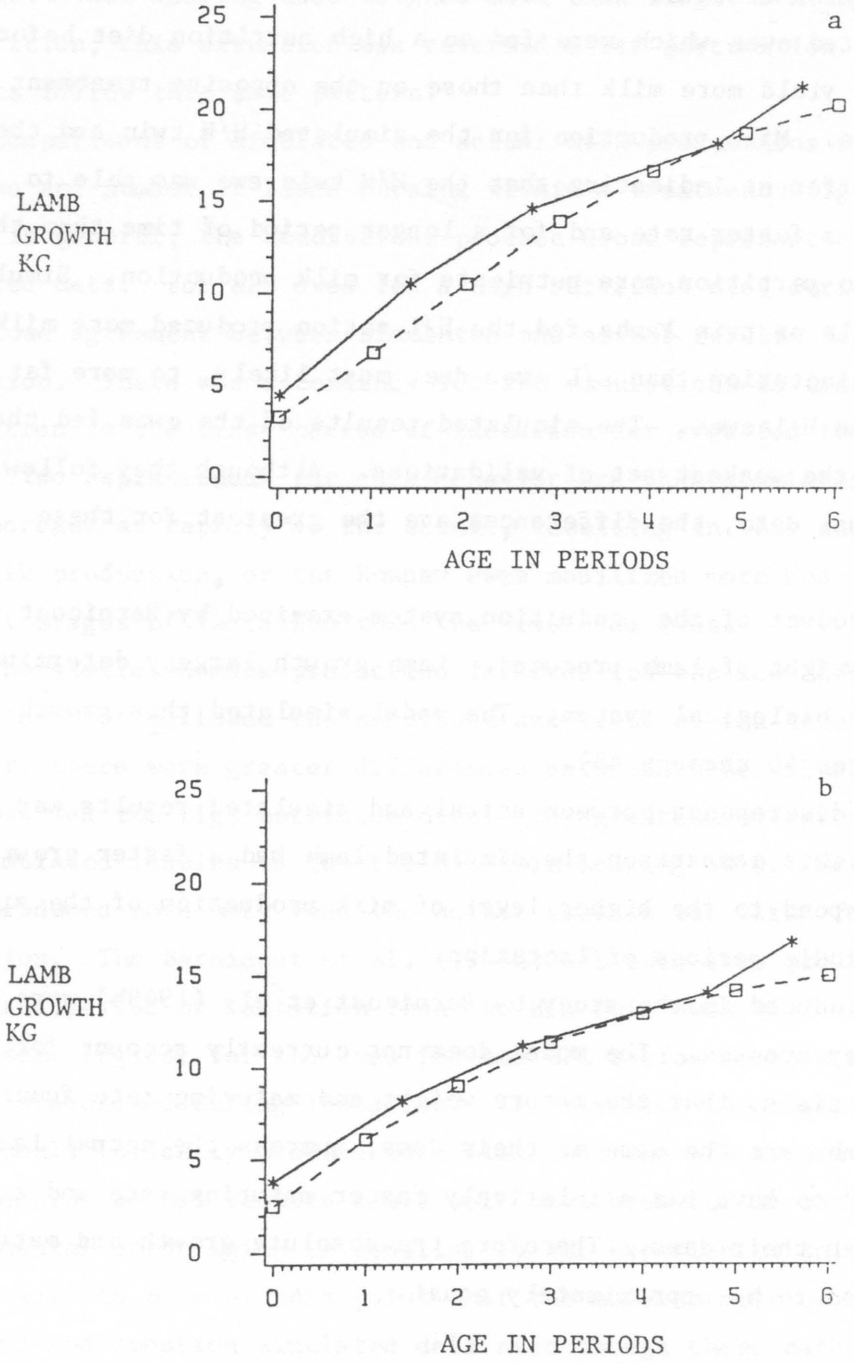

Figure 45. The growth curves of lambs whose dams were fed H/H ration. a) single lamb b) twin lamb.
* Actual, □ Simulated

