ILCA Research Report

PN-AAP-064

ISN 33025

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September 1983

INTERNATIONAL LIVESTOCK CENTRE FOR AFRICA (ILCA)
ADDIS ABABA, ETHIOPIA

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ILCA Research Report No. 10
International Livestock Centre for Africa
September 1983

ORIGINAL: ENGLISH

ABSTRACT

A dynamic and stochastic cattle simulation model is briefly described and validated for production conditions in a study area in Botswana using Tswana and Simmental x Tswana cattle. The performances of the two genotypes under various milking and supplementation policies are compared, and the economic trade-offs between milk and meat production presented. An optimum production strateg is defined, and policy options for the development of Botswana's dairying sector are outlined.

KEY WORDS

/Botswana//simulation//cattle//Tswana cattle//Simmental cattle//milk production//meat production/ /animal performance//dairy industry//production policies//economic analysis/

RESUME

Le présent ouvrage donne une brève description d'un modèle dynamique et stochastique de simulation de troupeau de bovins, validé dans les conditions de la production d'une zone d'étude au Botswana, avec des bovins Tswana et Simmental × Tswana Les performances des deux génotypes gérés dans des conditions caractérisées par des politiques de traite et de complémentation différentes ainsi que les avantages comparés des productions de lait et de viande ont été présentés. Une stratégie optimale de production a été définie et des optioins relatives aux politiques de développement du secteur laitier du Botswana ont été décrites dans les grandes lignes.

MOTS-CLES

/Botswana/ /simulation/ /bovin Tswana/ /bovin Simmental/ /production laitière/ /production de viande/ /performance animale/ /industrie laitière/ /politique de production/ /analyse économique/

PREFACE

Livestock researchers are often asked to provide technical advice to policy makers on issues where the data required for appraisal go beyond those provided by experimental results. In such cases the researchers are usually obliged to depend upon informal concepts or models of the system in question to tailor their available data to the particular questions being posed. This informal approach makes for particular difficulties when the questions concern problems requiring detailed projections of the productivity and response of livestock systems to a range of different interventions. The application of systems simulation techniques involving the use of an appropriate simulation model or models can often assist by providing quantitative estimates of systems performance which would not otherwise be obtainable.

Dairy products are a major import into Botswana. An important policy question recently posed to livestock researchers in the country concerned the extent to which these imports could be reduced by increasing milk production from indigenous and crossbred cattle in the country without impairing beef production. Beef production is the principal livestock product in Botswana and a major source of export income. A substantial body of data was available from research by the Animal Production Research Unit (APRU) in Botswana on the productivity of indigenous Tswana and Simmental x Tswana crossbred cattle kept under ranch conditions for beef production. Information on milk production from both genotypes was available through the indirect measure of calf growth. APRU researchers considered that by combining these data and the collective experience of APRU staff and others associated with livestock production in Botswana it would be possible to address the complex of issues related to dual-purpose beef and milk production through the application of a simulation model. The cattle herd dynamics model developed by ILCA was considered to be appropriate to the problem. Full details of this model are given in ILCA Research Report 2.

This Research Report summarizes the principal results of the application of the ILCA model to this Botswana policy question.

ACKNOWLEDGMENTS

This application of the ILCA model to a practical policy question was at the invitation of APRU in Botswana. Such applications are the proving grounds of the usefulness of systems simulation techniques and of this model in particular. For this reason the authors gratefully acknowledge both the invitation of APRU to undertake the work and the able assistance and enthusiasm of APRU staff in the course of the application of the model and in the preparation of this report. Special thanks are extended to N. Buck, T. Rose and D. Light and their assistants in APRU without whose detailed input and professionalism this application would not have been possible.

CONTENTS

1. INTRODUCTION

Botswana, with nearly 80% of its total area in natural rangeland, supports around 3.3 million cattle in addition to a sheep and goat population of approximately 1.8 million (1977 estimates)[1]. This yields a 5 to 1 ratio between LUs and human population, the highest in Africa. The main emphasis in livestock research and development in the past has been on commercially oriented beef cattle production systems. As a result, exports of animal products, mainly in the form of fresh meat, account for 20 to 25% of the country's total exports. Before the recent expansion of the mining industry, the livestock sector was even more important to the economy[2].

Despite its high livestock population, Botswana imports relatively large quantities of milk products. Dairy imports in value terms increased from P 1.3 million in 1975 to P 7.6 million in 1979, reflecting a substantial increase in both the price and the volume of imports[3]. The main sources of dairy products are the Republic of South Africa and Zimbabwe. The prices of imports from both sources are expected to increase rapidly.

The high increase in the imports of dairy products has resulted mainly from rapid urbanization[4], the attractiveness of imported products to urban consumers (cost, convenient packaging, hygienic products) and the difficulties (cost, perishability, product presentation) of getting surplus milk (if any) from rural areas to urban markets. The demand for milk in the towns is growing at a rate of some 20 to 25% per year.

Milk consumption in the rural areas is usually seasonal. Partial milking of indigenous cow is traditionally practised, providing more than adequate milk supplies for household consumption during the rainy season. Most of the milk sold in village areas is in the form of local milk products *(madila)*. Another important activity has been cream production for both domestic and export markets. However, the importance of this occupation has declined in most areas, probably due to the more favourable price of beef, the recognition that milk deprivation is responsible for poorer calf growth and the difficulties of obtaining farm labour[5].

In view of this situation, there is considerable interest at the national level in the development of the dairy industry. Due to the vastness of the country, efforts so far have concentrated on the development of small-scale dairies in or near each major town to supply local needs. However, because of the considerable importance attached to the viability of the beef cattle industry, an important policy question has been the extent to which indigenous and crossbred cows can be used for dual-purpose production without impairing their performance as beef producers[6]. It is frequently contended that increasing milk offtake prejudices calf growth and should be discouraged. However, provided the value of milk obtained exceeds the loss of value in calf growth, overall productivity may be in favour of milking at some level. Thus, with the existing and rapidly growing milk markets in Gaborone and other towns and in view

[1] Livestock constitute the principal agricultural resource, contributing 80% of the value added by agriculture (ILCA, 1979).

[2] Before 1974, livestock exports accounted for over 50% of export earnings (ILCA, 1979).

[3] One P equals approximately US$ 1.20.

[4] The average annual population growth rate in the main towns is about 8% and that of the major villages about 6%. For Gaborone alone the growth rate is 15% (Fielding, 1978a).

[5] Cream exports from Botswana in 1976 were only 55% of their 1972 level in value terms, and in volume terms only 37.7% (Fielding, 1978a).

[6] Recently, APRU has initiated field experimentation with a dual-purpose herd at Broadhurst Farm, near Gaborone. The purpose of this experimental herd, consisting of about 40 cows, is to investigate the technical and economic factors in the partial milking of T and ST cows.

of the present deficit in milk production, the formulation of an optimum milking policy based on economic considerations is necessary.

Several studies have examined the economic feasibility of dairying and the technical and institutional constraints in the development of the dairy industry (Silichena, 1976; Fielding, 1978a, 1978b; Rose, 1978; APRU, 1980a). In addition to the substantial foreign exchange savings, expanded rural milk production would bring other even more important benefits, such as higher incomes to livestock producers and the creation of jobs in milk production, processing and distribution. However, these conclusions are reached from simple static cash-flow analyses based on certain assumptions on livestock productivity and potential milk offtake rates. The dynamic effects of implementing such alternative production regimes are not elaborated in these studies. ILCA (1978) provides an indication of these dynamic effects and an overall idea of the direction of short- and long-term costs and benefits. That study suggested that milking can result in short-term gains, however, at the expense of a longer term reduction in the capital value of the herd due to increased calf mortality, deferred female maturity and extension of intercalving intervals. The exact nature of the economic trade-offs between milk and meat production are not elaborated, nor is the sensitivity of the results at different milk offtake rates, supplementation levels, and input and output prices.

The objectives of the present study are to evaluate the potential of two genotypes (T and ST crosses) as milk producers, to determine the viability of alternative production options within a dynamic system, and to establish the economic trade-offs between milk and meat production under various levels of feed supplementation. The study area is the Masiatilodi and Matlolakgang ranches, both west of Gaborone, a brief description of which is given in Section 2. The analysis employs a dynamic and stochastic cattle simulation model (Konandreas and Anderson, 1982). Section 3 provides an overview of this general model and its components, and gives complete details of the model's driving variables. The validation of the simulation model in the study area is presented in Section 4. Section 5 presents the response of key production variables to various interventions on the input and output sides of the herd enterprise and compares the simulated performance of the two genotypes on the basis of individual production traits. The overall comparison between the two genotypes, for the range of interventions and on the basis of the economic criteria, is presented in Section 6. Optimum input and output levels are estimated as well as the sensitivity of the results to different pricing structures. Finally, Section 7 presents overall conclusions and policy recommendations.

2. THE STUDY AREA

In its efforts to develop the dairy industry, the Government of Botswana decided to concentrate on main "dairy development areas", lying within 2 hours' journey (some 80 km on reasonable roads) from a milk market. The farmers outside these areas would not be encouraged to shift to dairy production but would continue to concentrate on beef production (Fielding, 1978a).

There are two major livestock production systems in Botswana: a fenced ranching system, and the traditional "cattle post" system in which cattle are grazed on unenclosed communal pasture. Within the dairy development areas several options are available, namely to upgrade cattle post fodder production by growing fodder crops, to establish communal ranches, or to allow a farmer to fence his own cattle post. Recognition that dairy development must be complemented with parallel improvements in management and the diets of either the cow or the calf is explicit in these options[7]. In both beef and dairy systems it is recommended that before increased production through improved range management, nutrition or crossbreeding is considered, a certain level of management must be attained. A "reasonably acceptable" management level, as practised on the network of 18 government ranches in Botswana, provides (APRU, 1981):

- A degree of fencing so that breeding herds may be controlled, young stock separated and standing hay retained for dry-season feeding.
- Continuous mineral supplementation and prophylactic disease control.
- Adequate year-round water supplies within a reasonable distance of the grazing area.

The system selected for this analysis is that of leasehold fenced ranching in the Masiatilodi and Matlolakgang ranches west of Gaborone, with central Kalahari bush and arid, sweet-bush savanna on sand veld (see Figure 1). In addition to the indigenous T cows, ST cows are considered in the analysis. Earlier comparisons by APRU showed that ST cows produced significantly heavier calves at birth and that the growth of these calves to weaning was superior to that of calves produced by all other cow breeds (Trail et al, 1977; APRU, 1980b). These findings reflect the superior potential of these cows as milk producers.

APRU has gathered considerable data on both primary production and animal productivity over the last decade. Research on cattle post systems has been limited, however, and only incomplete data are available. Efforts have concentrated mainly on the network of research stations operated by APRU itself. The Masiatilodi and Matlolakgang ranches are part of this network. These locations were chosen for this study merely because the comprehensible and reliable input – output data essential for model validation were available there. However, it should be possible, through the experience of the Botswana researchers, to extrapolate the results of this analysis to other locations within the main "dairy development areas".

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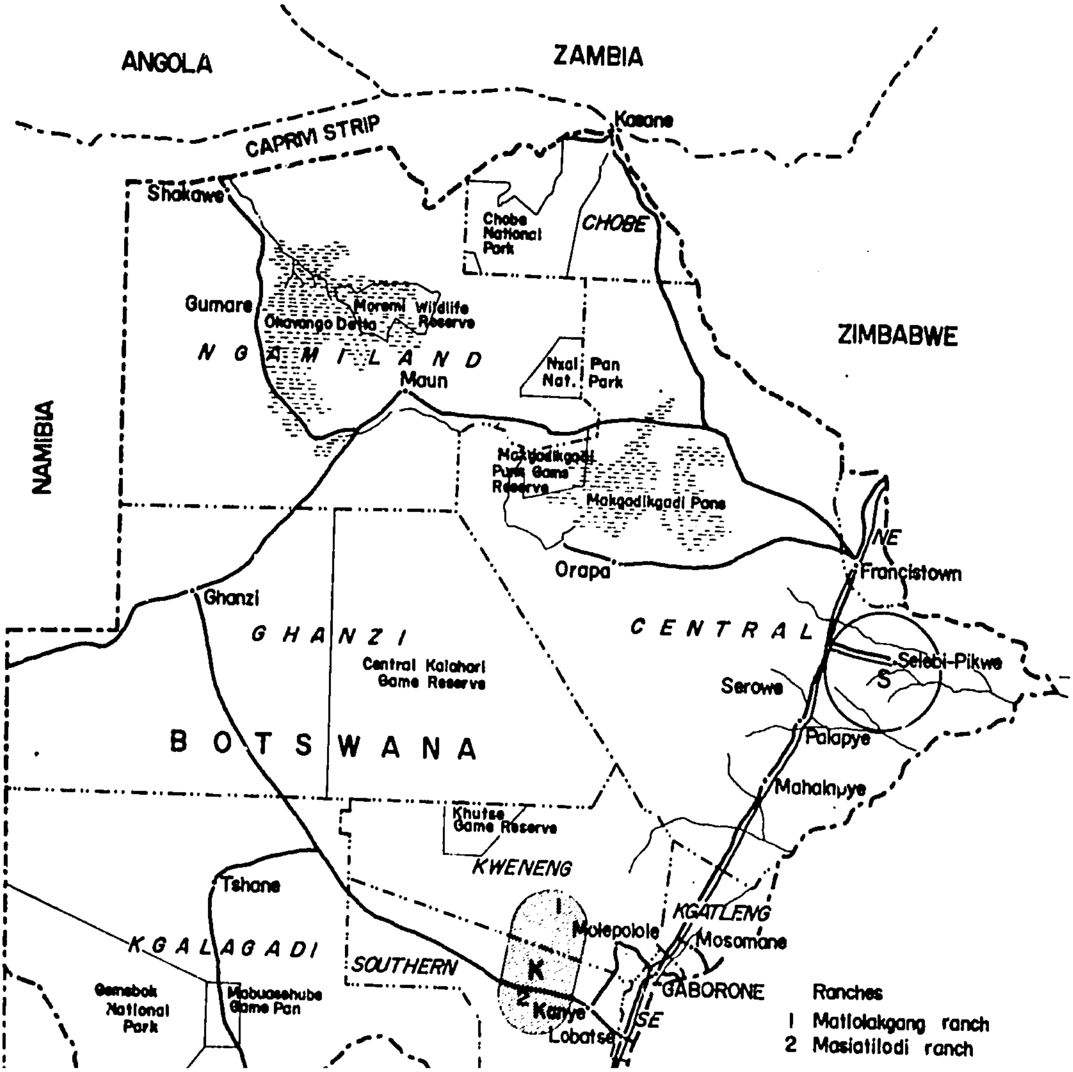
[7] Supplying farmers with high yielding cows of exotic breeds has often been regarded as an easy alternative, but unless satisfactory levels of inputs are provided to these cows, their milk yields, reproductive performance and survival rates are severely impaired.

Figure 1. *Botswana and the study area.*



3. THE SIMULATION MODEL AND SPECIFICATION OF ITS DRIVING VARIABLES

A general cattle herd simulation model in which a herd is simultaneously represented as both a biological and an economic system is used in the study. As the structure and detailed mathematical description of this model are presented elsewhere (Konandreas and Anderson, 1982), only its essential components and features are outlined here.

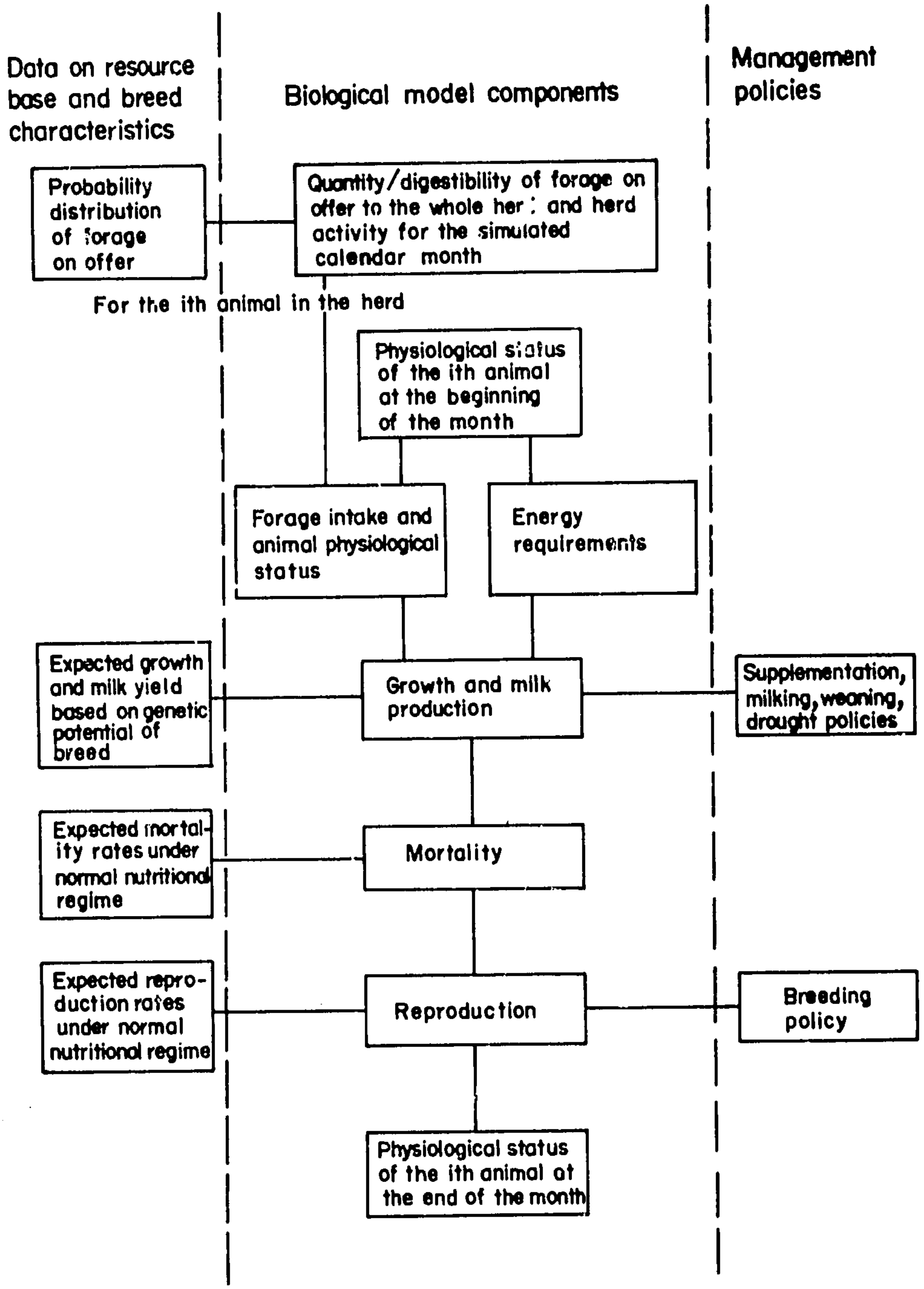
The model is time-dynamic, stochastic and non-optimizing, and treats simulated animals as individual entities. The parameters of mathematical representations of the various biological processes drawn from the literature are adjusted to particular systems under study, based on observations from these systems. Thus, the model is data-based where possible, and adequately modularized so that alterations and refinements can be made relatively easily. Another feature of the model is that it provides the user with an array of policy options so that herd performance can be studied under a variety of management regimes. These policy options allow for the simulation of certain parameters influenced by husbandry practices, such as breeding season and age of calf weaning. Additionally, input and output policy options can be specified with an adequate degree of detail relating to the management of the herd as an economic unit. On the input side, animals can be purchased and a range of supplements can be provided for increasing meat and milk production and/or for strategic reasons such as ensuring the survival of the breeding herd during drought periods. On the output side, milk and meat offtake can be regulated as can the sale of surplus females over and above a planned herd size within the constraints of the available resource base.