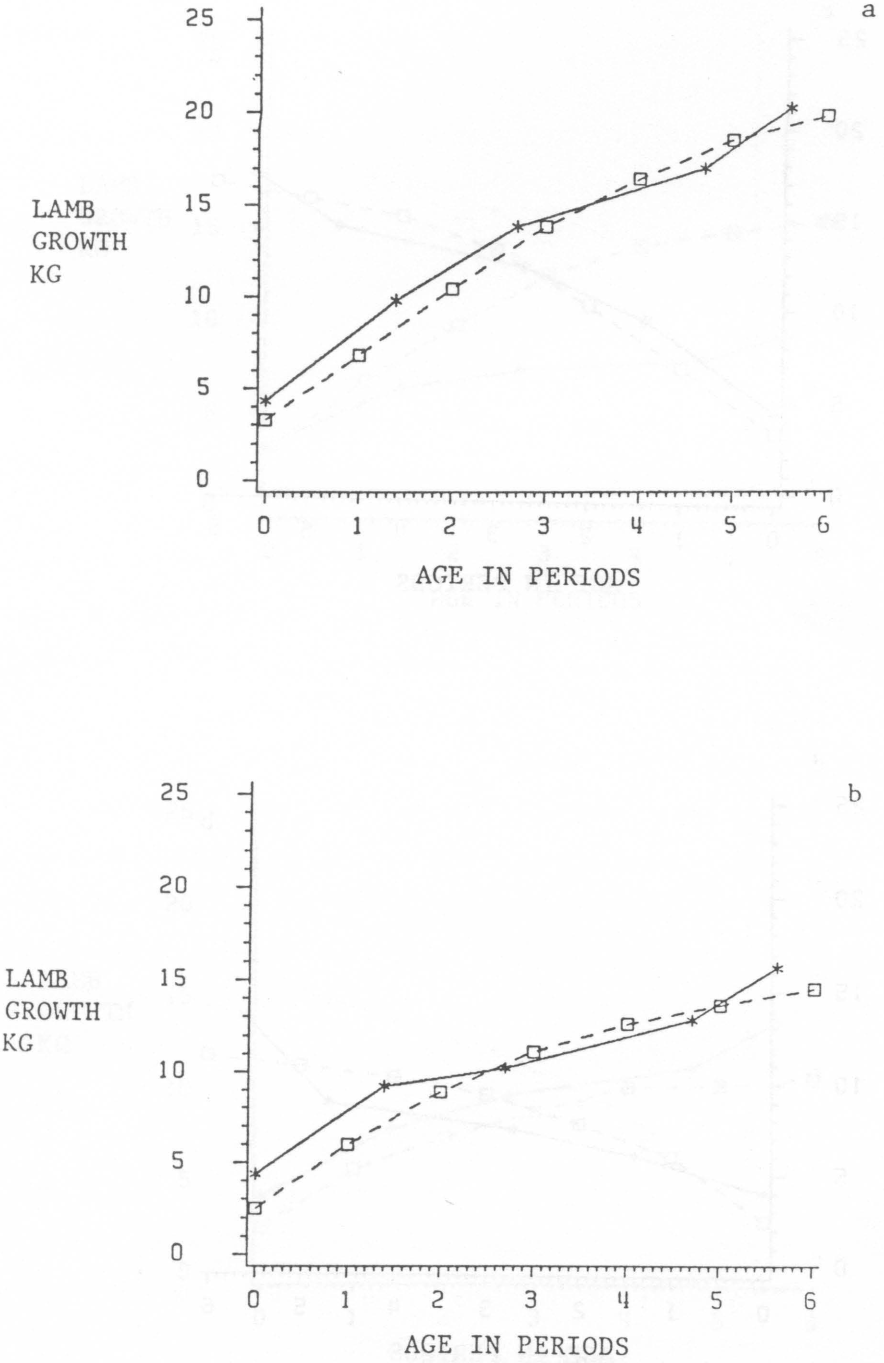

Figure 46. The growth curves of lambs whose dams were fed L/H ration. a) single b) twin
* Actual, □ Simulated

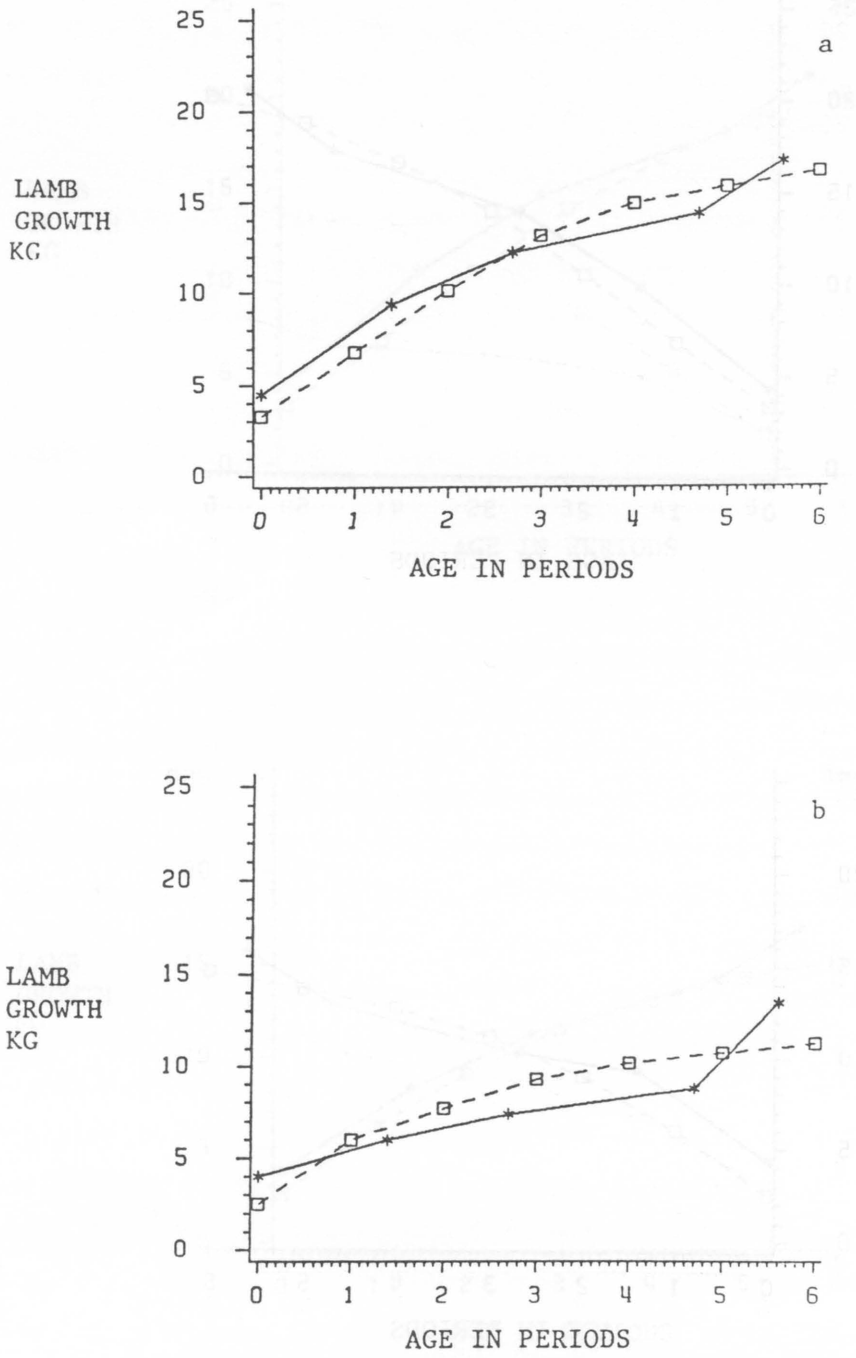

Figure 47. The growth curves of lambs whose dams were fed H/L ration. a) single lamb b) twin lamb.
* Actual, □ Simulated

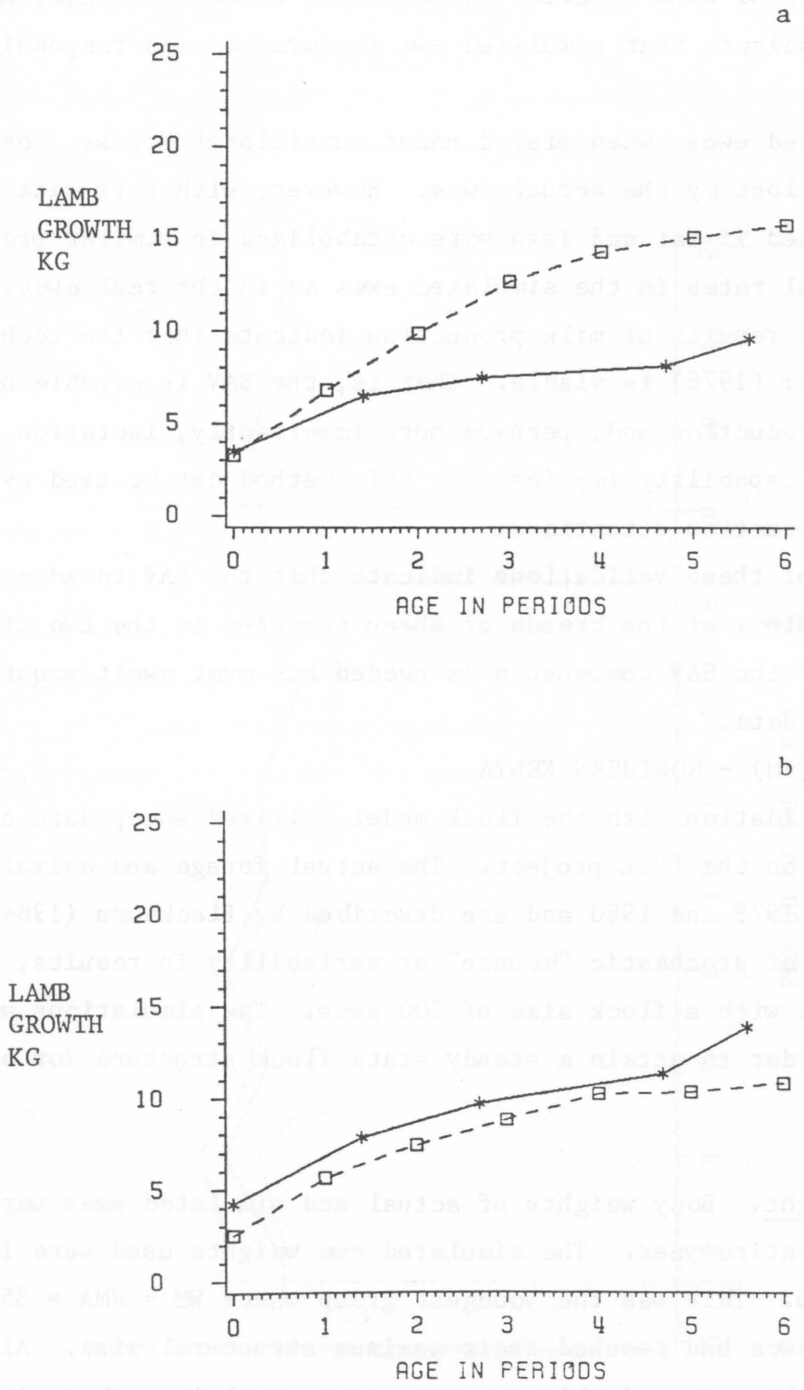

Figure 48. The growth of lambs whose dams were fed L/L ration. a) single lamb b) twin lamb.
* Actual, ◻ Simulated

The simulation of data reported by Barnicoat et al. (1949a,b) and Treacher (1970) indicate that simulated ewe performance was responsive to the feed resource.

Also, simulated ewes, when placed under nutritional stress, lost weight similarly to that lost by the actual ewes. However, with this data set it cannot be determined if fat and lean were catabolized in similar proportions and at proportional rates in the simulated ewes as in the real ewes.

The simulated results of milk production indicate that the technique proposed by Bywater (1976) is viable. That is, the SAV is capable of simulating milk production and, perhaps more importantly, lactation curves accurately. This capability implies that this method can be used over a broad range of production situations.

The results of these validations indicate that the SAV is adequately simulating the biology of the breeds of sheep reported in the two studies. Further testing of the SAV components is needed but must await acquisition of new comprehensive data.