The simulation of biological systems such as cattle herds requires, necessarily, one basic simplification. Although the links between the different interrelated processes of a system are time-continuous phenomena, they must be specified in discrete time steps within a computer-simulated environment. The length of the time step used in this model is 1 calendar month. One month corresponds, in general, to the usual and practicable frequency of field data collection at the herd level. Such a correspondence is a prerequisite for model validation. Additionally, a monthly time step is within the accuracy required for specification of the management regime of the system in terms of breeding season, weaning age, supplementation strategies etc. Thus, the model can adequately simulate the impact of alternative management policies.

Within a time-dynamic environment, the various animal processes which determine the transition in the status of an animal from one month to the next must be mathematically described. These processes are illustrated diagrammatically in Figure 2. At the beginning of each month of simulation the model determines the quality and quantity of forage on offer to the herd and the level of animal activity for that calendar month. Forage on offer is simulated independently, based on historical time-series data. After the forage on offer has been obtained, the model determines the changes taking place in the status of each animal during the month, based on its genetic potential and using the endogenous biological processes regulated by exogenous management policies. Each animal in the herd is processed separately except for cows with suckling calves. As suckling calves secure at least some of their energy from their dams, their joint energy requirements must be determined simultaneously.

Six general components in the model account for changes in the biological status of animals during each month of simulation. These are forage

Figure 2. *Basic components of the simulation model.*



on offer, forage intake, energy requirements, growth and milk production, mortality and reproduction.

3.1 FORAGE ON OFFER

The quantity and quality of forage on offer in the study area varies considerably from season to season within a year, and from one year to the next. There are two ways in which this variability can be incorporated into a herd simulation model.

The first way consists of a quantitative, i.e. mathematical, description of the biological processes determining forage productivity, given the driving variables of the primary production system (rainfall, soil fertility, solar radiation, grazing pressure etc). Mathematical representation of the primary production system along these lines is difficult, as these biological processes are not well understood and data requirements are overwhelming (see for example Sullivan et al, 1981; van Keulen and de Wit, 1975).

The second way, which is used in this model, bypasses the underlying processes of the primary production subsystem and involves a statistical description of the quantity and quality of forage on offer based on field observations over several years, covering a wide spectrum of environmental variability. The seasonal level of activity of grazing animals is also associated with the degree of environmental variability. Animals respond to a situation of low forage density and inferior quality of forage on offer by exercising selective grazing, implying an increased level of activity.

Five year types have been identified to provide an adequate representation of environmental variability in the production system under study. At present with the stocking rates on the ranches studied, the quantity of forage on offer is not a constraint to animal intake. However, its quality varies considerably. Table 1 presents the digestibility, CP and animal activity vectors for the five year types identified. Also shown are the probabilities of occurrence of each year type and the corresponding months of the beginning of the growing season.

In 80% of all situations, growth starts in October and the forage consumed is of adequate quality (digestibility above 45% and CP above 5%) until July. A below average year type implies a late start to the growing season in December or even January (5% probability), which results in an extended period (4 to 5 months) of very low quality of forage consumed (digestibility at or below 40% and CP as low as 3%). During these late-start-of-growth years, the onset of rains results in very high quality forage (digestibility 70% and CP as high as 13%), but due to the relatively short growing season the total quantity of forage produced is below normal. This high quality forage lasts for only 4 to 6 months, until April to May. In the simulation model, year types are drawn at random, based on the probability distribution of Table 1, with the further assumption of independence between successive draws.

3.2 FORAGE INTAKE

The forage intake of extensively grazing cattle is influenced by the environment, the age and physiological status of individual animals and the quality of forage on offer. Considerable experimental work has been done, particularly in the last two decades, to quantify the separate influences of the individual determinants of intake*. This work, although lacking standardization of measurement and, in some cases, adequate definition of the experimental animals involved, shows clearly that for a given quality of forage on offer, *ad libitum* intake is a function of body liveweight and the physiological status of individual animals (Conrad et al, 1964; Montgomery and Baumgardt, 1965; Elliot and Fokkema, 1961; Elliot et al, 1961; Hodgson, 1968). However, within a given functional form, estimated parameters can vary considerably between breeds and climatic conditions.

The general voluntary intake relationship used in this model and referred to as physical limit is a modified version of the form suggested by Conrad et al (1964) and has the form

$$I = a\,W^{0.75}/(1-d) \qquad (3.1)$$

where

- I = DM intake in kg/d,
- W = body liveweight in kg,
- d = digestible fraction of the forage on offer, and
- a = a breed- and system-specific parameter whose value is a function of age and physiological status of individual animals.

At high digestibility levels, intake for mature animals is reduced due to chemostatic or thermostatic mechanisms (Conrad et al, 1964; Montgomery and Baumgardt, 1965; Baile and Forbes, 1974), implying a constant energy intake for these higher digestibility levels. It is therefore assumed in the model that for digestibility greater than 65%, feed intake is of a level such that the resulting metabolizable energy is equal to that obtained from the above relationship at the 65% digestibility level. This assumption implies a relationship (referred to as physiological limit) of the form

$$I = b\,W^{0.75}/d \qquad (3.2)$$

where

$$b = 1.86a$$

Intake figures for different breeds and under various environmental conditions can vary considerably (see for example Cordova et al, 1978). Additionally, within a given breed and environmental regime intake is influenced by the physiological status of animals. For example, estimation of equation 3.1 using the data reported by Elliot et al (1961) and Elliot and Fokkema (1961) shows that cows in the last 3 months of pregnancy and

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* See overviews of experimental work by Balch and Campling (1962), Baile and Forbes (1974), and Cordova et al (1978).

Table 1. *Seasonal forage quality and animal activity levels at Masiatilodi and Matlolakgang ranches (averages for the two locations)*[a].

	Year types[b]														
	Good			Above average			Average			Below average			Poor		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
January	65	10.0	5.0	65	10.0	5.0	60	8.6	6.0	65	11.8	5.0	70	13.0	5.0
February	60	9.5	6.0	69	9.5	6.0	57	7.8	6.0	55	12.8	7.5	60	12.0	6.0
March	55	9.0	7.5	55	9.0	7.5	50	7.3	8.0	50	9.0	8.0	50	8.0	7.5
April	50	7.0	8.0	50	7.0	8.0	49	5.8	8.0	50	7.0	8.0	45	6.0	8.5
May	50	6.0	8.0	50	6.0	8.0	47	5.4	8.5	45	5.0	8.5	43	4.0	9.0
June	48	5.0	8.5	46	5.0	8.5	46	5.0	8.5	43	4.0	8.5	40	3.0	9.0
July	45	4.5	8.5	45	4.5	8.0	45	4.5	8.5	40	3.0	9.0	40	2.5	9.0
August	43	4.3	9.0	40	4.3	9.0	40	4.0	9.0	35	2.5	9.0	30	2.0	8.0
September	40	4.0	9.0	40	3.8	9.0	40	3.8	9.0	30	2.5	9.0	30	2.0	8.0
October	55	5.2	7.5	55	5.2	7.5	55	5.2	7.5	30	2.5	8.0	30	2.0	8.0
November	60	6.5	6.0	60	6.1	6.0	58	6.1	6.5	30	2.5	8.0	30	2.0	8.0
December	65	8.8	5.0	65	8.8	5.0	65	8.8	6.0	70	10.0	5.0	30	2.0	8.0
Month of start of growing season	October			October			October			December			January		
Probability of occurrence	0.15			0.30			0.35			0.15			0.05		

[a] Data compiled by APRU.

[b] Columns 1, 2 and 3 under each year type show: 1) average digestibility of forage consumed (%), 2) average CP in forage consumed (%), and 3) average distance walked (km/d).

lactating cows have a 7% and 15% higher intake respectively than dry, non-pregnant cows. The estimated coefficients "a" were 0.042, 0.045 and 0.049 for dry, pregnant and lactating cows respectively.

Little is known about the voluntary intake of young calves. Hodgson (1968) experimented with calves from 3 to 6 months of age grazing on forage of digestibility ranging between 65 and 80% and observed that physiological limits are not constraining for young, fast-growing animals. Estimation of equation 3.1 using his figures yields a coefficient of 0.022, i.e. about 53% of the coefficient for dry cows obtained from the data of Elliot et al (1961).

The relative values of coefficient "a" for the different physiological conditions of animals are assumed as above for the purposes of modelling forage intake. However, the absolute levels of these coefficients are obtained from a calibration of equation 3.1 to the breeds and system under study. For this purpose a mature, dry and non-pregnant reference cow is considered. Field data indicate that such a reference animal is in a state of liveweight equilibrium (i.e. neither gaining nor losing weight) for the month of July during a year of average forage quality. Stated alternatively, this implies that the daily DM intake during July in an average forage year is just sufficient to maintain body weight at the level of activity for that month. Solving equation 3.1 for intake requirements of the known quality for July, which are sufficient to cover maintenance and the animal's level of activity, yields an estimate of the intake coefficient "a" for the reference animal. The estimated value for the reference animal, along with those for the other animal classes as discussed above, are shown in Appendix Table A.1. The intake coefficient for very young calves (3 to 6 months of age) is taken as 53% of the estimated coefficient for the reference animal, and is increased linearly until the level of the reference animal is reached at 18 months of age. Similarly, the intake coefficients of pregnant and lactating cows are taken as 107% and 115% of the estimated coefficient of the reference animal.

In addition to the above, there are other adjustments to the level of voluntary intake. When CP content of the forage on offer drops below 5%, which approximately corresponds to 40% digestibility, intake is reduced by the factor $(d/0.4)^{0.6}$. Further, older animals (over 8 years) are assumed to have intake reduced by the factor $[1 - 0.03\,(\text{age} - 8)]$. These correction factors have been argued to be appropriate adjustments to voluntary intake by Sanders and Cartwright (1979). Finally, the general model allows for adjustments to intake due to limitations in the quantity of forage on offer and grazing time limitations as a result of long walking distances to watering points or seasonal migrations. However, for the system under study these two factors are not constraining and thus not in effect.

3.3 ENERGY REQUIREMENTS

Organic nutrients obtained from the feed consumed by an animal are used for a variety of functions, namely maintenance, construction of body tissues, the synthesis of milk and conversion to mechanical energy for work done by the animal. The net energy requirements for these activities are in general a function of the size of the animal and the level of each activity (MAFF, 1975; Blaxter, 1969; Webster, 1978). The conversion efficiency of nutrients to net energy for different body functions is higher the higher the quality of the feed consumed, and is also a function of its end use (Pigden et al, 1979; MAFF, 1975). Construction of body tissues, for example, has a lower conversion efficiency than net energy required for mechanical work.

In the model, the intake of feed energy is exactly balanced by its utilization for maintenance (plus pregnancy and lactation as appropriate) and weight gain or loss. The production and growth algorithms are different for calves and cows and weaned males. They determine liveweight change for calves or non-lactating cows and males, and both milk production and liveweight change for lactating cows. However, for the model to be able to predict the production levels of individual animals, parameters specifying the potential of the breeds under study must be provided.

3.4 GROWTH AND MILK PRODUCTION

Liveweight evolution from birth to maturity is a function of the genetic potential of the breed, the sex of the animal and its nutritional status at the different stages of its development. The model requires an age- and breed-specific average growth curve to be specified for both males and females. These average growth curves are used as a reference for determining the simulated condition and production potential of individual animals. Such curves can be estimated from recorded liveweight data (by age and sex) incorporating, to the extent possible, data acquired for the complete range of year types which can occur in the system under study. If this can be done then there will be minimum bias in the simulation towards higher or lower liveweight levels because the data to specify the model came from a particular sequence of favourable or unfavourable production years. When sufficient data are available it is possible to estimate not only averages but also measures of the distribution of liveweights around the means at any age. These statistics can then be used to estimate upper and lower limits of liveweight fluctuations (defining the boundaries of feasible liveweights), such that observed liveweights will lie within these limits with a specified degree of confidence.

Estimation of average growth curves in the model requires a minimum of three point estimates of liveweight evolution: weights at birth, at the age of growth slowdown (inflection point), and at the age of maturity. The model then fits a continuous and monotonically increasing curve consistent with these point estimates. Data on these three points of the growth curves for both T and ST genotypes are presented in Table 2.

For T cattle under ranching conditions in Botswana, average liveweights at birth are 31 kg and 28 kg for males and females respectively. The trend of the growth curve is almost linear up to about 18 months of age, at which time average weights are 310 kg and 280 kg for males and females respectively. Males reach a mature weight of 720 kg at about 72 months of age, while females reach a mature weight of 480 kg at about 54 months of age. The genetic growth potential of ST types is marginally higher. Average birth weights are 8% higher than for T types (APRU, 1980b), i.e. about 34 kg and 31 kg for males and females respectively. At 18 months of age and at maturity ST liveweights are about 11% above T liveweights. Thus, average 18-month liveweights for ST cattle are taken as 340 kg and 310 kg for males and females respectively. Maturity is assumed to be reached at the same age as in T cattle, with mature weights of 800 kg and 516 kg for males and females respectively.

Liveweights of individual animals are assumed to be distributed normally around their age-specific means, with a coefficient of variation of 0.30 for calves up to weaning age, dropping linearly to 0.25 by 18 months of age and remaining constant thereafter. This coefficient implies that in two thirds of all situations the liveweights of mature T females would be between 352 kg and 607 kg and those of mature ST females between 379 kg and 653 kg. Similarly, with a 95% confidence level (which is taken as determining the limits of permissible liveweights in the model), the minima of female liveweights are 244 kg and 257 kg and the maxima are 714 kg and 768 kg for T and ST cows respectively. Such upper and lower boundaries exist for all ages and both sexes, calculated on the basis of corresponding mean liveweights and coefficients of variation, and define the feasible sets for liveweignt evolution.

These liveweight boundaries are assumed to operate for all animals of each genotype, and are used as references for defining the liveweight condition of individual animals in the herd. This condition index is then used to modify their potentials for reproduction and milk production. Additionally, as explained in Section 3.5, the lower liveweight boundary represents the limit below which animals are assumed unable to survive unless they recover their lost weight[9].

Specification of milk yields involves three components: data on the maximum potential yield per lactation of a cow in ideal condition and at the age when its reproductive capacity is maximal; age-specific milk yields per lactation (expressed as a fraction of the maximum potential yield); and finally, information for specifying the lactation curve within a given lactation.

The maximum potential yield per lactation for T cows in the system studied is assumed to be 1900 kg and that of ST cows 3500 kg[10]. It may be achieved by animals between 5 and 8 years of age. For animals older than 8 years maximum potential milk yield per lactation decreases gradually to 70% of this level by 12 years of age. For animals younger than 5 years maximum potential milk yield per lactation decreases gradually to 70% of the above level for animals in their first lactation. Appendix Table A.2 provides complete details of the assumed effect of age on potential lactation yields.

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[9] It is recognized that this is a simplification of the complex factors which cause fluctuations in liveweights, as substantial differences are observed between individuals of the same breed. However, since data are not adequate to ascribe particular genetic potentials to each animal in the simulated herd, it is assumed here that all animals of the breed under study are genetically equivalent as regards their potential for liveweight growth and their tolerance to liveweight fluctuations. It is also assumed that animals of the same class and physiological status have identical constraints on intake and identical conversion efficiencies of feed to energy for production.

[10] The maximum potential milk yield of a pure S cow is about 5100 kg per lactation. The maximum potential milk yield of an ST F_1 cross is estimated as midway between the yields of the two pure breeds, that is about 3500 kg. Additionally, the butter fat content of T milk is assumed to be 52 g/kg, which corresponds to an energy content of 3.5 MJ/kg. The butter fat content of pure S milk is assumed to be 40 g/kg and, assuming again that the butter fat content of ST milk is midway between that of the two breeds, it follows that the energy content of ST milk is 3.3 MJ/kg.

Table 2. *Summary of production parameters used in the model for the T and ST genotypes in the environment of the study area*[a].

Attribute	Genotype	Males	Females
Growth parameters:			
Liveweight at birth (kg)	T	31	28
	ST	34	31
Expected liveweight at 18 months (kg)	T	310	280
	ST	340	310
Expected liveweight at maturity[b] (kg)	T	720	480
	ST	800	516
Coefficient of permissible liveweight variability		0.25	0.25
Mortality parameters[c]:			
Survival rate to 1 year (%)		97	97
Survival rate to 2 years (%)		96	96
Mortality rate for 3- to 8-year-olds (%/year)		0	0
Mortality rate for 12+ year-olds (%/year)		2	2
Fertility parameters:			
Reproductive maturity			
– expected age in months (and liveweight in kg)	T		20 (302)
for animals in normal condition	ST		20 (328)
– earliest age in months (and liveweight in kg)	T		12 (318)
for animals in very good condition	ST		12 (332)
– latest age in months (and liveweight in kg)	T		42 (233)
for animals in very poor condition	ST		42 (251)
Expected annual calving rates[c]			
– for 2-year-old cows (%)	T		80
	ST		88
– for 5- to 8-year-old cows (%)	T		92
	ST		97
– for 12+ year-old cows (%)	T		80
	ST		88
Lactation parameters:			
Maximum potential milk yield per lactation	T		1900
for 5- to 8-year-old cows (kg)	ST		3500
Fraction of maximum potential milk yield for cows in their first lactation (%)			70
Fraction of maximum potential milk yield for 12+ year-old cows (%)			70
Maximum lactation period (months)	T		9
	ST		10

[a] All data relating to the genetic potential of the two genotypes in the environment of the study area have been taken or constructed from APRU (1980b, 1981), Buck et al (1976), Pratchett et al (1977), Rennie et al (1977). Trail et al (1977) and personal communication with scientists at APRU. See text for additional qualifications on individual parameters reported here.

[b] Maturity is reached at 72 months for males and 54 months for females.

[c] Under adequate nutritional regime.

The maximum duration of any given lactation in this system is assumed to be 9 months and 10 months for T and ST cows respectively. Additionally, it is assumed that 33% and 28% of the milk yield of a given lactation is produced during the first 2 months post-partum for T and ST cows respectively. On the basis of this information the model approximates the shapes of the lactation curves for the two breeds as presented in Appendix Table A.3. Thus, for example, the simulated absolute maximum daily milk yield of a T cow between 5 and 8 years of age, during the first 2 months post-partum, is calculated as 10.45 kg/d, and that of an ST cow as 16.33 kg/d. These maxima may or may not be achieved, depending on the feeding regimes of individual animals during their lactation period.