II. FLOCK MODEL (FM) - NORTHERN KENYA

The first validation with the flock model utilized sheep data collected in northern Kenya on the IPAL project. The actual forage and animal data were collected in 1979 and 1980 and are described by Blackburn (1984). To reduce the amount of stochastic "bounce" or variability in results, the simulation was run with a flock size of 300 ewes. The simulations were run for 10 years in order to attain a steady state flock structure for both 1979 and 1980.

a. 1979 Results

Ewe Body Weight. Body weights of actual and simulated ewes were compared for the entire year. The simulated ewe weights used were from the 4.5 year age group. This was the youngest group where WM = WMA = 35kg, meaning that the ewes had reached their maximum structural size. Also, for most research results ewes of this age group are at their peak producing ability. Empty body weight (EBW) and full weight (W) were compared to the actual ewe weights (figure 49). It is necessary to compare all three curves in figure 49 because actual ewe weights were recorded in the morning after

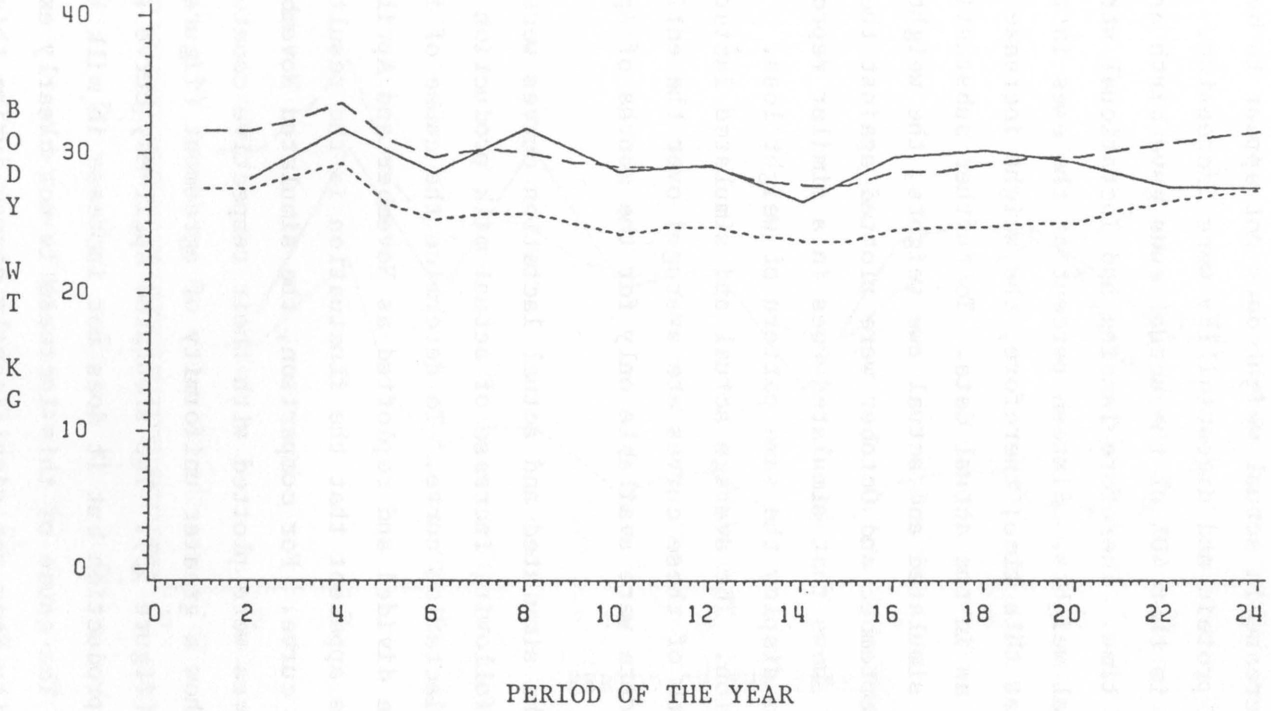

Figure 49. Comparison of 1979 actual (solid line), simulated total (dashed line) and simulated empty body (dotted line) weights.

being enclosed all night in a pen and, therefore represent an intermediate weight.

For the greatest part of the year there is consistent agreement between the simulated and actual weights. The largest divergence between simulated and actual results occurred in the last 3 months of 1979. At first inspection the decrease in actual weight does not appear to be logical, because the crude protein and digestibility were increasing. An explanation for this response is that 40% of the actual ewes gave birth and/or were lactating at this time. Therefore lambing and lactational stress caused the reduction in actual weights. Sixteen percent of the ewes in the simulated flock gave birth at this time; therefore, the weight increase and decrease were not as great as in the actual data. To further substantiate the agreement between simulated and actual ewe weights, the weights of simulated ewes lambing in September and October were plotted against the actual data. Figure 50 clearly shows that simulated ewes in a similar reproductive phase as the actual ewes display the same pattern of weight loss.

Milk Production. The average actual and simulated lactation curves are in figure 51. Both of these curves are averaged over the entire year. Actual lactation data were available only for the months of April, May and November.

In general the simulated and actual lactation curves were in agreement. The decrease and following increase of actual milk production did not occur in the simulated lactation curve. To determine the cause of fluctuation, the actual curves were divided and replotted as November and April and May. From these curves it is apparent that the fluctuation is the result of the April and May lactation curve. For comparison, the simulated November, April and May lactation curves were plotted with their respective counterparts. The November curves show a greater uniformity of agreement (figure 52) than the April-May curves (figure 53). The simulated April-May curve shows a similar decrease in milk production but it does not increase in milk production during period 4. The cause of this increase is not clearly explainable, because feed quality does not significantly change during this time. Due to

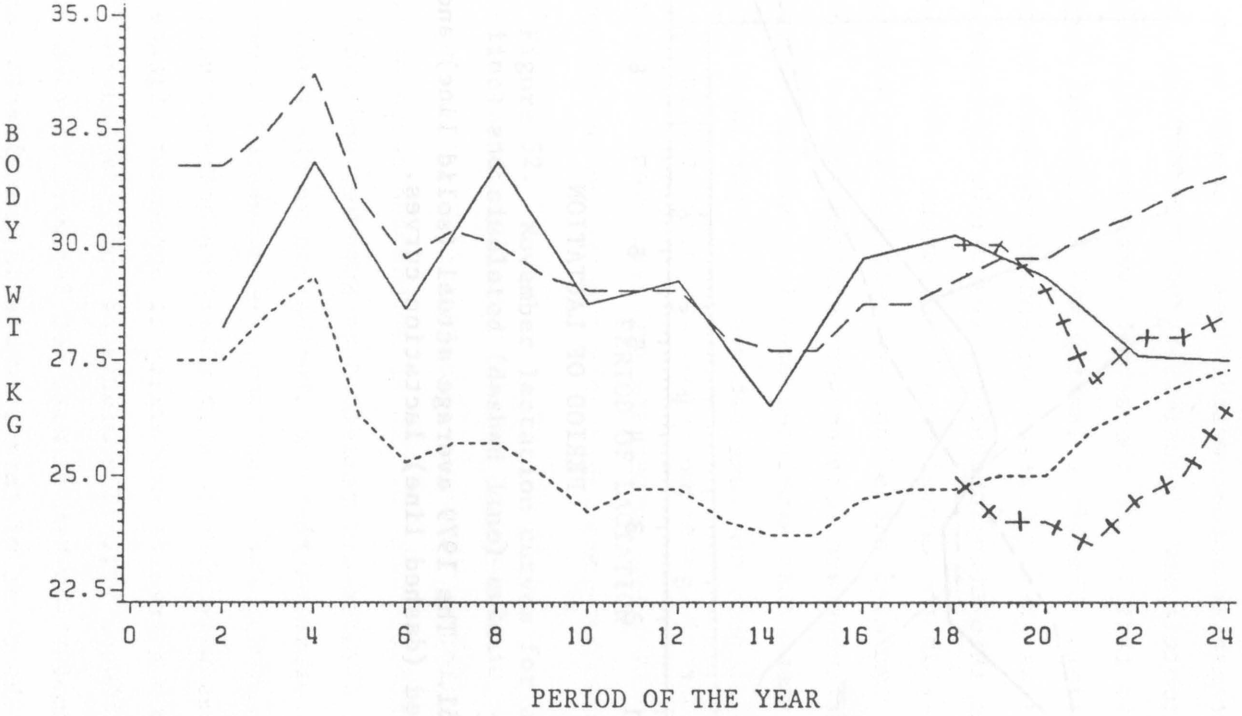

Figure 50. Comparison of 1979 actual (solid line), simulated total (dashed line) and simulated empty body (dotted line) weights. Crosshatched lines are the divergence of simulated total and empty body weights of ewes lambing in period 18 from the simulated flock average.

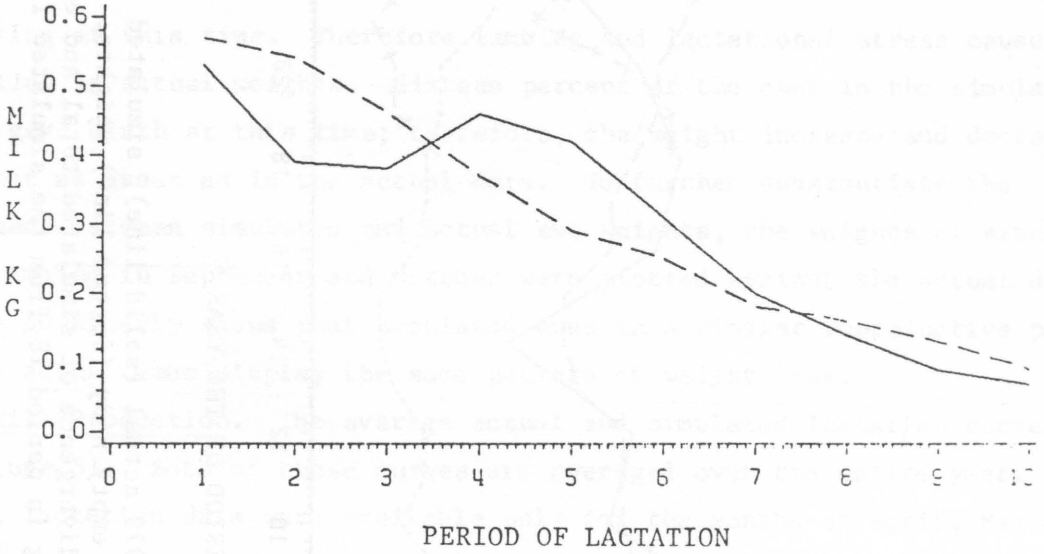

Figure 51. The 1979 average actual (solid line) and simulated (dashed line) lactation curves.