3.5 MORTALITY

The mortality component of the model determines whether an animal dies during a given month of simulation. Mortality is modelled as a probabilistic process qualified by the age of the animal and its nutritional status.

Mortality due to epidemics is minimal in ranching systems in Botswana as a result of effective disease control measures. Mortality is usually accounted for either by nutritional stress due to occasionally inadequate feed supplies, or by a complex set of factors not directly related to their nutritional status.

The lower boundary of liveweights, as obtained from the assumptions made in Section 3.4, corresponds to the poorest condition in which an animal can remain in the simulated herd. If an animal loses sufficient weight or does not gain weight as it should in accordance with its increasing age, it eventually develops an age - liveweight combination below this lower boundary. When an animal's liveweight drops below this boundary and the lost weight is not recovered within the subsequent month of simulation, then it is assumed in the model that death due to nutritional stress occurs. This source of death is deterministic in the sense that simulated death inevitably occurs when these conditions apply.

Animal losses not relating to nutritional status (referred to as "normal" losses) are dependent on age. For animals over 2 and up to 8 years of age such losses are insignificant. However, losses of younger animals which are not related to nutritional stress can be substantial. Overall mortality to 1 and 2 years amounts to 5.5% and 6.5% respectively in the system under study (including both nutritional stress and all other causes). APRU (1980b) identified nine causes of mortality to 2 years of age (stillbirths, accidents, predators etc.), which accounted for 50% of all reported deaths. The causes of the residual 50% of deaths are unknown. It is assumed here that in the total mortality to 2 years causes not associated with nutritional stress account for 75% of all reported mortalities, with the residual 25% being the result of nutritional stress. This implies a "normal" mortality rate of 0.75% (75% of 1%) for animals between 1 and 2 years of age.

For animals over 2 and up to 8 years, "normal" annual mortality is assumed to be zero, with all probable mortalities for animals within this age interval being the result of nutritional stress. Finally, for animals over 8 years of age "normal" annual mortality rates are assumed to increase gradually to 2% by 12 years of age, reflecting problems associated with older age. This assumption implies an annual mortality rate of 0.1%, 0.5%, 1.1% and 2%, for animals in the age groups 8-9, 9-10, 10-11 and 11+ years respectively.

The mortality information provided to the model to account for "normal" losses is used to generate monthly probabilities of mortality which are the test values in a binomial distribution trial. Death occurs if a randomly selected number between 0 and 1 is below the appropriate test value for the animal under consideration.

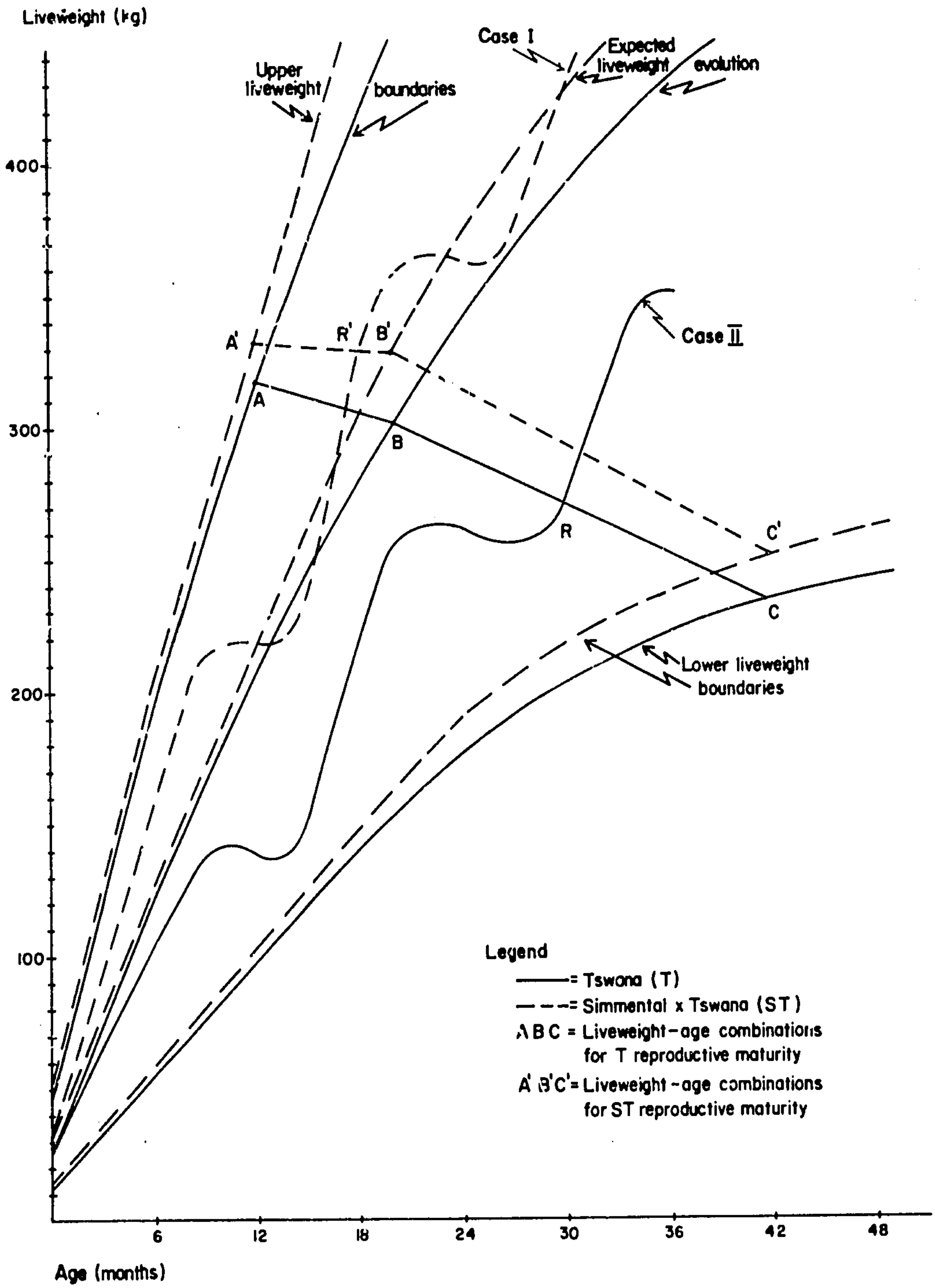
3.6 REPRODUCTION

The reproduction component of the model determines whether a non-pregnant cow conceives and a pregnant cow gives birth during a given month. Conception is modelled as a probabilistic process and is further qualified depending on whether the animal is a heifer or a mature cow. In addition to the nutritional status of individual animals, conception may be influenced by exogenous management practices, indicated as breeding policy in Figure 2, regulating the length of the breeding season and specifying a minimum weight and age of individual animals before they are first mated.

The specification of female fertility requires firstly information on reproductive maturity, and secondly age-specific expected calving rates for mature cows obtained from the system under consideration. The fertility and availability of males are assumed not to be limiting factors.

Onset of puberty is a function of weight and age, and on average occurs at about 20 months of age for both T and ST animals. For animals with a very favourable liveweight growth, puberty can be reached by 12 months of age, and at the other extreme animals with a very poor liveweight growth reach reproductive maturity at 42 months of age. Table 2 presents the ages for reproductive maturity associated with different liveweight growth conditions, and the corresponding liveweights at maturity. These liveweights have been obtained from the expected liveweight evolution curves and associated liveweight boundaries for

Figure 3. *Liveweight - age combinations foı reproductive maturity.*



the two breeds as shown in Figure 3. Two exemplary cases are also demonstrated in this figure. In Case I, an ST female with a normal growth pattern reaches reproductive maturity at 18 months weighing 330 kg (point R'). In Case II, a T female with below average growth reaches delayed reproductive maturity at 30 months weighing about 270 kg (point R)[11].

[11] A female reaching reproductive maturity does not necessarily conceive. Her probability of conception is a function of the expected calving rate (successful conceptions) for her age-class, and additionally of the breeding policy in effect (see Section 3.7).

The probability of successful conception for all animals of reproductive age is assumed to be a function of age, and within an age-class a function of the liveweight conditions of individual females. Maximum reproductive capability is assumed to apply for animals between 5 and 8 years of age. Before 5 and after 8 years reproductive performance is reduced. Table 2 provides data on expected calving rates by age for T and ST genotypes. The detailed age-specific calving rates and corresponding expected monthly probabilities of conception are given in Appendix Table A.4. Actual conception rates for cows within a given age group can be lower or higher than these expected values, depending on the condition of individual cows (Buck et al, 1976)[12]. Thus, if the model selects a succession of 2 years with favourable production conditions simulated then conception rates will be above the average, and vice-versa for a sequence of unfavourable production conditions.

3.7 HERD MANAGEMENT REGIME

A well defined management regime is required by the simulation model. Management options in the model should, to the extent possible, replicate practices in the real system. In the ranching system as it is presently managed, specific weaning, breeding and sale policies are followed. The specification of these policies in the model are described in this section and summarized in Table 3.

Breeding is completely controlled in this system and occurs only during 3 months of the year, from January to March inclusive. This implies calvings from October through December. In addition to the season of breeding, management has control over the age and weight of animals to be bred. Individual animals are bred only if they are older than 24 months and maintain a liveweight of at least 270 kg for T and 290 kg for ST animals during the breeding season.

Calf weaning takes place at 7 months of age, regardless of the condition of the calf and the milk yield of its dam at that time. As calvings take place from October to December, weaning occurs from May to July. However, weaning necessarily occurs at an earlier age in the case of death of the dam. No milk is removed for human consumption. All the milk produced is consumed by calves, and dams cease lactating immediately their calves are weaned.

The sales policy specifies the conditions under which males and surplus females are removed from the herd. Males are sold at the end of June after they have reached at least 2.5 years of age. Sales of females take place so that a breeding herd size of 40 animals is maintained[13]. Selective disposal is followed with the objective of progressively eliminating the most unproductive animals until the target herd size is achieved. Productivity is measured by the simulated reproductive performance of individual animals.

Animals reaching 13 years of age are compulsorily sold regardless of their past reproductive performance, as their present potential for reproduction is considerably reduced. These old cows are sold during August so that they can complete their current lactation period, if they happen to be lactating. Second in the order of sale are cows with relatively long calving intervals. These sales take place during June, when animals are in relatively good condition, and only if the time since their last calving is over 16 months and they have not yet conceived. As calvings occur at the earliest during October and conception takes place at the latest during March, this policy implies that cows must miss two complete breeding seasons to be sold because of poor reproductive performance. Third in the order for sale are heifers which have not yet conceived. Again, the sale of females in this category takes place in June. Finally, if the aggregate of sales from the above categories does not reduce the size of the breeding herd below 40 animals, older animals are sold, starting with the oldest and progressively lowering the sale age from 13 down to 10 years of age. June is again the month of sale for females in this category.

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[12] Expected conception probabilities apply to cows of normal liveweight for their age. The probability conception drops linearly by 10% for animals 20% below normal weights, and by a further 40% for animals near the lower liveweight boundary. This is closely in line with results reported by APRU (1981), whereby animals weighing less than 340 kg had a reconception success about 30% below animals weighing over 450 kg. For animals with liveweights above normal, the probability of conception is assumed to increase linearly by 10% for animals 15% above normal weights, and to decrease thereafter to 90% of the expected probability level for very heavy animals (near the upper liveweight boundary).

[13] The size of the breeding herd, at 40 animals, was arbitrarily selected here. It is large enough to reflect the dynamics of the herd and small enough not to present serious computational problems. It does not necessarily reflect an economically optimum herd size. For example, APRU (1980) reports that the optimum for a beef cattle production herd is somewhere near 600 LUs or about 200 breeding cows.

Table 3. *Summary of management practices in the system under study*[a].

Practice		
Weaning:		
Age at weaning (months)		7 (both sexes)
Breeding:		
Minimum breeding age (months)		24
Minimum weight for breeding (kg)	T	270
	ST	290
Breeding season (inclusive months)		Jan.–March
Sales:		
Minimum sale age (months) for males and calendar month of sale		30 (June)
Minimum sale age (months) for old cows and calendar month of sale		156 (August)
Target size of breeding herd[a]		40
Calendar month for sale of surplus females		June
Minimum infertile period for sale of less productive females (months)		16

[a] See footnote 13 for additional qualifications.

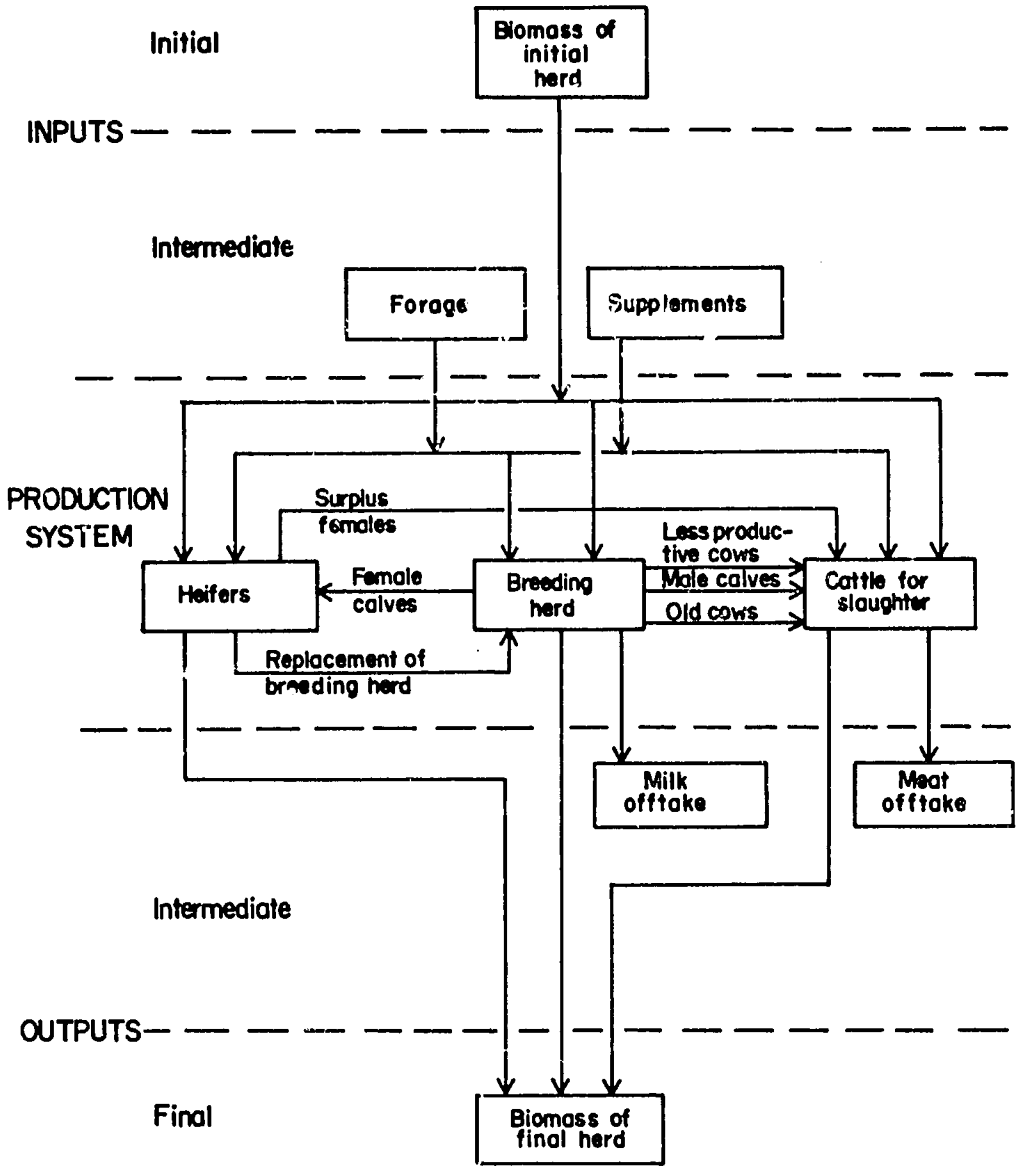
3.8 THE SIMULATION PROCESS AND INITIAL HERD COMPOSITION

Experimentation with this herd simulation model consists of a quantitative description of the productivity of the livestock system under study, evolving over a predetermined number of years. Figure 4 is a schematic representation of this production system showing its inputs and outputs. The production process starts at the beginning of the simulation period, with an initial herd which evolves into the final herd at the end of it. Intermediate inputs and outputs during this period include the feed consumed and the milk and meat produced. The evolution of the herd is a stochastic process. Starting with the same initial conditions and management regime, there exists an infinite number of realizations of the evolution of the herd through the entire simulation period. Thus, in the context of a stochastic simulation model, the outcome consists not of a single realization but of a probability distribution of realizations. Realizations differ from each other not only because of the variability in the forage regime, but also because of the inherently random outcome of the various biological processes of conception and mortality, the sex of offspring etc., embedded in the model.

A simulation experiment for a livestock production system under a given management regime involves a series of independent realizations of the system's outcome over a specified time horizon. The time horizon considered here is 15 years, and each experiment is replicated 10 times over the 15-year period to establish the statistical significance of the simulated results.

An initial total herd size of 60 animals is considered, consisting of females only with an age composition as shown in Appendix Table A.5. Out of the total herd 40 animals are of reproductive age (i.e. over 2 years of age). The first month of the simulation is October, at which time 34 out of the 40 cows are pregnant and expected to calve during October, November and December. Initial liveweights are assumed slightly below the average liveweights corresponding to the animals' age, to reflect the generally below average liveweights prevailing in the real system at the beginning of October.

Figure 4. *Summary of inputs and outputs of the system under study.*



4. BASELINE RUN AND MODEL VALIDATION

The purpose of the baseline run is to establish the validity of the model for the system under study. Using the production parameters as described in the previous section and applying the management practices presently followed in this system, 10 replications over a 15-year period are made and the simulated performance of a herd over this period is compared with data obtained from the real system. Each replication is assumed to start with a "good" year type (see Table 1), and thereafter year types are drawn probabilistically. Appendix Table A.6 presents the simulated year type sequences for the 10 replications and the overall occurrence of each year type. Simulated year type frequencies correspond closely to the assumed probabilities of occurrence in Table 1.

Validation of the model for this production system involves comparison of field data with simulated results. Real input and output data are available for the system under study over a 10-year period from 1970 to 1980 (APRU, 1980a and 1981)[14]. The model is considered to be validated for the production system under study if the following criteria are satisfied:

a. the simulated values of key production traits correspond closely with values from the real system; and
b. the simulated growth curves for indicator classes of livestock correspond closely with recorded performance.

For model validation under criterion (a) five key production traits are considered:

1. The calving rate, i.e. the number of calves born divided by the number of breeding females at the end of the breeding season (early April), adjusted for interim sales.
2. The survival rate of calves up to 12 months of age, i.e. the number of 1-year-old calves divided by the number of calves born.
3. The survival rate of animals up to 2 years of age, i.e. the number of 2-year-old animals divided by the number of calves born.
4. The weaning weight, i.e. the average weight of all calves at 7 months of age.
5. The 18-month weight, i.e. the average weight of all animals at 18 months of age.