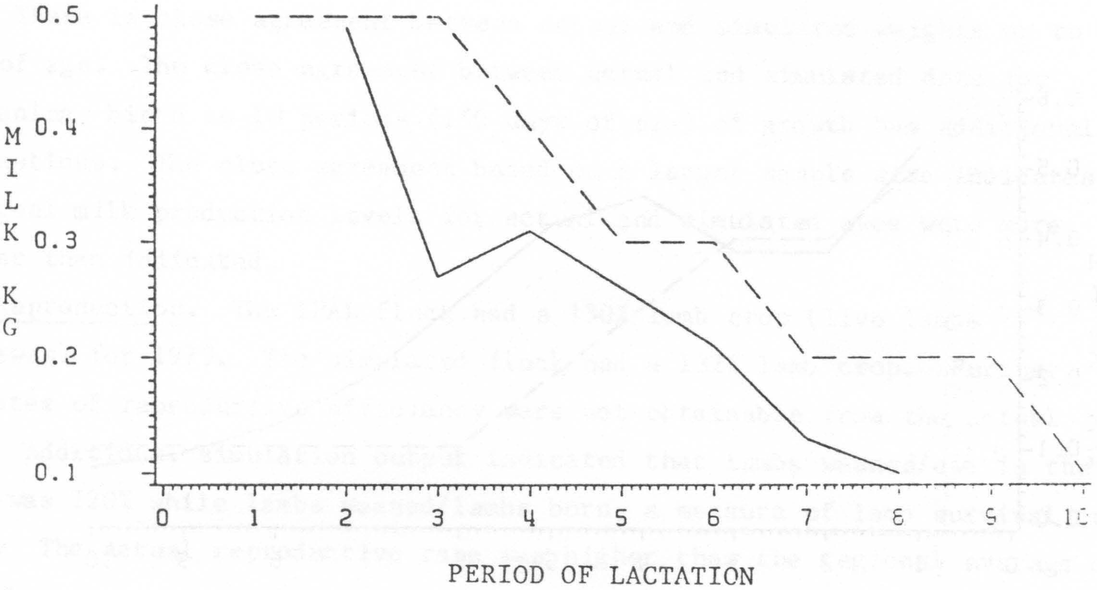

Figure 52. November lactation curves for actual (solid line) and simulated (dashed line) ewes.

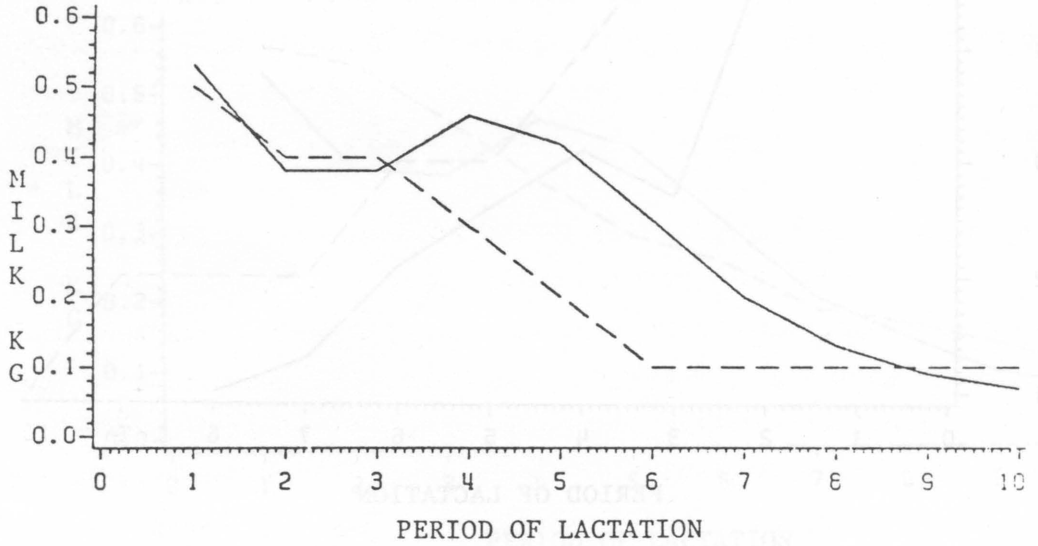

Figure 53. April and May lactation curves for actual (solid line) and simulated (dashed line) ewes.

the small number of lactations, it is possible that the increase was due to a peculiar artifact not counterbalanced as would be expected for a larger sample size.

Lamb Growth. One of the final products of this system is lambs produced. A comparison of the least squares means of the actual lamb weights and the simulated W and WM weights averaged over the year was made (figure 54). There is close agreement between actual and simulated weights up to 300 days of age. The close agreement between actual and simulated data for preweaning, birth to 10 periods (150 days of age) of growth has additional implications. The close agreement based on a larger sample size indicates that real milk production levels for actual and simulated ewes were more similar than indicated.

Reproduction. The IPAL flock had a 130% lamb crop (live lambs born/ewes) for 1979. The simulated flock had a 132% lamb crop. Further estimates of reproductive efficiency were not obtainable from the actual data. Additional simulation output indicated that lambs weaned/ewe in the flock was 120% while lambs weaned/lambs born, a measure of lamb survival, was 76.4%. The actual reproductive rate was higher than the regional average due to IPAL ewes receiving higher levels of management (e.g., drenching and dipping). The simulated lamb survival to weaning is closer to the regional mean (IPAL, personal communication).

b. 1980 Results

Ewe Body Weight. The 1980 year was drier than 1979, and the effects of the drier year resulted in lower ewe body weights. Also, the altered environment resulted in a different ewe body weight pattern. The simulated ewes emulated the actual ewe body weight fluctuations (figure 55). The decreases and increases that occurred in ewe body weight for 1980 fit more closely than for the 1979 data. The 1980 simulated ewe weights had a greater change in magnitude between the high and low weights especially for the weights in June (periods 12 and 13). It appears that the simulated ewes were given (in the input forage vector) greater access to forage than the real ewes. The difference between the actual weight and simulated weight in June was 16.8% which, taken with the pattern for the entire year, was considered to be a close validation.