The comparison between simulated and actual values of the above five production traits is presented in Table 4. The simulated values correspond very closely to the actual ones, with a maximum divergence of 1.5%.

For model validation under criterion (b), actual detailed liveweights exist for T animals only, and only up to 2.5 years of age, so a comparison of actual and simulated figures is possible for that genotype only. Figure 5 shows simulated average seasonal liveweight fluctuations of T females from birth to maturity, together with corresponding actual values (to the extent available) from the real system. Within the extent of available data from the real system, simulated liveweights correspond closely to actual liveweights, in terms of both seasonal liveweight changes and the overall trends with increasing age.

After weaning (May to July) there is a drop in simulated liveweights of about 30 kg during the dry season and animals reattain their weaning

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[14] On the input side the 10 actual years involved, classified on the basis of annual rainfall (although annual rainfall alone does not adequately reflect forage quality), correspond to 3 "good", 2 "above average", 2 "average", 1 "below average" and 2 "poor" years. Their corresponding frequencies are 0.1, 0.3, 0.2, 0.1 and 0.2, compared with the simulated frequencies of 0.167, 0.287, 0.33, 0.173 and 0.04, respectively (Appendix Table A.6). It would have been a coincidence if the frequency distribution of the short 10-year period had closely matched that of the longer term. However, a comparison between the average and expected outcomes is more favourable. The average outcome of the actual 10-year period falls halfway between an "above average" and an "average" year, which is very close to the expected outcome, based on the longer term probability distribution, which falls two thirds of the way between the same year types.

Table 4. *Comparison between baseline simulation results and actual production for T and ST herds.*

Production trait	T		ST	
	Actual[a]	Simulated	Actual[b]	Simulated
Calving rate (%)	87.5	88.5	91.9	91.8
Survival rate to 1 year (%)	93.5	94.3	94.8	94.5
Survival rate to 2 years (%)	92.5	92.8	93.8	93.0
Weaning weight (kg)	194	191	216	218
18-month weight (kg)	320	322	355	351

[a] Actual values for T are from APRU (1980b; 1981).

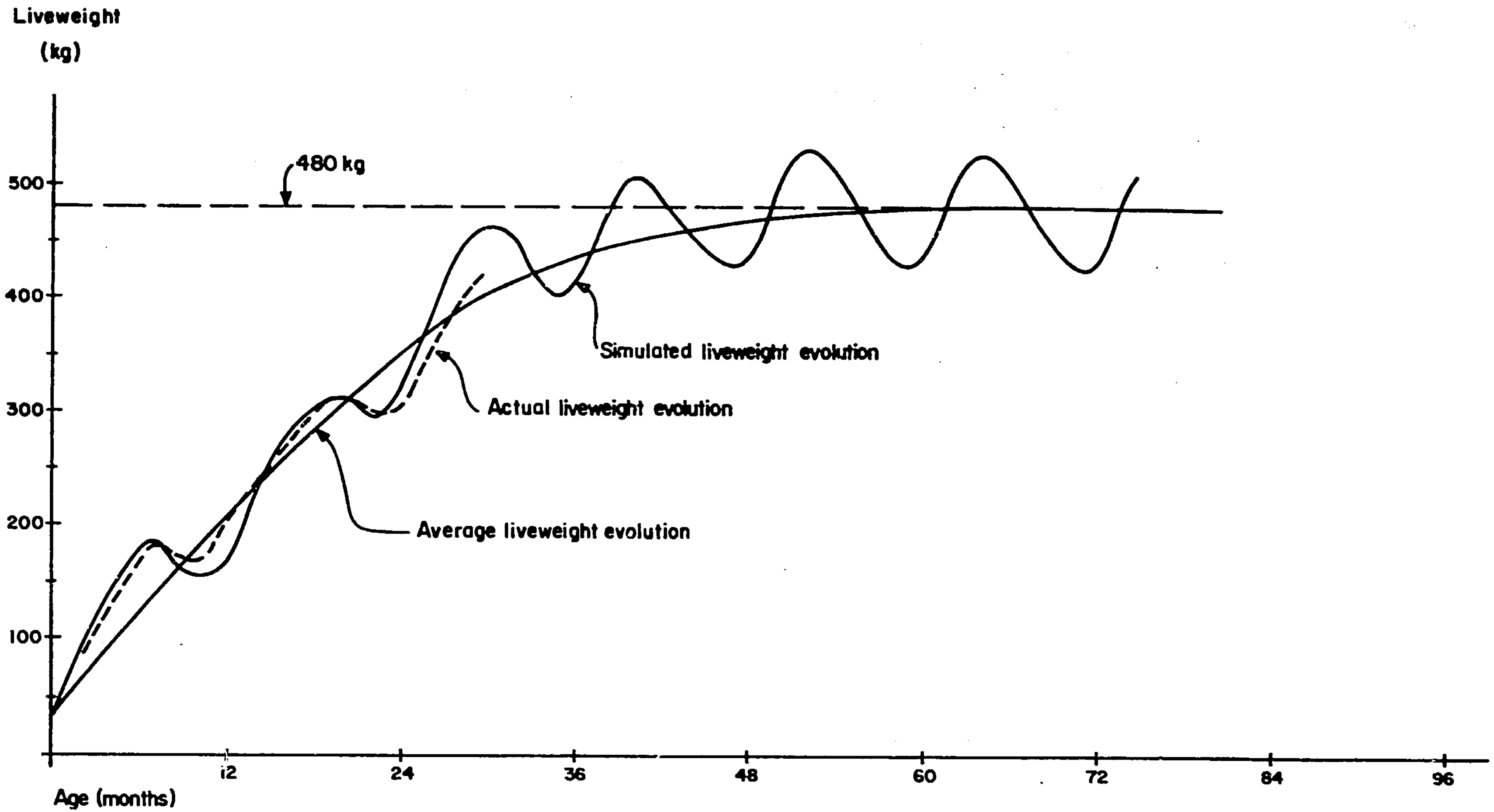
[b] Actual values for ST are inferred from comparisons between indigenous and crossbred cows at APRU's experimental station at Musi (APRU, 1980b; 1981). These results indicate that ST animals perform considerably better than T; calving rates were about 5% higher, survival rates about 1.4% higher, and weaning and 18-month weights about 11% higher.

weight about 6 months later during November to January. Thereafter the fluctuation in their liveweights follows the seasonal variability of forage on offer. After maturity, at about 480 kg which is reached between 4 and 5 years of age, cows lose on average 100 kg during the dry season, which they regain during the wet season. In absolute terms, simulated liveweights for mature cows fluctuate on average between 425 and 525 kg[15].

On the basis of these criteria and the subjective evaluation of the simulated results by field personnel familiar with the production system, the model is considered to replicate the real world with an adequate degree of accuracy for practical purposes.

[15] Note that the simulated liveweight fluctuations reported in Figure 5 derive from simulations including the full range of year types. As such they indicate seasonal liveweight ranges which should be expected to be wider than would occur in a normal forage year, i.e. an average year type. Similarly, the seasonal liveweight fluctuations which would occur in the real world in a very poor forage year would be likely to cause wider ranges in liveweight to occur than those simulated in the baseline run.

Figure 5. *Comparison between simulated and actual liveweight evolution curves for Tswana females.*



5. SIMULATED PERFORMANCE OF TWO GENOTYPES UNDER VARIOUS MILKING AND SUPPLEMENTATION POLICIES

The analysis of the previous section was carried out under the management regime prevailing in the real system with the objective of establishing the validity of the model for the system under study. This validated model is now used for experimentation to investigate the probable impact on the real system of several interventions, namely various milking strategies under different supplementation regimes for lactating T and ST cows. Specifically, the objectives of the experimentation are:

- To compare the simulated performance of the two genotypes under alternative production strategies. This comparison is done on the basis of different measures of performance, as the ranking of strategies might vary according to the criteria used.
- To estimate the response of key performance variables to various input levels.
- To estimate optimum input and output levels based on economic criteria.

5.1 EXPERIMENTAL DESIGN

The variables in this experiment are the level of milk offtake for human consumption and the level of supplementation. A 4 x 6 factorial experiment is conducted, i.e. four levels of milk offtake and six levels of supplementation, the details of which are given in Table 5. For example, experiment number 15 tests a 40% milk offtake for human consumption and a supplementation level of 1.5 kg/d per lactating cow. Experiment number 1 is the baseline run described in Section 4. The breeding, weaning and sales policies assumed in the experimental runs are also identical to those used in the baseline run[16]. In addition to this general specification of the experimental runs, two other controls over milking are effective in the model.

Firstly, in the absence of suckling calves, both for T and to a lesser extent for ST cows, complete milk let-down is not possible. A limited experiment by APRU (1981) showed that extracted milk as a percentage of potential was about 22% and 42% for T and TS cows respectively[17]. The absolute levels of milk let-down potential for both breeds are expected to be higher, and are assumed in the model to be 30% and 60% for T and ST respectively. Operationally, this implies that after weaning only 30% of the potential milk yield of a T cow and 60% of an ST cow can be extracted.

Secondly, regardless of the milking policy in effect, offtake from cows in their first lactation is limited to a maximum of 20% of their yield. This provision is designed to allow young lactating cows, which have a lower milk potential than mature cows, to provide an adequate supply of milk to their calves.

Lactating cows are supplemented for 1 month before calving and during 7 months post-partum,

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[16] As in the baseline run, the evolution of the herd is examined over a time horizon of 15 years, and 10 replications are made for each experiment. Again, each replication begins with a "good" forage year type (see Table 1), after which year types are drawn probabilistically. The sequence of year types drawn is the same for each experimental run (and identical to that drawn for the baseline run, see Appendix Table A.6), so that there is no bins between runs due to different year type sequences applying.

[17] The experiment consisted of oxytoxin treatment of 18 cows of each breed prior to milking, which produced milked-out yields of 3.7 kg for T and 5.9 kg for ST cows. Milk produced without treatment was about 0.83 kg and 2.5 kg for T and ST respectively.

Table 5. *Combinations of milk offtake and supplementation levels for the 24 simulation experiments*[a].

Milk offtake[b] (% of total production)	Supplementation level of lactating cows (kg/head/d)					
	0	0.5	1.5	2.5	5.0	7.5
0	1	2	3	4	5	6
20	7	8	9	10	11	12
40	13	14	15	16	17	18
60	19	20	21	22	23	24

[a] Experiment 1 is the baseline run analysed in Section 4 (i.e. no milk offtake and no supplementation).

[b] For human consumption.

but only when the digestibility of the forage consumed is at 60% or below. Animals that calve during October are thus supplemented during that month and for 7 months afterwards until the end of May. During an average year type, supplements will be provided for every month during this period except December, when the digestibility of the forage consumed is above 60%. Dairy meal concentrate (15% protein, 3% fat, 9% fibre, 1.5% calcium and 0.6% phosphorus) is the supplement considered. It has a metabolized energy content of 12.5 MJ/kg of DM, and presently costs P 190/t ex-Lobatse. However, this concentrate is taken as an example only, and the exact type, quality characteristics and availability of supplements in the different locations which might be considered for dairy development will have to be assessed before such projects are implemented.

5.2 COMPARATIVE SIMULATED PERFORMANCE

The simulated performance of the two genotypes under alternative production regimes can now be considered. This comparison is made on the basis of individual production traits, before an overall comparison is made on the basis of energetic efficiency.

5.2.1 Fertility

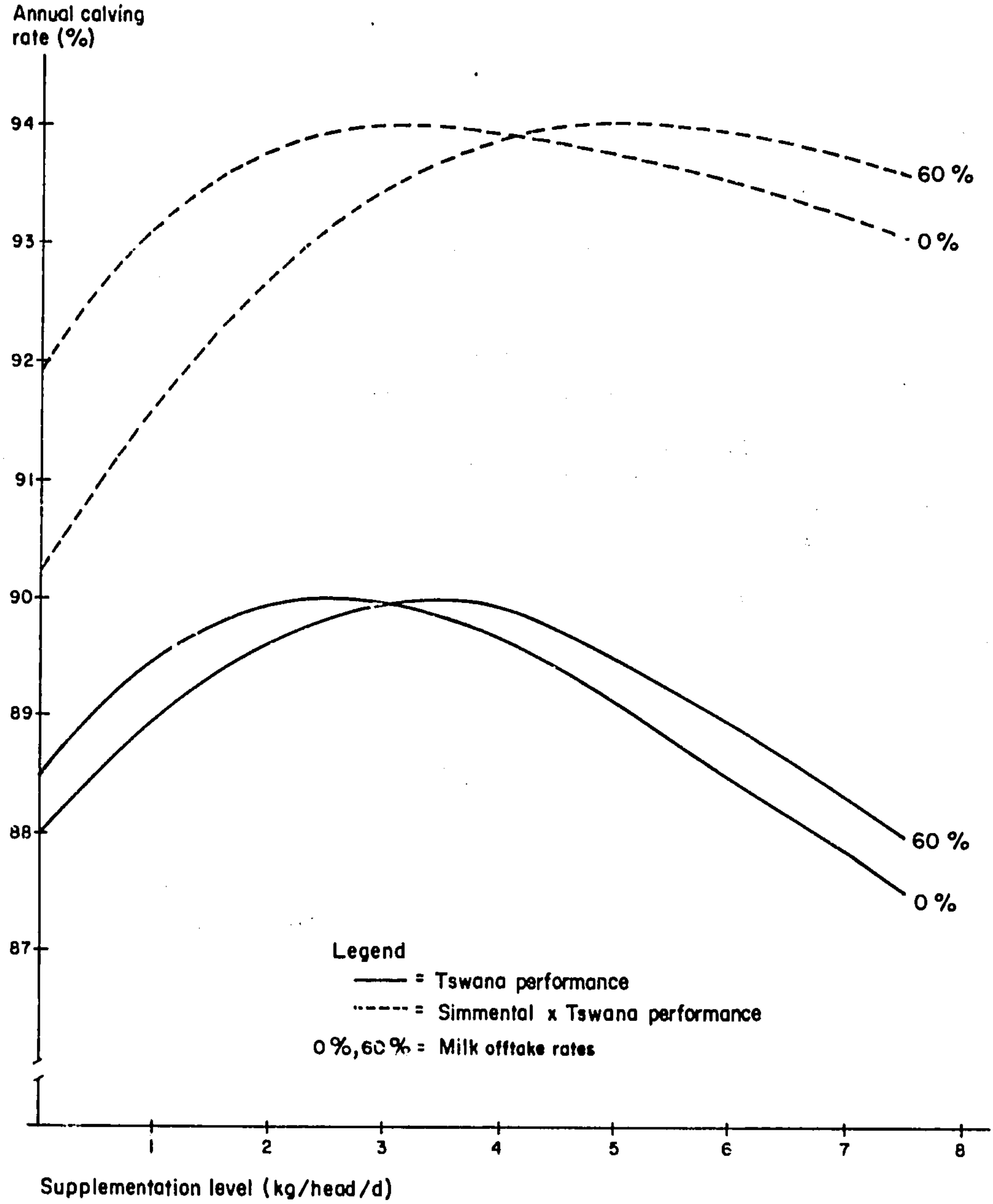
The effect of supplementation on herd reproductive performance, as measured by annual calving rates, is presented in Table 6. Figure 6 provides a graphical representation of this effect for the two extreme milk offtake rates considered.

The simulated reproductive performance of the ST genotype is clearly higher than that of T,

Table 6. *Simulated average annual calving rates (%) under various supplementation levels and milk offtake rates.*

Milk offtake rate (%)	Genotype	Supplementation level (kg/head/d)					
		0.0	0.5	1.5	2.5	5.0	7.5
0	T	88.48	89.03	89.81	90.00	89.08	87.50
	ST	91.85	92.57	93.52	93.90	93.75	93.05
20	T	88.40	88.93	89.76	89.92	89.23	87.60
	ST	90.58	91.63	92.72	93.67	93.78	93.23
40	T	88.15	88.71	89.62	89.87	89.34	87.72
	ST	90.40	91.47	92.34	93.36	93.84	93.46
60	T	88.02	88.50	89.36	89.84	89.52	87.75
	ST	90.16	90.76	92.10	93.05	94.05	93.65
Average	T	88.26	88.79	89.64	89.91	89.29	87.64
	ST	90.75	91.60	92.67	93.50	93.86	93.35

Figure 6. *Simulated effect of supplementation on cow reproductive performance for two milk offtake rates.*



by 2 to 6 percentage points depending on the milking policy in effect and the level of supplementation provided. At low levels of supplementation, increasing the milk offtake rate from 0 to 60% results in a reduction of calving rates by about half a percentage point for T and about one and half percentage points for ST[18]. As supplementation of lactating cows increases from 0 to 7.5 kg/head/d, calving rates increase up to a point, reaching a maximum at about 2.5 – 3 kg for T and 3 – 5 kg for ST animals, and decline thereafter. This increase amounts to 1.7 – 2.3% for T and 2.2 – 15.5% for ST, depending on the milk offtake rate. The higher the milk offtake rate (putting cows under greater stress), the higher the relative increase in calving rates as a result of supplementation[19].

[18] The cause of this reduction in reproductive performance is the extended lactation period from 7 months to 9 and 10 months for T and ST respectively, when milking takes place. The higher milk potential of ST cows implies higher energy demands during this extended lactation period, resulting in greater weight losses and thus greater reduction in their reproductive performance.

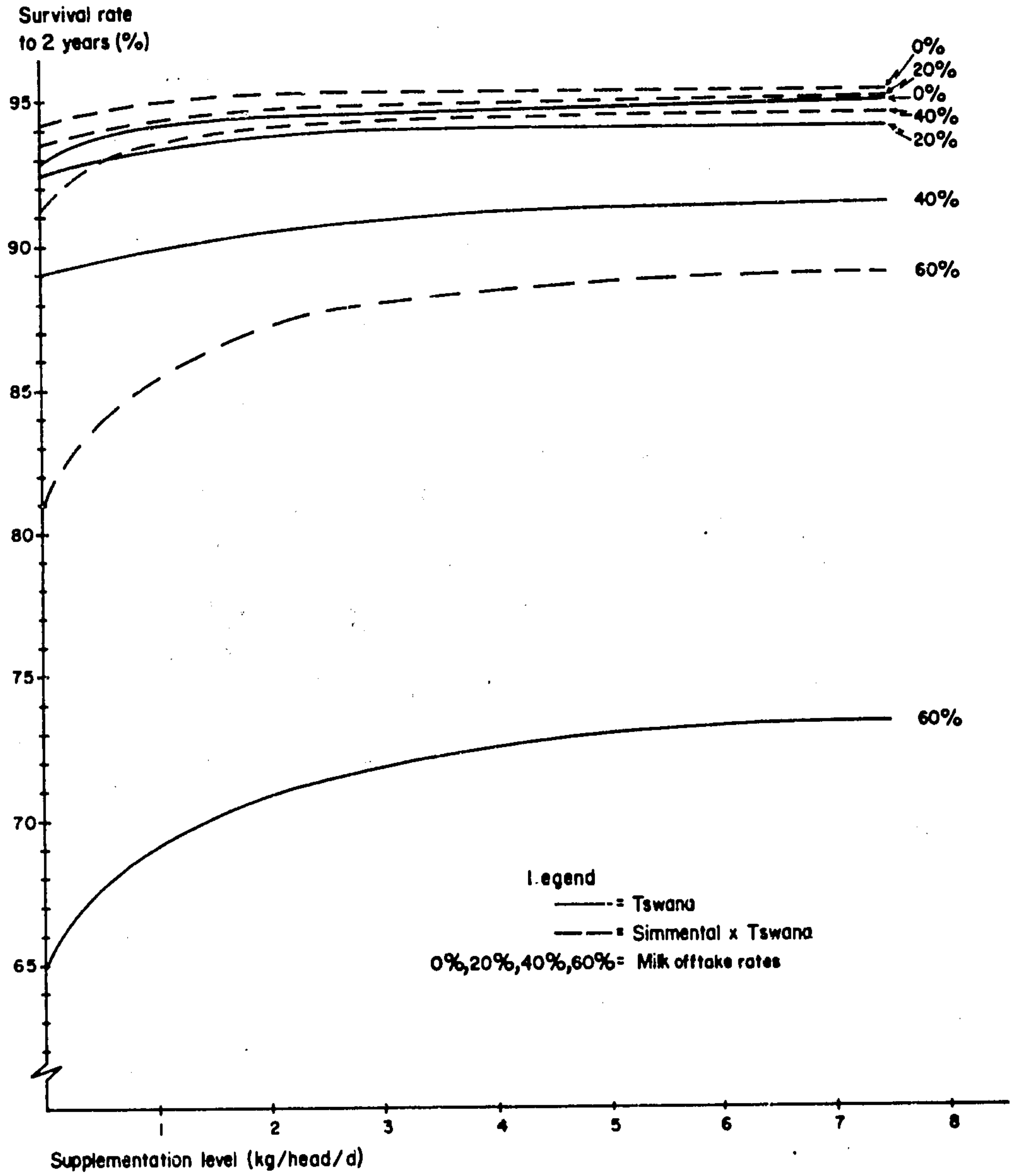
Table 7. *Simulated average calf survival rates and average annual cow mortality rates for various supplementation levels and milk offtake rates.*

Milk offtake rate (%)	Genotype	Supplementation level (kg/head/d)					
		0.0	0.5	1.5	2.5	5.0	7.5
		Average calf survival rate to 1 year (%)					
0	T	94.31	95.08	95.59	95.97	96.08	96.44
	ST	94.46	95.39	96.01	95.86	95,94	96.16
20	T	94.26	94.95	95.57	95.92	95.95	95.95
	ST	95.33	95.33	95.83	95.97	96.33	96.35
40	T	92.04	92.01	93.54	94.08	94.68	94.73
	ST	93.83	95.06	95.80	95.84	96.29	96.30
60	T	68.94	72.16	73.79	74.93	76.28	77.72
	ST	85.12	87.00	91.53	92.52	93.91	94.48
		Average calf survival rate to 2 years (%)					
0	T	92.78	93.72	94.00	94.52	94.60	95.07
	ST	93.00	94.09	94.85	94.92	95.00	95.35
20	T	92.49	92.94	93.35	93.84	93.77	93.90
	ST	93.71	93.89	94.12	94.67	94.79	95.10
40	T	89.02	88.66	90.38	90.46	91.10	91.13
	ST	91.17	92.92	94.08	93.90	94.51	94.25
60	T	64.59	67.91	69.72	71.18	72.28	73.89
	ST	81.01	83.54	87.28	87.38	88.46	88.96
		Average annual cow mortality rate (%)					
0	T	1.20	0.56	0.53	0.37	0.30	0.36
	ST	2.00	1.34	0.52	0.46	0.31	0.28
20	T	1.22	0.59	0.40	0.27	0.27	0.27
	ST	3.00	1.87	1.36	0.41	0.39	0.39
40	T	1.30	0.66	0.43	0.20	0.30	0.34
	ST	3.02	1.81	1.24	0.51	0.49	0.38
60	T	1.46	0.64	0.38	0.24	0.27	0.34
	ST	3.20	2.54	1.30	0.59	0.43	0.43

Maximum calving rates occur at the optimum liveweights for reproductive performance. The simulated optima are at about 600 kg and 630 kg liveweight for T and ST cows respectively. The model assumes that cows with liveweights above these levels will have a reduced reproductive performance. The outlet of increased energy intake through supplementation is first in increased milk yields, but once the milk yield potential is achieved the residual energy is absorbed in liveweight gains. The lower the milk yield potential and milk offtake rate, the higher this residual energy for liveweight gain. Thus, it should be ex-

[19] Trials were carried out at Musi to find out the effects of supplementary feeding on the reproductive performance of breeding females (APRU, 1981). An average improvement in conception of 7.1% above the control group was reported. The results also showed that stressed cows had a much higher response in conception to supplementation of 14.4%. The simulated effects reported here are, in general terms, in line with these results.

Figure 7. *Simulated effect of supplementation on calf survival for various milk offtake rates.*



pected that, as supplementation levels increase, optimum liveweight for reproductive performance is reached for T cows before ST cows and, within a genotype, at lower milk offtake rates. This occurred in the simulation and is demonstrated in Figure 6.

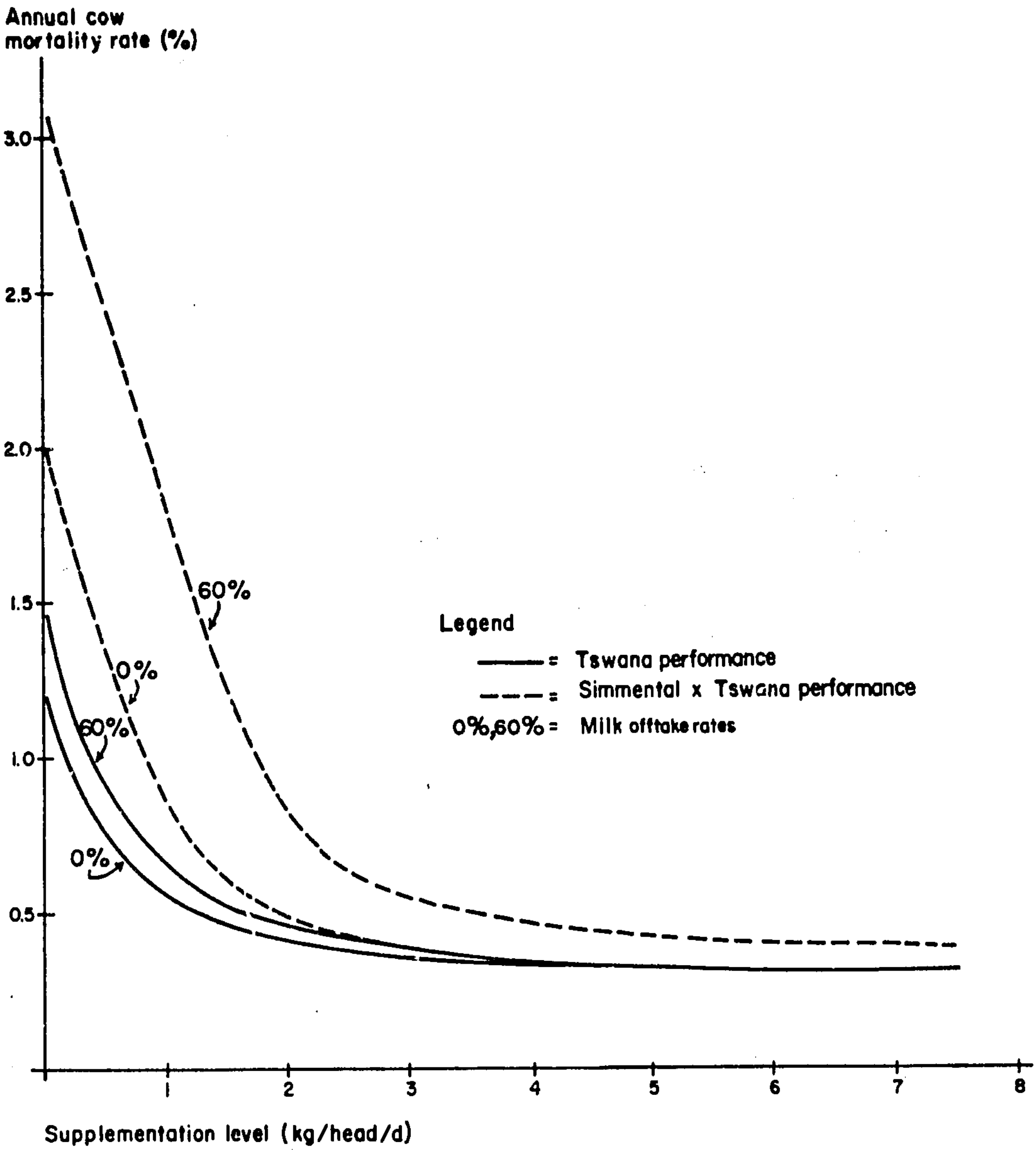
5.2.2 Mortality

The simulated effect of different supplementation levels on mortality is shown in Table 7, and in Figures 7 and 8 for calves and cows respectively. When up to 20% of the milk produced is removed for human consumption, the effect on the survival of animals to 2 years is relatively small. However, over that level the impact on calf mortality is exponential, reducing the survival rate of calves to 2 years by about 21 to 28 and 6.4 to 12 percentage points for T and ST calves respectively, depending on the level of supplementation provided.

Higher milk offtake rates also result in increased cow mortality, particularly for ST cows at low supplementation levels. At a supplementation level below 1.5 kg/head/d, the mortality rate of ST cows almost doubles as milk offtake rates increase from 0 to 60%.

The effect of milking on mortality can be shown more clearly in marginal terms. For example, the survival rate of T calves to 2 years is reduced by 0.02 to 0.06 percentage points (depending on the level of supplementation) for each

Figure 8. *Simulated effect of supplementation on cow mortality for two milk offtake rates.*



additional percentage point of milk offtake, as milk offtake increases from 0 to 20%. However, as milk offtake increases from 40 to 60%, the same rate is reduced by 0.86 to 1.22 percentage points for each additional percentage point of milk offtake. Thus the survival rate of T calves to 2 years decreases almost 25 times faster when over 40% of milk is removed than when milk offtake is from 0 to 20%.

As seen from Figures 7 and 8, supplementation substantially improves the simulated survival rates of both calves and cows. Almost all this improvement takes place as supplementation increases from 0 to 2.5 kg/head/d. After that level the improvement is minimal.

The much higher milk potential of ST as compared with T cows is reflected in the better survival rates of ST calves to 2 years. For example, when the 60% milk offtake policy applies, the survival rate of ST calves is higher than that of T calves by as much as 16 percentage points. However, this substantial increase in ST calf survival rates is not achieved without cost. As might be expected, *ceteris paribus* the higher milk potential of ST cows must result in an overall lower body condition as compared with T cows, and therefore in higher cow mortality rates. The simulation results support this hypothesis. As shown in Figure 8, the mortalities for ST are markedly higher than for T cows at supplementation levels up to 2.5 kg/head/d. Above that level the difference between the two genotypes is insignificant.

Table 8. *Simulated growth to 7 and 18 months (average for males and females) for various supplementation levels and milk offtake rates.*

Milk offtake rate (%)	Genotype	Supplementation level (kg/head/d)					
		0.0	0.5	1.5	2.5	5.0	7.5
		Average 7-month weaning weight (kg)					
0	T	190.5	191.1	191.6	191.8	191.9	192.0
	ST	218.2	221.2	223.7	224.5	224.6	224.7
20	T	175.3	176.8	177.6	178.2	178.4	178.7
	ST	204.0	209.9	214.1	215.4	215.9	216.0
40	T	156.7	157.6	158.6	159.6	160.0	160.2
	ST	187.1	192.8	197.8	199.8	200.6	201.1
60	T	117.8	119.1	120.2	120.9	122.4	123.0
	ST	153.4	158.5	164.5	167.0	170.2	171.6
		Average 18-month weight (kg)					
0	T	322.2	322.4	322.5	322.6	322.8	323.0
	ST	350.5	351.7	352.7	353.1	353.1	353.2
20	T	311.0	311.0	311.1	311.2	311.2	311.4
	ST	336.7	343.0	344.7	345.6	345.6	345.7
40	T	294.8	295.0	295.0	295.8	295.8	295.9
	ST	323.5	329.1	331.6	332.6	332.9	332.9
60	T	268.6	269.4	269.8	269.9	270.0	270.2
	ST	298.7	300.5	305.0	305.7	307.8	309.0

5.2.3 Animal growth

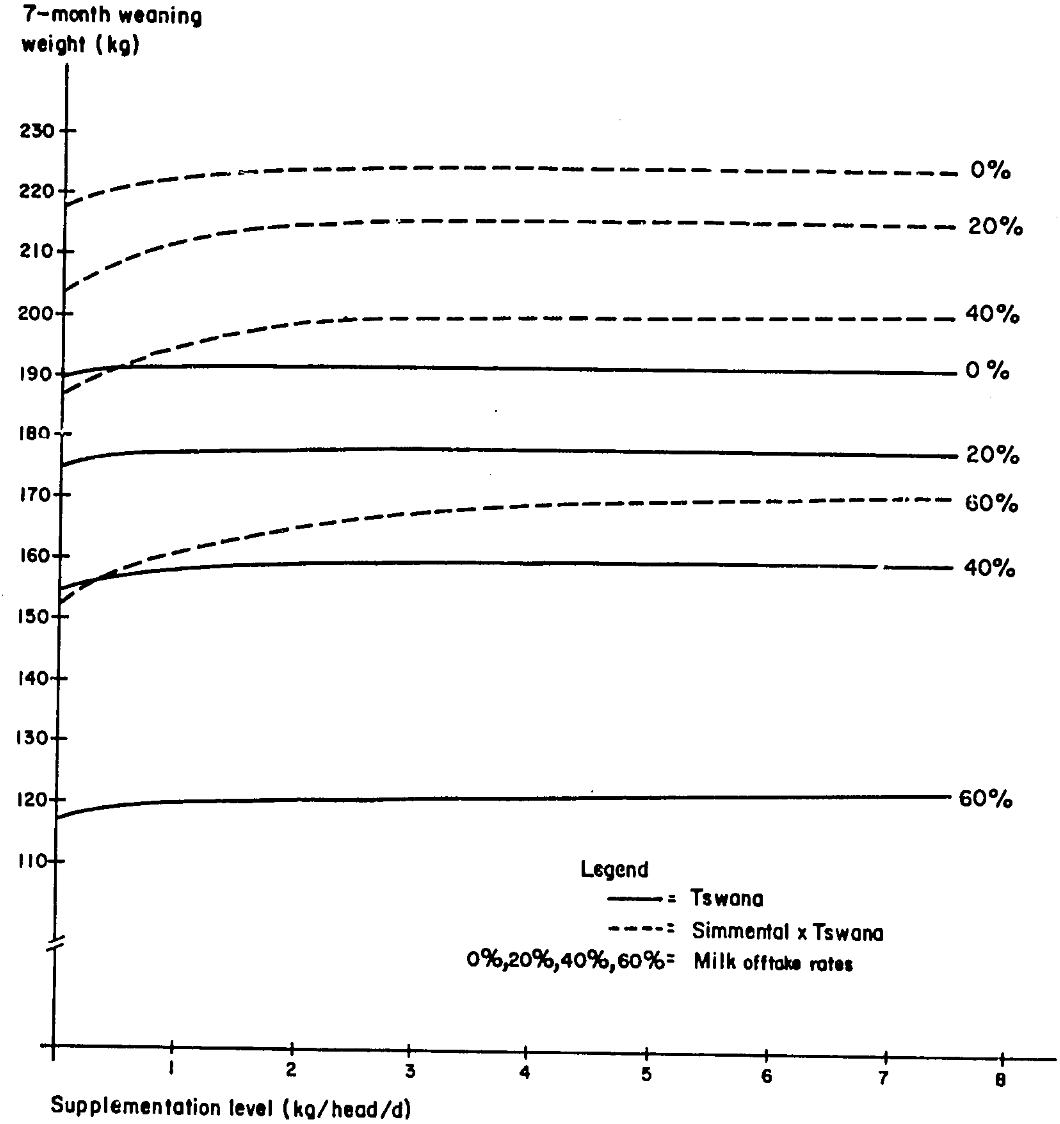
Average 7-month weaning weights and 18-month weights for both males and females are shown in Table 8 and Figures 9 and 10. The milk offtake rate has a substantial effect on 7-month and 18-month weights at any level of supplementation. Weaning weights are reduced by about 70 kg and 60 kg for T and ST calves respectively, as milk offtake rates increase from 0 to 60%. Similarly, 18-month weights are reduced by about 53 kg and 47 kg for T and ST animals respectively, again as milk offtake rates increase from 0 to 60%. As expected, because of the lower milk potential of T relative to ST cows, the effect of milking on calf growth is more severe in the case of T calves[20].

The marginal effect of milking on calf growth increases as higher milk offtake rates apply. As the milk offtake rate increases from 0 to 20%, weaning weights decrease by about 0.5 to 0.7 kg (depending on the genotype and the supplementation level) for each additional percentage point of milk removed. On the other hand, the marginal decreases in weaning weights when the milk offtake rate increases from 40 to 60% are about 1.4 kg to 1.9 kg (again depending on the genotype and the supplementation level). On average, weaning weights when the milk offtake rate is over 40% thus decrease almost three times faster than when it is 0 to 20%.

Supplementation has relatively little effect on weaning and 18-month weights, particularly for T calves and for both genotypes when a low nilk offtake rate applies (below 20%). Supplementation has a substantial effect at higher milk offtake rates, particularly on the growth of ST calves, due to the higher milk potential of their dams, which are capable of realizing a higher fraction of their potential at higher supplementation levels. At a 60% milk offtake rate weaning and 18-month weights of ST calves increase by about 18 kg and

[20] Weaning and 18-month weights for T animals at a 60% milk offtake rate, expressed as a percentage of corresponding weights when no milk is removed, amount to about 63% and 83% respectively. The corresponding figures for ST animals are much higher, about 74% and 87% respectively.

Figure 9. *Simulated effect of supplementation on weaning weights for various milk offtake rates.*



10 kg, compared with about 5 kg and 2 kg for T calves, as supplementation rises from 0 to 7.5 kg/head/d. Again, as was also observed for the effect of supplementation on fertility and mortality, the marginal contribution of supplementation to calf growth diminishes at higher supplementation levels.