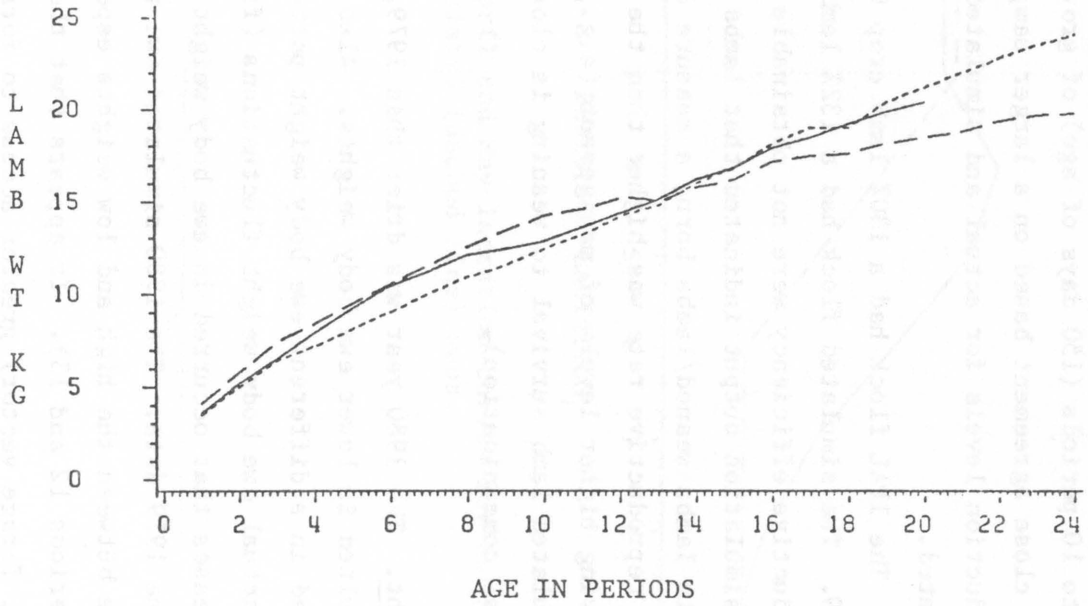

Figure 54. Comparison of 1979 lamb growth patterns for actual weight (solid line) and simulated total weight (dashed line) and simulated structural size (WM; dotted line).

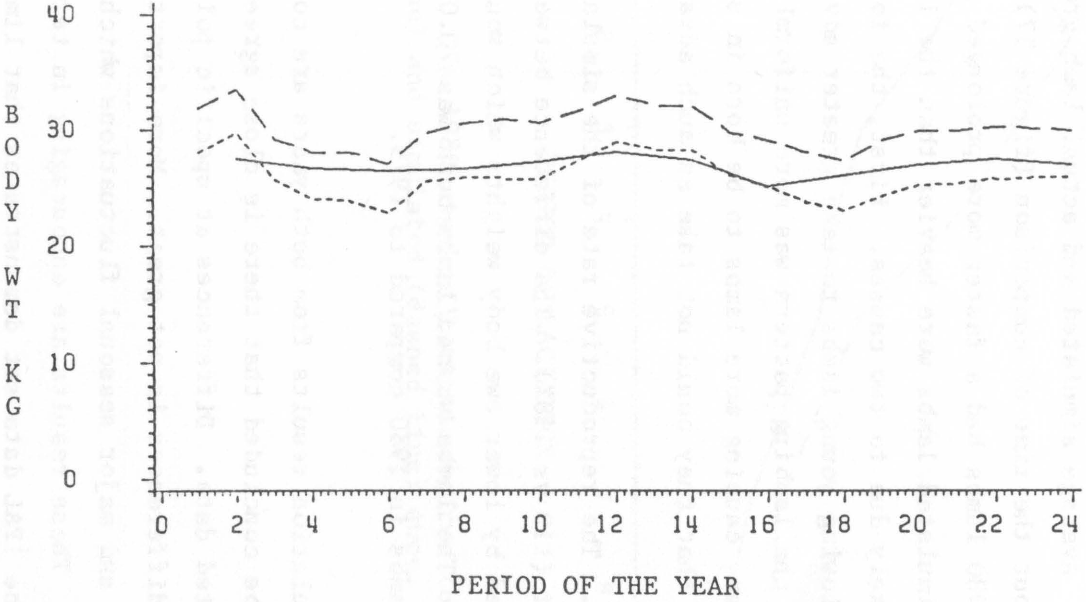

Figure 55. Comparison of 1980 ewe body weights for actual weight (solid line), simulated total weight (dashed line) and simulated empty body weight (dotted line).

Milk Production. The shape of the 1980 lactation curve is different than the 1979 curve in that it lacks an increase after the peak had been reached (figure 56). In general, the simulated lactation curve was higher than the actual data curve. The greatest divergence occurred during the 2nd through the 4th periods of lactation. The divergence implies that the simulated ewes were able, either through catabolism of body tissue or access to higher quality forage, to produce more milk during these times.

Lamb Growth. Average simulated and actual lamb growth are in close agreement throughout the time of comparison (figure 57). Compared to the 1979 lambs, the 1980 lambs had a faster more prolonged growth. At 300 days of age the 1980 simulated lambs were heavier than the 1979 lambs. The difference was likely due to two causes. First, the forage quality was higher in 1980 allowing young lambs to take greater advantage of grazing. Secondly, in 1979 the lambing pattern was more uniformly distributed throughout the year, causing more lambs to be born in seasons of lower quality forage so that they could not take as much advantage of grazing as in 1980.