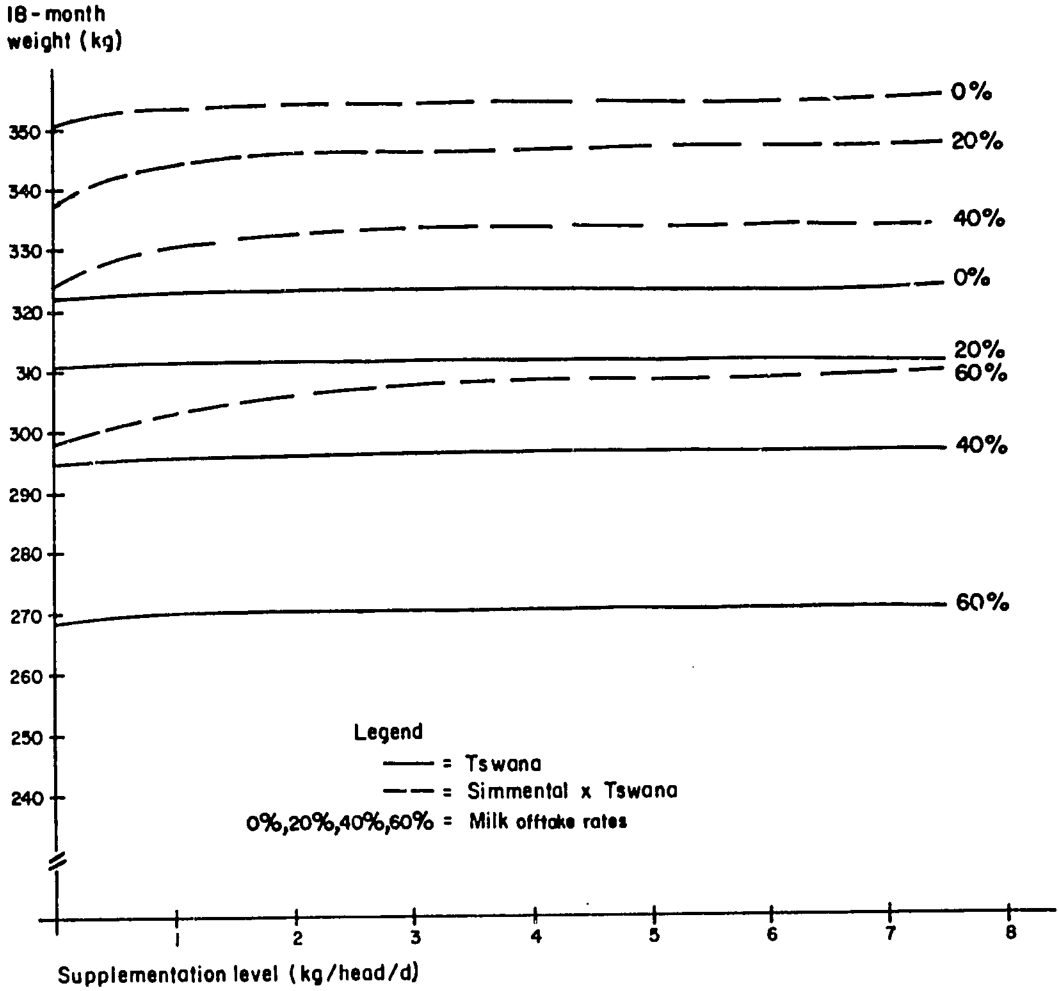
5.2.4 Feed inputs and milk and meat offtake

Figure 4 summarized the inputs and outputs of the livestock production system under study. The production process started with an initial herd which evolves into a final herd at the end of a 15-year simulation period, with intermediate inputs and outputs in the form of the feed consumed and the milk and meat produced[21].

These inputs and outputs are presented in Tables 9, 10, 11, 12 and 13 for all the 24 production alternatives considered. There is some increase in the total quantity of forage consumed for higher levels of supplementation and some decrease for higher levels of milk offtake. However, these differences are not the result of different consumption levels per animal. The explanation lies in the size of the whole herd under the various production alternatives (see Appendix Table A.7). The average forage consumption for the average animal in the system studied amounts to about 2850 kg/year or about 7.9 kg/d.

[21] The only inputs quantified by the simulation model are those of feed requirements. The production alternatives considered here would in addition require fixed expenditures for infrastructure (e.g. equipment for feeding and milking), as well as variable inputs such as labour. Quantification of these other "less variable" inputs does not necessarily require the use of a model and can be done straightforwardly.

Figure 10. *Simulated effect of supplementation on 18-month progeny weights for various milk offtake rates.*



Available quantities of supplements per head per day are maximum levels which a lactating cow has at its disposal for consumption. Whether these maximum quantities are totally consumed depends on the energy outlets that lactating cows have. As Table 10 shows, total consumption of supplements by ST cows is higher than for T cows, reflecting the higher energy outlets of ST cows due to their higher milk yield potential. At high supplementation levels T cows, after satisfying their energy demands for milk production and increasing liveweight to the extent allowed by their genetic potential, do not have any other use for the extra supplements available to them. Thus the saturation point for T cows is somewhere between 2.5 and 5.0 kg/head/d, whereas the corresponding saturation point for ST cows is somewhere between 5.0 and 7.5 kg/head/d.

This observation is made on the basis of a comparison between total annual supplement consumption of the two genotypes at levels of 2.5, 5.0 and 7.5 kg/head/d. ST consumption levels increase by about 100% as the available quantity of supplements increases from 2.5 to 5.0 kg/head/d, implying that all available supplements are consumed. However, T consumption levels increase by about 66%, implying that T animals reach a saturation point at about 4.2 kg/head/d. Similarly, for ST cows consumption levels increase by about 40% as the available quantity of supplements increases from 5.0 to 7.5 kg/head/d, implying that they reach a saturation point at about 6.9 kg/head/d[22].

The annual total milk and liveweight offtake under the different production alternatives considered are presented in Tables 11 and 12. The ef-

[22] Supplement utilization is not uniform throughout the year, as shown in the example in Appendix Table A.8. The months of heaviest use are October, November and February to May. Utilization during December and January is relatively small due to the usually very high quality of forage on offer at that time.

Table 9. *Simulated average annual forage consumption (t) by the herds for various supplementation levels and milk offtake rates.*

Milk offtake rate (%)	Herd genotype	Supplementation level (kg/head/d)					
		0.0	0.5	1.5	2.5	5.0	7.5
0	T	344.7	353.7	356.6	359.6	355.1	352.6
	ST	355.7	374.2	385.1	388.2	387.5	385.3
20	T	333.7	347.4	354.3	355.1	349.9	348.3
	ST	358.9	356.3	380.2	387.8	390.6	390.7
40	T	316.3	331.6	341.2	343.6	341.4	338.5
	ST	344.0	347.3	367.3	380.1	387.2	384.9
60	T	265.9	282.0	287.8	294.8	298.4	297.7
	ST	303.6	324.0	342.0	359.7	366.0	368.8

Table 10. *Simulated average annual supplement consumption (kg) by the herds for various supplementation levels and milk offtake rates.*

Milk offtake rate (%)	Herd genotype	Supplementation level (kg/head/d)					
		0.0	0.5	1.5	2.5	5.0	7.5
0	T	0	3339	10127	16730	25804	29978
	ST	0	3381	10552	16864	34[illegible]85	43343
20	T	0	3379	10377	17067	26556	31199
	ST	0	3295	10524	17909	35953	49779
40	T	0	3332	10270	17009	26811	31510
	ST	0	3242	10280	17691	36041	50337
60	T	0	3273	9942	16719	26913	31242
	ST	0	3279	10136	17748	35880	50503

Table 11. *Simulated annual milk offtake (kg) from the herds for various supplementation levels and milk offtake rates.*

Milk offtake rate (%)	Herd genotype	Supplementation level (kg/head/d)					
		0.0	0.5	1.5	2.5	5.0	7.5
0	T	0	0	0	0	0	0
	ST	0	0	0	0	0	0
20	T	13057	13903	14477	14608	14620	14640
	ST	26024	28668	33502	36593	38181	38483
40	T	21273	22986	23927	24066	24107	24126
	ST	38156	41194	47758	52253	55498	55693
60	T	29839	31735	32813	33083	33187	33197
	ST	48729	55014	62261	68763	72582	72869

Table 12. *Simulated average annual liveweight offtake (kg) from the herds for various supplementation levels and milk offtake rates.*

Milk offtake rate (%)	Herd genotype	Supplementation level (kg/head/d)					
		0.0	0.5	1.5	2.5	5.0	7.5
0	T	14485	15046	15327	15582	15620	15650
	ST	15162	15783	16370	17050	17180	17245
20	T	13902	14471	14869	15012	15097	15137
	ST	14840	14857	15820	16363	16793	16943
40	T	12878	13438	14048	14317	14384	14410
	ST	13846	14347	15051	15757	16378	16455
60	T	8831	9809	10331	10735	11094	11218
	ST	11343	12177	13446	14094	14736	15089

fect of supplementation in increasing milk yields and consequently milk offtake is evident. The increase for T cows is relatively small, reflecting the low milk yield potential of this genotype. However, for ST cows milk offtake increases by almost 50% as the quantity of available supplements increases from 0 to 7.5 kg/head/d. An overall comparison of the two genotypes confirms the superiority of ST cows as milk producers. The greatest difference between the two genotypes occurs at high supplementation levels, when ST cows are able to achieve their higher potential milk yields.

Total annual milk offtake figures are not proportional to the corresponding milk offtake rates, as might be expected. As noted earlier, higher milk offtake rates are associated with lower reproductive rates, higher mortality rates, and generally lower liveweights of lactating cows. The combined effect of all these factors is smaller average breeding herds (see Appendix Table A.7) and lower milk yields per lactating cow at higher milk offtake rates.

Higher milk offtake rates are directly reflected in much lower liveweight offtakes, particularly at low levels of supplementation, as shown in Table 12. When no supplementation is in effect, liveweight offtake decreases by almost 40% for T and 26% for ST animals as the milk offtake rate increases from 0 to 60%. At high supplementation levels, the effect of milking is still high for T (28% reduction) but very small (4% reduction) for ST animals. This is again the result of the low milk yield potential of T cows compared with ST. Regardless of the quantity of supplements available, when 60% of the milk is removed the residual

Table 13. *Simulated average annual changes in herd biomass (kg) for various supplementation levels and milk offtake rates*[a].

Milk offtake rate (%)	Herd genotype	Supplementation level (kg/head/d)					
		0.0	0.5	1.5	2.5	5.0	7.5
0	T	513	617	752	825	915	928
	ST	418	637	825	976	1173	1263
20	T	402	558	692	776	851	864
	ST	249	392	621	760	1024	1141
40	T	232	407	594	681	760	758
	ST	128	248	537	684	961	1066
60	T	10	78	198	412	536	516
	ST	−179	78	267	498	761	894

[a] Compared with baseline herd at the beginning of the 15-year simulation.

milk available to calves from T cows is inadequate. As seen in Sections 5.2.2 and 5.2.3, this results in both high calf mortalities and slower growth, the combined effects of which are low liveweight offtake levels.

The above results highlight the fact that a thorough comparison between the two genotypes and between the different production alternatives requires the simultaneous consideration of both milk and meat output. This simultaneous consideration will be undertaken in Section 5.2.6 in terms of energetic efficiency, and finally in Section 6, where the economic trade-offs between these outputs for the various production alternatives considered are analysed.

5.2.5 Herd viability

In addition to the level of outputs from the system, reflected in the quantities of milk and meat produced, the desirability of different policies must be examined within the context of long-term herd viability. For example, although a policy of high milk offtake might be associated with a higher overall income, it may also increase the probability of system failure to unacceptable levels.

In systems where forage on offer varies markedly from year to year, there is always a probability (however small) of an extended dry season occurring for two or more years running. Milk yields drop substantially during such periods of drought, there is a higher than usual calf mortality and, depending on the length of the drought period, the consequences for the whole herd can be catastrophic. Management will usually react to the prospect of a catastrophe by selectively disposing of the less productive animals and perhaps by strategic supplementation of the remaining breeding herd. Such a policy ("drought policy") is available within the general management options of this simulation model.

The experiments presented so far were conducted without any drought policy in effect, so that the impact of nutritional stress is reflected directly in the performance of the different production alternatives considered. However, the accounting part of the model records the incidence of nutritional stress, the occurrence of which is determined at the beginning of each month of simulation and is defined as a situation in which the average liveweight condition of the whole herd is very low (e.g. liveweights are below 300 kg and 323 kg for mature T and ST females respectively) and the quality of forage on offer for that month is below the level sufficient for liveweight maintenance. Such situations imply continuation of liveweight losses for the whole herd for that month with, in turn, an expected increase in mortality.

The average intervals between severe nutritional stress situations are presented in Table 14 and Figure 11. Out of the 24 experiments conducted for each genotype, 3 for T and 5 for ST herds proved to be catastrophic: in other words, all animals in the herd died of starvation (indicated by an asterisk in Table 14). These catastrophies took place during replication 6, when a sequence of 3 consecutive below average years occurred (see Appendix Table A.6).

In general, severe nutritional stress situations, as defined earlier, occur more frequently at higher milk offtake rates and also more frequently for the ST genotype. For example, when no supplementation is given the frequency of nutritional stress in the T system increases from once every 16.5 years to once every 4.5 years as milk offtake rates increase from 0 to 60%. The corresponding frequencies for the ST genotype are 12.5 years and 2.7 years. Although not shown here, the severity of nutritional stress, as measured by the quantities of strategic supplements that would have been required to alleviate its consequences, is higher at higher milk offtake rates and also higher for the ST genotype.

Supplementation of lactating cows substantially alleviates nutritional stress by reducing its frequency at any one milk offtake rate. At the maximum supplementation rate of 7.5 kg/head/d, nutritional stress did not occur at any milk offtake level with either genotype.

The economics of strategic supplementation is itself a topic warranting a separate study and is not covered here. However, the above analysis was undertaken to gain an appreciation of the long-term consequences of different intervention policies within the context of a viable production system.

5.2.6 Overall comparative performance on the basis of energetic efficiency

So far the performance comparisons of the different production alternatives considered in this analysis have been based on individual measures of performance, namely herd reproduction, mortality, animal growth, milk and meat output, herd viability and input requirements. Ranking of production alternatives on the basis of single measures of performance is not feasible, as the rank of a given alternative depends on the criterion used. An overall performance index is thus required.

Table 14. *Simulated average interval (years) between severe nutritional stress situations for various supplementation levels and milk offtake rates*[a].

Milk offtake rate (%)	Genotype	Supplementation level (kg/head/d)					
		0.0	0.5	1.5	2.5	5.0	7.5
0	T	16.5	19.0	45.0	300.0	–	–
	ST	12.5	14.0	37.0	150.0	–	–
20	T	12.5	13.5	25.0	150.0	–	–
	ST	6.5*	7.5	13.0	18.0	300.0	–
40	T	8.0*	9.0	14.0	37.0	–	–
	ST	5.5*	6.0*	7.5	13.5	75.0	–
60	T	4.5*	5.5*	9.5	21.0	–	–
	ST	2.7*	3.0*	4.0	5.5	20.0	–

[a] The cases indicated by an asterisk were catastrophic; that is, an unfavourable sequence of below average years occurred, during which all animals in the simulated herd died of starvation.

In the long term, intermediate measures of performance such as fertility, mortality and animal growth are directly reflected in the overall outputs from the system, i.e. milk and meat offtake and the capital value of the herd at the end of the period. For the purposes of constructing an overall measure the different production alternatives can be evaluated on the basis of outputs and corresponding inputs. Tables 9, 10, 11, 12 and 13 presented annual inputs and outputs of the production process and also the net change in the herd biomass (expressed in annual terms) over the 15-year simulation period. These figures are now used as the basis for an overall comparison between the different production alternatives.

The approach, in the construction of an overall performance index, is to compare the total outputs from the system with the total inputs. In order to sum up the individual components of inputs and outputs, these must be expressed in the same units of measurement. On the input side the quantities of forage and supplements consumed annually are expressed in MJ of metabolizable energy. Similarly, on the output side the annual milk and meat offtakes and the annual change in herd biomass are expressed in MJ on the basis of their energy content.

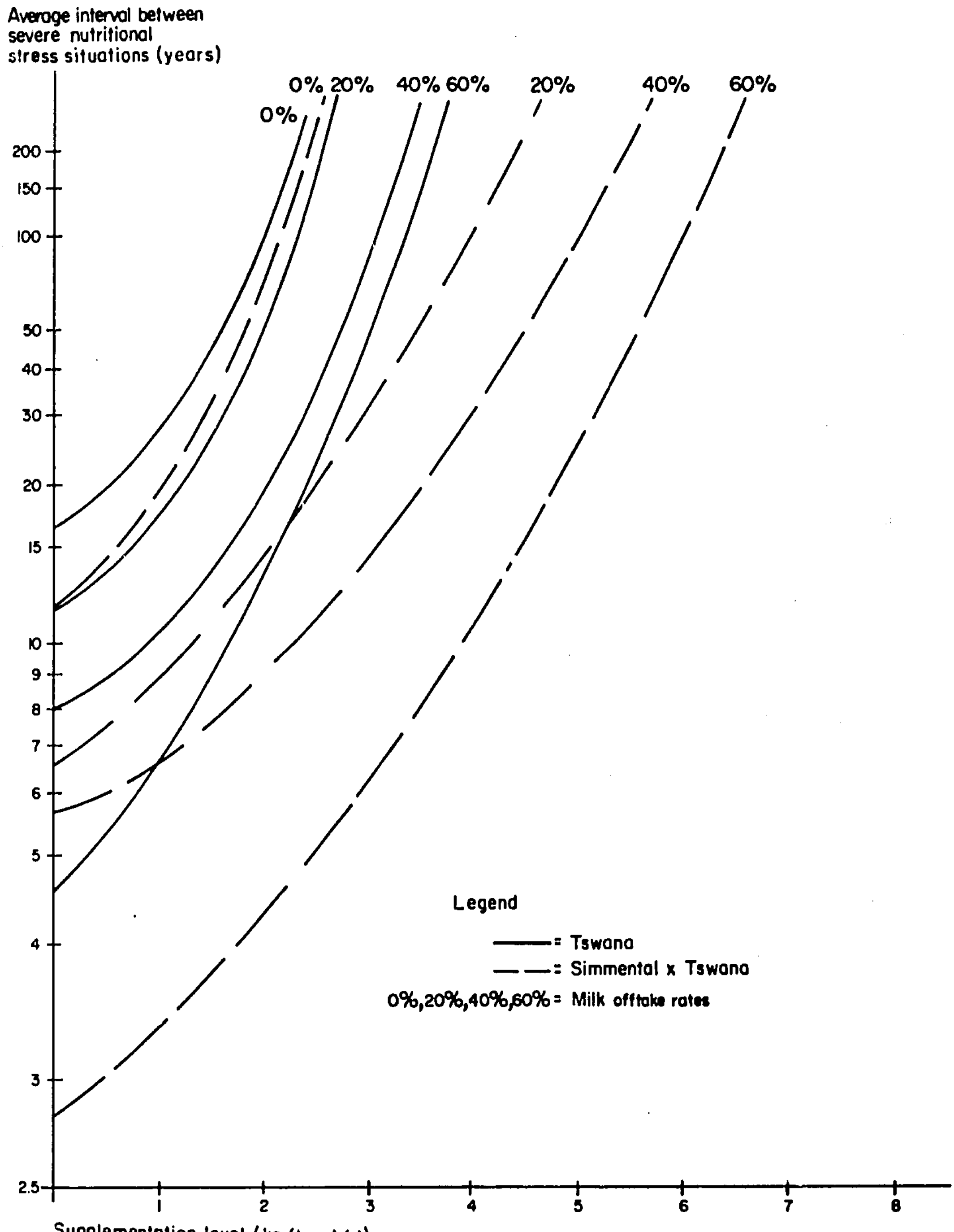
Formally, define:

- f = quantity of forage consumed annually in t (Table 9);
- x = quantity of supplements consumed annually in kg (Table 10);
- e_f = average metabolizable energy (MJ/t of forage consumed); based on the values of Table 1, the average digestibility of the forage of the five year types (weighted by their respective probabilities of occurrence) is 0.50; further, taking the average energy content of forage as 18 MJ/kg and the ratio of metabolizable to digestible energy as 0.82, the average metabolizable energy content of forage equals 7380 MJ/t;
- e_x = metabolizable energy of the supplements consumed, which equals 12.5 MJ/kg;
- q_1 = annual quantity of milk offtake in kg (Table 11);
- q_2 = annual quantity of liveweight offtake in kg (Table 12);
- ΔQ = change in total herd biomass (kg) for the whole 15-year period expressed annually (Table 13);
- e_1 = net energy content of milk. As discussed in Section 3.4, this equals 3.5 MJ/kg and 3.3 MJ/kg for T and ST milk respectively;
- e_2 = net energy released from the mobilization of body tissues; assuming 20 MJ/kg of body weight and a coefficient of efficiency for its utilization in different body functions of 0.82, the result is a net energy content of 16.4 MJ/kg of body weight.

Based on the above, the energetic efficiency of the different production alternatives considered can be obtained from the relationship

$$c = \frac{e_1.q_1 + e_2.q_2 + e_2.\Delta Q}{e_f.f + e_x.x} \cdot 100$$

Figure 11. *Simulated effect of supplementation on the incidence of severe nutritional stress for various milk offtake rates.*



where c is the energy equivalent of the total output expressed as a percentage of the total metabolizable energy utilized by the production system.

Table 15 and Figure 12 present the energetic efficiencies obtained using the above relationship for the various production alternatives considered. For both genotypes energetic efficiency increases monotonically for higher milk offtake levels at any given level of supplementation. This implies that at higher milk offtake rates the energy loss from lower liveweight offtake is less than the increase in energy output in the form of milk. It is clear from the values of Table 15 that the increase in total energy output from higher milk offtake rates is in favour of the ST genotype. At a 60% milk offtake rate the energetic efficien-

Table 15. *Simulated herd level energetic efficiency (%) for various supplementation levels and milk offtake rates.*

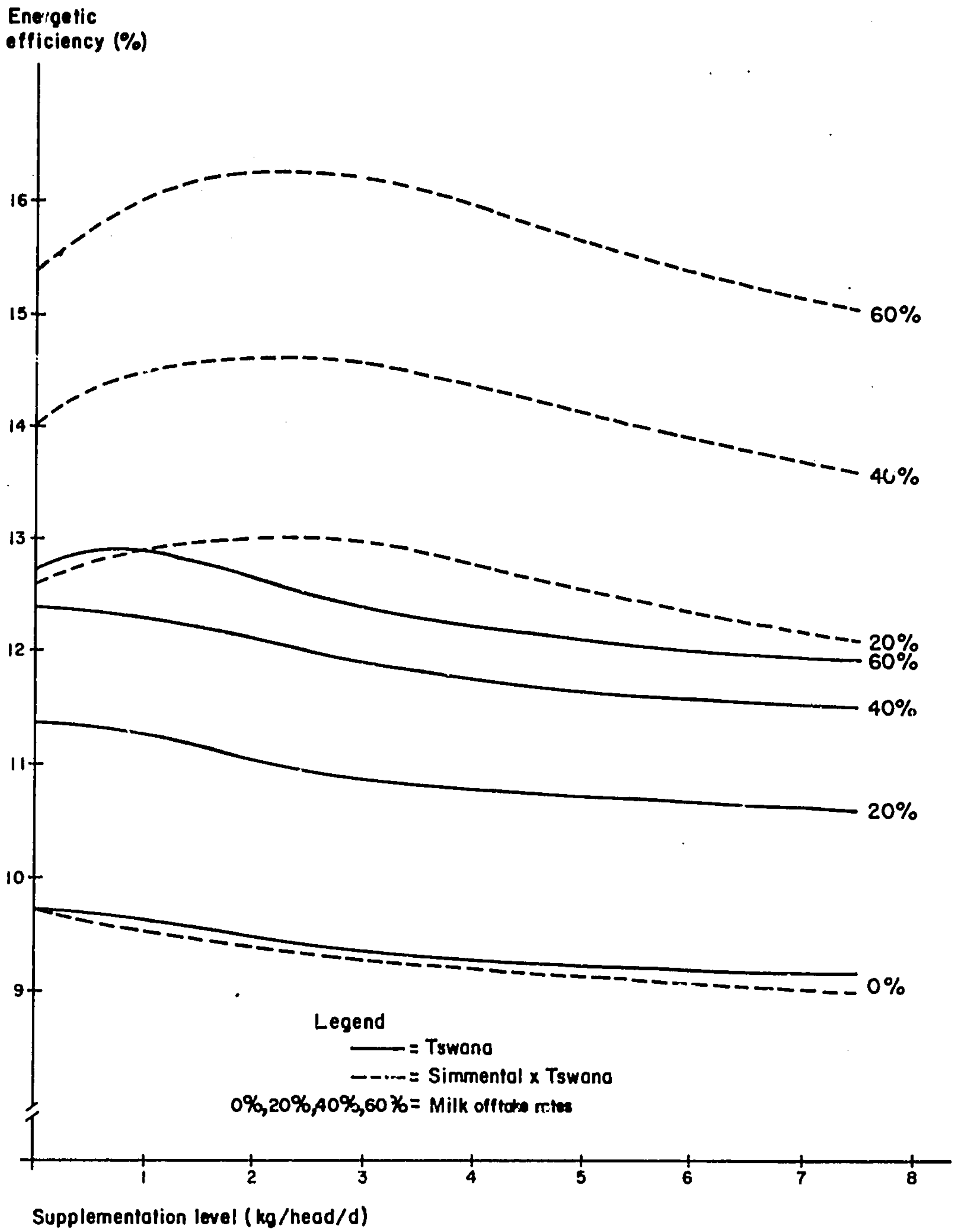
Milk offtake rate (%)	Genotype	Supplementation level (kg/head/d)					
		0.0	0.5	1.5	2.5	5.0	7.5
0	T	9.67	9.65	9.56	9.40	9.21	9.13
	ST	9.73	9.60	9.48	9.35	9.14	8.97
20	T	11.38	11.33	11.15	10.94	10.73	10.59
	ST	12.59	12.91	12.94	13.01	12.55	12.08
40	T	12.40	12.36	12.24	12.01	11.66	11.52
	ST	13.99	14.41	14.56	14.61	14.13	13.58
60	T	12.71	12.88	12.79	12.52	12.09	11.93
	ST	15.35	15.73	16.20	16.21	15.67	14.99

cy of the ST genotype is higher than that of the T genotype by as much as 3 percentage points. At the other extreme, ST cows are marginally inferior to T in a beef production system (i.e. no milking).

The energetic efficiency is equally sensitive to the level of supplements provided. Except in the case of the 60% milk offtake rate, the maximum energetic efficiency for T cows occurs at zero supplementation. Even in this exceptional case, the optimum supplementation level on the basis of energetic efficiency, is only 0.5 kg/head/d. For the ST genotype maximum energetic efficiencies are achieved at a supplementation level of 2.5 kg/head/d[23]. Providing supplements above that level decreases energetic efficiency, such that the percentage increase in total energy output is less than the corresponding percentage increase in the level of supplements consumed. Whether this energetically efficient supplementation level is also economically efficient depends on the prevailing relative prices between meat, milk and supplements. A comparison between the different production strategies on the basis of economic efficiency is the topic of the following section.

[23] For both genotypes the energetic efficiency optima occur well below their saturation levels of supplement consumption (4.2 and 6.9 kg/head/d) as obtained in Section 5.2.4.

Figure 12. *Simulated effect of supplementation on energetic efficiency for various milk offtake rates.*



6. ECONOMIC ANALYSIS

6.1 TRADE-OFFS BETWEEN MILK AND MEAT PRODUCTION

The two main outputs (milk and meat) of the system under study are technically interdependent. Production of milk alone is not possible without meat production, and vice-versa. Formally, the production process in the case of joint products can be represented by an implicit production function of the form (Henderson and Quandt, 1971)

$$H(q_1, q_2, x) = 0$$

where

q_1 = quantity of milk produced,
q_2 = quantity of meat produced, and
x = quantity of feed supplements provided.

Solving the above relationship explicitly for x yields the cost of production as a function of the quantities of the two outputs produced, i.e.

$$x = h(q_1, q_2)$$

A product transformation curve is defined as the locus of output combinations that can be produced from a given level of inputs. The family of product transformation curves for milk and meat production for the system under study is shown in Figure 13, obtained from the milk and liveweight offtake values given in Tables 11 and 12[24]. Thus, for a given input level there exist infinite numbers of output combinations of milk and meat. The rate of product transformation (RPT) is defined as the quantity of one product that must be forgone in order to obtain more of the other without varying the input level. The measure of this rate is the negative of the slope at any point of the product transformation curves. Because the curves are concave to the origin, the higher the production level for one of the two products the higher the rate at which the production of the other is sacrificed. For example, moving from point A to point B on the ST 2.5 kg/head/d curve, i.e. increasing milk output by 10 000 kg (from 20 000 kg to 30 000 kg), results in a reduction of meat output by about 100 kg, compared to a reduction of about 420 kg when moving from point C to point D, i.e. increasing milk output by the same amount (from 50 000 kg to 60 000 kg).

The higher performance of the ST over the T genotype is clearly shown in Figure 13. The production frontiers for ST are far above those of T for any level of supplementation. For example, at a supplementation level of 1.5 kg/head/d, an annual meat offtake of 7000 kg is associated with a milk offtake of 23 900 kg for the T system, as compared with more than twice as much from the ST system, i.e. 56 200 kg.

Due to the variable RPT along each product transformation curve, for a given level of feed supplementation the combination of milk and meat production that yields the maximum revenue will depend on milk and meat relative prices. It can easily be shown that revenue is maximized when the RPT equals the ratio of milk and meat prices, i.e. when

$$RPT = \frac{p_1}{p_2}$$

where

p_1 = unit price of milk, and
p_2 = unit price of meat.

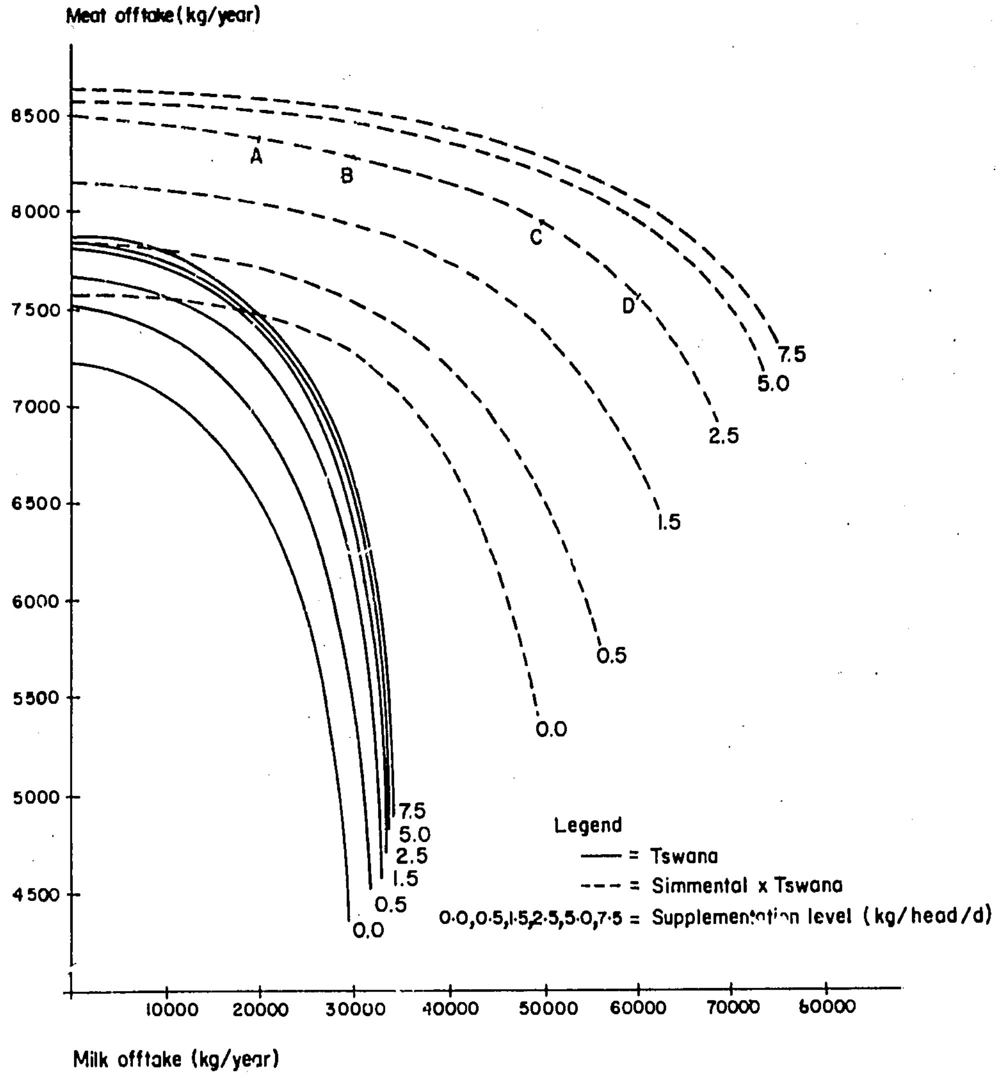
There is only one point on each product transformation curve which satisfies the above condition, and the loci of such points constitute the output expansion path of the joint milk and meat production system.

6.2 PROFIT MAXIMIZATION AND THE OPTIMUM PRODUCTION STRATEGY

The determination of the optimum production strategy must take into consideration, in addition

[24] Assuming carcass weight is 50% of liveweight.

Figure 13. *Simulated herd-level product transformation curves between milk and meat output for various supplementation levels.*



to the relative prices of milk and meat, the cost of inputs to the system. In the short run only the cost of intermediate inputs and the revenue from intermediate outputs need to be taken into account. In the long run the initial and final capital value of the herd and all other capital holdings must additionally be taken into account. The optimum combination of milk and meat production will be that which maximizes annual net revenue (NR), i.e. gross revenue from the sale of milk and meat minus costs. NR can be expressed by the relationship

$$NR = p_1q_1 + p_2q_2 - rx - sz - w$$

where

- r = the unit cost of feed supplements,
- x = the quantity of supplements used,
- s = the unit cost of labour,
- z = the number of labourers employed, and
- w = all other fixed costs.

With respect to supplementation, NR is maximized when the value of the marginal product of feed supplements for the production of each output equals the price of supplements. Net revenue from supplementation would increase if the return to its use for the production of either product exceeds its cost. Thus, the level of supplements employed would be that at which the returns from each product would be equal to the cost of supplements.

Table 16 presents current producer prices and associated costs. In addition to feed and labour costs, other costs related to maintaining a "reasonably acceptable" level of management have been taken into consideration. These include the establishment of fences and boreholes, the provision of water, minerals and routine veterinary care and, in the case of a dairy system, extra costs for veterinary care, AI and dairy equipment.

Based on the presently prevailing price structure and the assumptions made in Table 16 about other related production costs, the annual net revenue from the different production alternatives is given in Table 17 and in Figure 14. It is

Table 16. *Fixed and variable costs paid and prices received by producers in ranching enterprises in Botswana (1982)*[a].

Item	Cost/price (P)
Fixed costs:	
Maintenance of fencing and borehole (10% of establishment costs)[b]	2 640
Water, minerals and routine veterinary care (75 LU @ P 9.0/LU)	675
Total fixed costs of a beef system	3 315
Additional costs of a dairy system	
- Extra veterinary costs (40 cows @ P 10.0/cow)	400
- AI (40 cows @ P 5.0/cow)[c]	200
- Dairy equipment (10% of purchase cost of P 500.0)	50
Total fixed costs of a dairy system	3 965
Variable costs:	
Cost of feed concentrates per kg[d]	0.22
Labour per worker/year[e]	600
Labour requirements (worker-years)	
- beef system	2
- dairy system	
(a) annual milk output less than 25 000 kg	3
(b) annual milk output between 25 000 kg and 50 000 kg	4
(c) annual milk output greater than 50 000 kg	5
Price received by producers:	
Milk per kg[f]	0.30
Meat per kg[g]	1.26

[a] Costs and prices represent mid-1982 levels and were provided by APRU scientists.

[b] For 75 LU at a recommended stocking rate of 10 ha/LU, 750 ha are required. This area is assumed to be fenced to form 7 paddocks requiring 19 km of bushwood and wire fencing. At a present cost of P 600/km the initial expenditure on fencing would be P 11 400. The cost of the borehole is estimated at P 15 000, resulting in a total initial establishment cost of P 26 400.

[c] Two inseminations per conception are assumed, @ P 2.50 per insemination.

[d] The cost of supplements to livestock producers depends on their quality and the location of individual producers. Dairy meal consisting of 15% protein, 3% fat, 9% fibre, 1.5% calcium and 0.6% phosphorus costs about P 200/t ex-Lobatse. An additional charge of 10% is assumed for transport and handling, bringing the total cost to the producer to P 220/t.

[e] A monthly wage rate of P 50 is assumed here. Although wages for unskilled labour can be substantially lower, it is assumed that for a dairy operation to be viable it must be located relatively near a consumption centre, where labour wages are much higher than in remote areas.

[f] Current dairy-gate milk prices paid to producers are P 0.35/kg. Transportation and handling costs of 15% are subtracted from this price, leaving a net price to the producer of P 0.30/kg.

[g] Botswana has a well established marketing system for beef cattle. The price paid by the abattoir in Lobatse is about P 1.30/kg of carcass weight for animals of average quality. Additionally, a marketing cost of P 10 per animal is assumed, bringing the net price received by producers to about P 1.26/kg of liveweight.

Table 17. *Simulated annual net revenue (P) given current (1982) prices, for various supplementation levels and milk offtake rates*[a].

Milk offtake rate (%)	Genotype	Supplementation level (kg/head/d)					
		0.0	0.5	1.5	2.5	5.0	7.5
0	T	4206	3824	2508	1216	−756	−1656
	ST	4632	4279	3072	2111	−1 705	−3591
20	T	5905	5774	4658	3315	1 284	294
	ST	9186	9265	9732	9377	6 154	3297
40	T	7725	7859	6999	5727	3 626	2614
	ST	12199	12713	13578	12541	9 868	6830
60	T	6545	7010	6195	5040	3 054	2183
	ST	13795	14284	15749	16434	13 995	11086

[a] Based on quantities of supplements used and the milk and meat output values in Tables 11 and 12 and the costs and prices in Table 16.

clear that, under the present price structure, feed supplementation in a beef-only production system is not economical. A sensitivity analysis of annual NRs with variable costs of feed concentrates showed that their cost must be below P 0.10/kg for them to be used economically in a beef-only production system. Although not shown here, even in that case the optimum level of concentrates used is only 0.5 kg/head/d.