Reproduction. The reproductive rate of the simulated vs. the actual was in close agreement (119 vs 118%). The difference between the two years is partially explained by lower ewe body weights which would result in lower conception rates. The lambs weaned/lambs born was 70.0% indicating a greater loss of nursing lambs in 1980 compared to 1979.

C. Conclusions

When the simulation results from both years are considered in their entirety, it can be concluded that there is close agreement between the actual and simulated data. Differences at specific points do occur, but the magnitude of the differences is not great. More importantly the simulations follow the trends and major seasonal fluctuations which occurred with the Somali Blackhead. These results are encouraging in terms of model validity in two areas. The IPAL data set demonstrates that limited experimental numbers, but with major production characteristics measured, can be successfully utilized as baseline data for the model. This is critical if data from smallholder production systems are to be used. There is a paucity of data on fat-tailed or fat rumped hair sheep, therefore the majority of data reviewed in the development of the model was from wooled breeds which

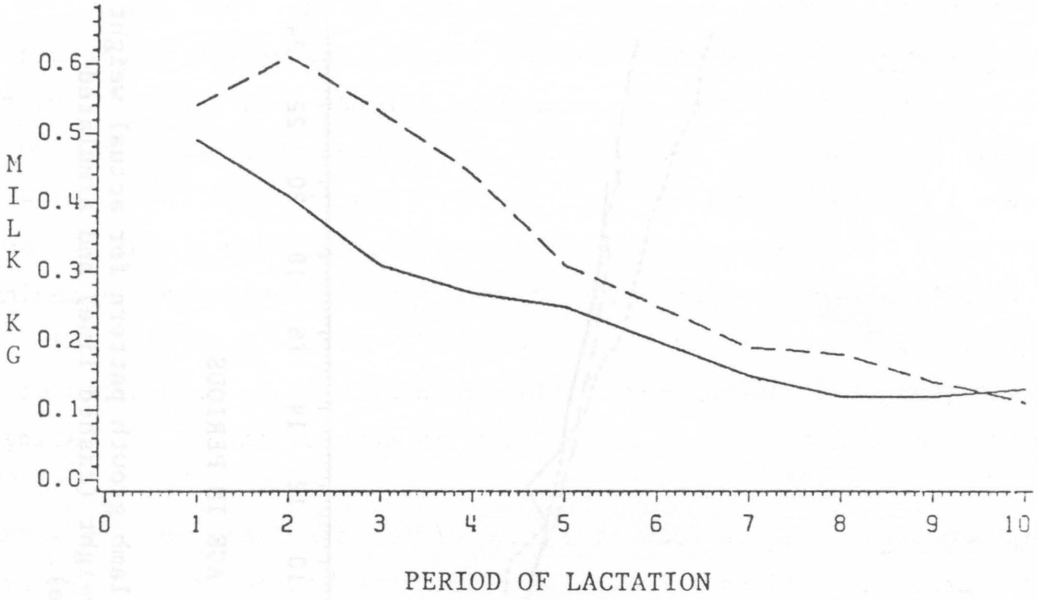

Figure 56. The 1980 average lactation curve for actual (solid line) and simulated (dashed line) ewes.

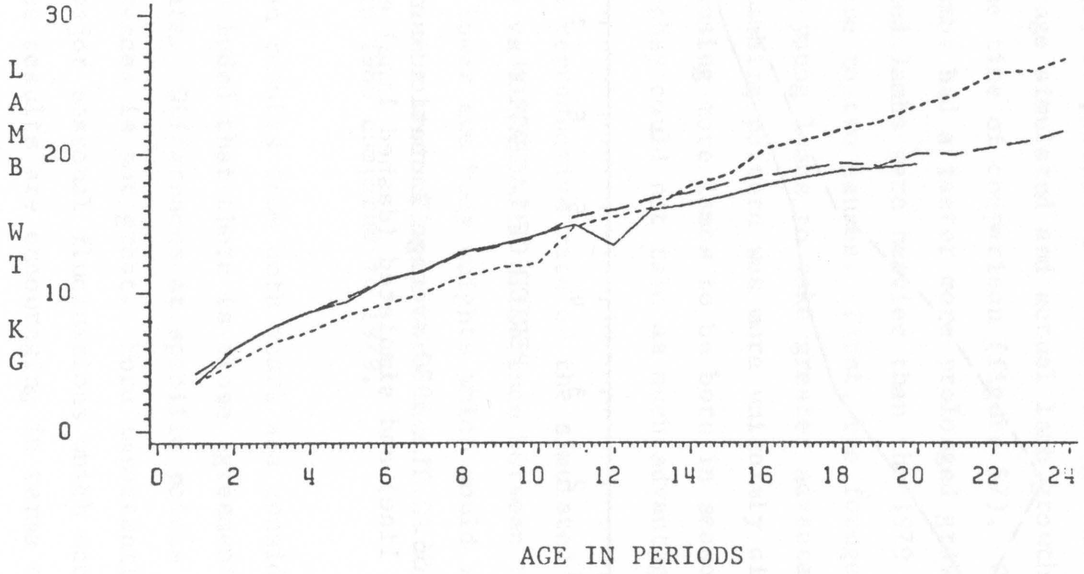

Figure 57. Comparison of 1980 lamb growth pattern for actual weight (solid line), simulated total weight (dashed line) and simulated structural size (WM; dotted line).

originated in temperate regions. These simulations indicate that the manner in which the biology of the sheep was modeled does apply to hair sheep as well as the wooled breeds.

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