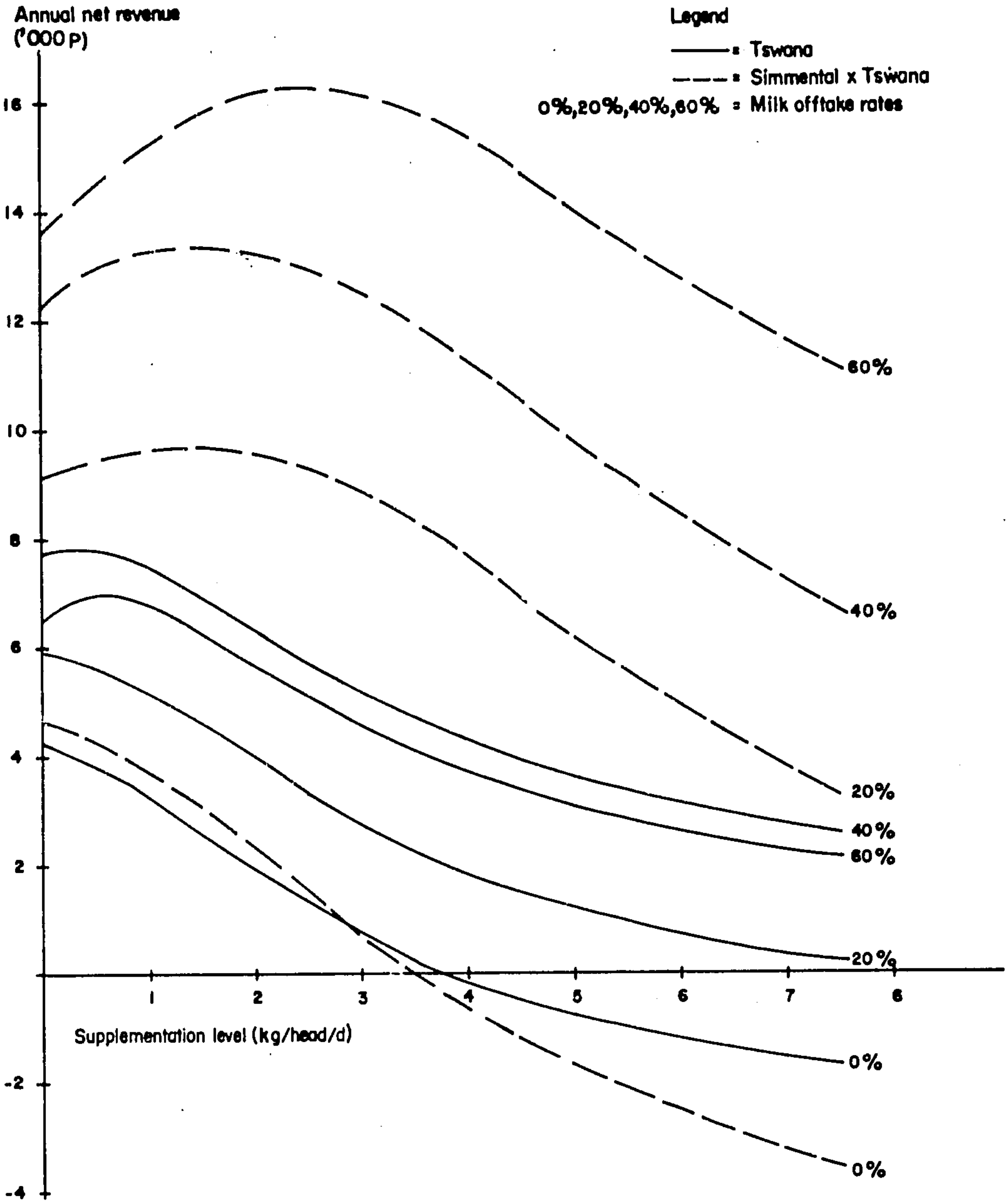
Before the economic merits of feed supplementation for the mixed beef – dairy production alternatives are discussed, a qualification is necessary on the basis of the findings of Section 5.2. In several production alternatives calf mortality was excessive and the viability of the herd could be threatened. Overall, calf mortality was relatively low up to a 40% milk offtake rate, but increased dramatically thereafter. High milk offtake alternatives, although associated with high average annual NR, also bear a high risk element which generally cautious livestock producers may not be willing to undertake. On the basis of these subjective risk considerations, the production alternative under which 60% of the milk yield would be extracted for human consumption is therefore not included in the set of economic alternatives.

The present annual NR level for a beef-only production system (i.e. no milking) without feed supplementation is taken as the basis for comparison. Simulated NR in this case equals P 4506 for the T system and P 4632 for the ST system. Under a 40% milk offtake rate, the highest income is obtained with a supplementation rate of 0.5 kg/head/d for T cows and 1.5 kg/head/d for ST cows. This optimum production strategy yields an annual NR of P 7859 for the T and P 13 578 for the ST system, or 75% and 193% higher, respectively, than present incomes.

The major determinants of profitability in the systems under consideration are the cost of concentrates and the prices received for meat and milk. With changing technological and marketing opportunities and constraints, current costs and prices must be viewed as temporary. Consequently, the extent to which the above results apply under different prices must be examined. These sensitivity analyses are depicted in Figures 15, 16 and 17 and are partial in the sense that in each case only one price is allowed to vary, whereas the other two prices are kept at their current (1982) levels. Thus, Figure 15 shows the simulated effect of the price of concentrates on annual NR, with the prices of milk and meat kept at their present levels. For the T system (lactating cows supplemented with 0.5 kg/head/d), annual NR is above present levels as long as the cost of concentrates is below P 0.49/kg, or more than twice their present cost. For the ST system (lactating cows supplemented with 1.5 kg/head/d), the threshold level is much higher, at P 1.09/kg or almost five times the present level.

Figures 16 and 17 depict the effects of the milk and meat prices received by livestock producers on their annual NR. Under present prices of concentrates and meat, annual NRs are higher than current levels as long as the price of milk is above P 0.19/kg for the T system and above P 0.12/kg for the ST system, or 63% and 40% respectively of the present net milk price received. Similarly, under present prices for concentrates and milk, an-

Figure 14. *Simulated effect of supplementation on annual net revenue for various milk offtake rates.*



nual NRs are above present levels as long as the price of meat is above P 0.86/kg for the T system and P 0.11/kg for the ST system, or 68% and 9% respectively of the present net price of meat.

In summary, the alternative production system under which 40% of the milk yield is removed for human consumption and T and ST lactating cows are supplemented with 0.5 kg/head/d and 1.5 kg/head/d respectively yields substantially higher i es than presently obtained. This conclusi s true under a wide range of concentrate and milk and meat prices.

Figure 15. *Simulated effect of concentrate cost on annual net revenue.*

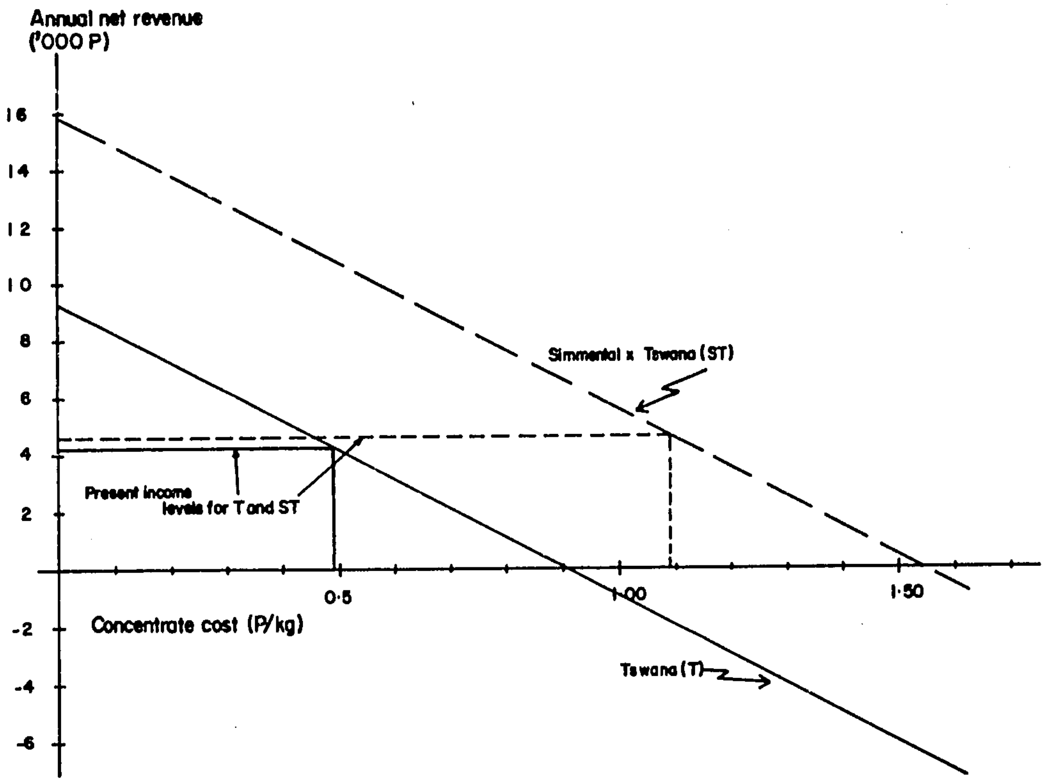


Figure 16. *Simulated effect of milk price on annual net revenue.*

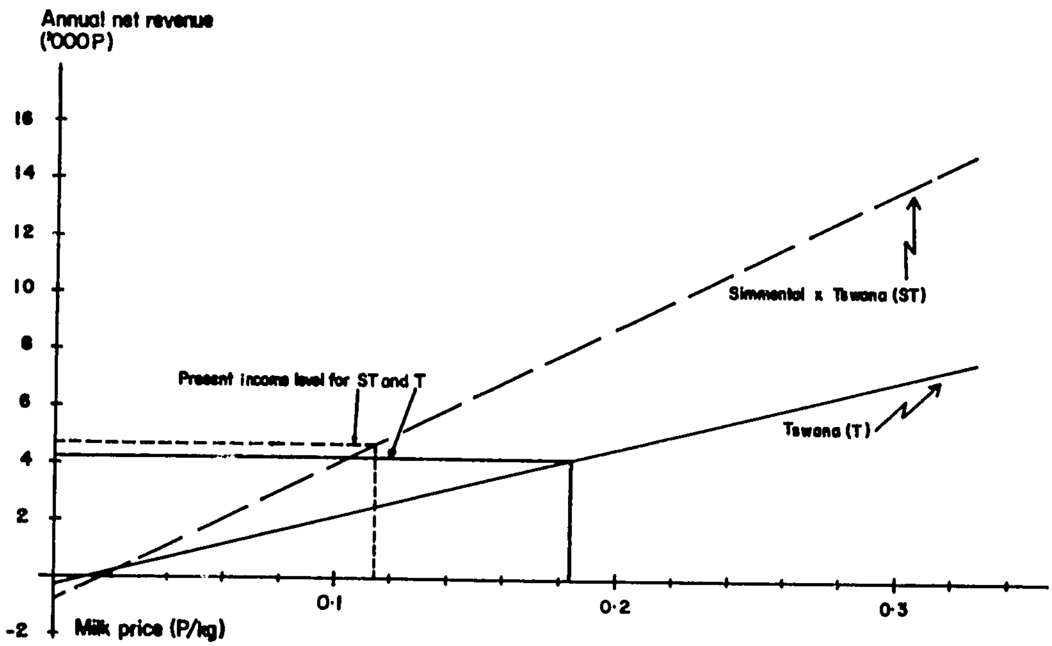
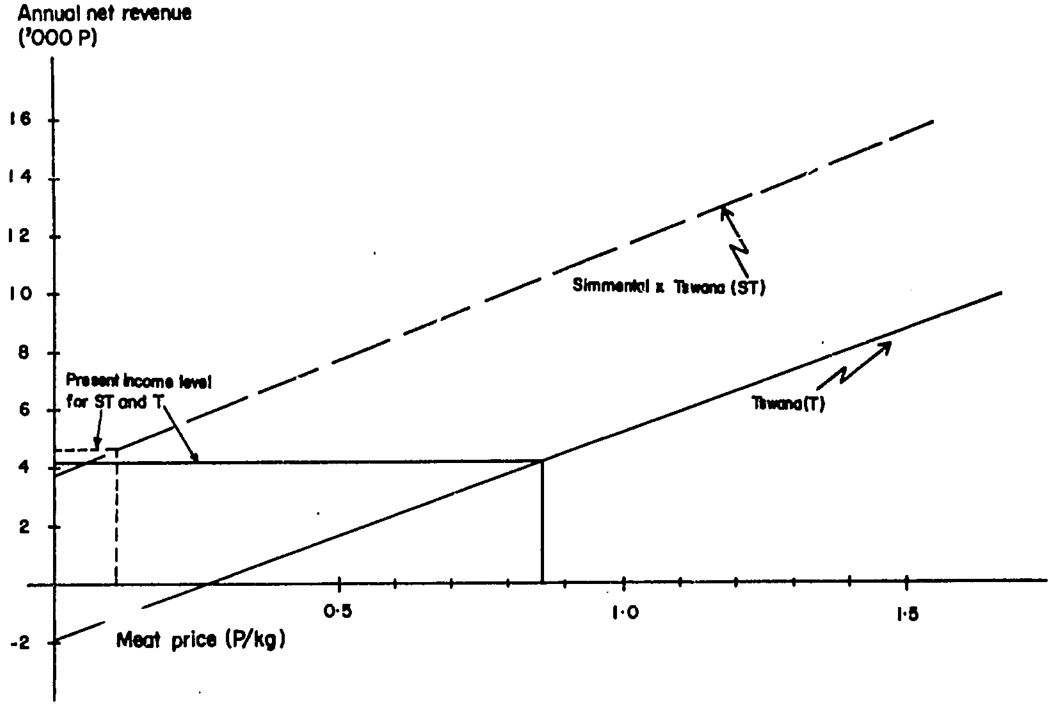


Figure 17. *Simulated effect of meat price on annual net revenue.*



7. CONCLUSIONS

The objectives of this paper were to investigate the overall performance of Tswana and Simmental x Tswana genotypes as milk producers, obtain the trade-offs between milk and meat production and formulate an optimum production strategy based on economic considerations. An array of performance measures was used for comparing the two genotypes under alternative production strategies, starting with conventional measures of performance, such as fertility and mortality, continuing with energetic efficiency and ending with economic efficiency. From this array of performance measures the rational livestock producer will choose firstly on the basis of economic criteria, and secondly, within the economically superior production alternatives, on the basis of his subjective conception of what constitutes an overall viable system.

The choice between the two genotypes as regards their potential for milk production without impairing herd viability is clearly in favour of ST. At the present cost of feed concentrates, a supplementation level of about 2.5 kg/head/d of ST lactating cows and a milk offtake rate of 60% yields the highest economic payoff. However, such a strategy is also associated with lower calf growth rates, a reduction in calf survival and a higher incidence of nutritional stress compared with the present system. The generally cautious livestock producer would probably view these short-term indicators of herd performance as dangerously low and opt for a lower return at a lower risk. Thus, on the basis of both economic efficiency and subjective evaluation of herd viability and performance, a milking rate of 40% concurrent with a supplementation rate of 1.5 kg/head/d for lactating ST cows is suggested. For the breeding herd of 40 cows considered in this analysis, such a policy results in an annual offtake of about 48 t of milk and 7.5 t of carcass weight and requires about 10.3 t of feed concentrates per year.

Under the present pricing structure and the assumptions made in this analysis, adopting a mixed beef - dairy production strategy with ST cows results in a substantial increase of producer incomes. This conclusion proves robust to changes in the cost of concentrates, and still applies even when this triples or quadruples from its present level, and equally robust to variations in the prices received by livestock producers for milk and meat. Consequently, Botswana's prospects of meeting its domestic dairy needs appear good.

Despite the strong economic rationale for dairy production systems with crossbred cows, the promotion and implementation of a dairy development policy based on crossbreds must be carefully considered case by case. Consequently, the results obtained here should not be extrapolated to other environments without the regard for differences between the production systems. The extensive nature of Botswana's rangeland does not lend itself to dairy production unless the dairy enterprise is favoured by relatively good feed resources and has easy access to a reliable market for its products. This, coupled with the relatively small and isolated consumer centres, implies that dairy enterprises must be located near communal areas and must have security of land tenure, which is a precondition for making the necessary investments.

Finally, locally available feed resources are at present certainly inadequate to supply the high-quality feed needs of dairy operations on a large scale. These additional feed resources will have to be imported. The macro-economic implications of this latter option, both in terms of foreign exchange costs and security of supplies, need to be contrasted with those of continuing present dairy import trends. However, these macro-economic aspects are beyond the scope of this study.

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LIST OF ABBREVIATIONS

The following acronyms, abbreviations and units of measure are used in this report[1]:

AI	Artificial insemination
APRU	Animal Production Research Unit (Ministry of Agriculture, Botswana)
CP	Crude protein
d	Day
DM	Dry matter
LU	Livestock unit (250 kg)
MAFF	Ministry of Agriculture, Fisheries and Food (United Kingdom)
MJ	Megajoule
P	Pula (Botswana currency)
S	Simmental
ST	Simmental x Tswana
T	Tswana
t	Metric tonne

[1] Mathematical terms and concepts formally defined in the text are omitted here.

APPENDIX:
SUPPLEMENTARY TABLES

Table A.1. *Intake coefficients for different cattle classes.*

Animal class	Intake coefficients[a]	
	1	2
1. Calves under 2 months	0	0
2. Calves 3 to 5 months	0.0305	0.0305
3. Calves 6 to 18 months	Interpolation between class 2 and class 4	
4. Mature dry, non-pregnant females and mature males (reference class)	0.0575	0.1067
5. Pregnant females (last 3 months of pregnancy)	0.0615	0.1142
6. Lactating cows	0.0661	0.1228

[a] Intake coefficients in columns 1 and 2 refer to equations (3.1) and (3.2) respectively. See Section 3.2 for estimation procedure and qualifications of different animal classes.

Table A.2. *Milk yield potential by cow age groups[a].*

Cow age (years)	Fraction of maximum milk yield
2	0.70
3	0.85
4	0.93
5	1.00
6	1.00
7	1.00
8	1.00
9	0.98
10	0.93
11	0.83
12+	0.70

[a] Assumes the age effect on lactation yield is the same for both breeds.

Table A.3. *Fraction of total lactation yield produced each month by month of lactation.*

Month of lactation	Fraction of total lactation yield produced each month	
	Tswana	Simmental x Tswana
1	0.165	0.140
2	0.165	0.140
3	0.148	0.129
4	0.130	0.118
5	0.113	0.107
6	0.096	0.096
7	0.078	0.084
8	0.061	0.073
9	0.044	0.062
10	–[a]	0.051
Total	1.000	1.000

[a] The lactation length of Tswana cows is assumed to be 1 month less than in Simmental x Tswanas.

Table A.4. *Expected annual calving rates by age and corresponding monthly probabilities of conceptions*[a].

Cow age (years)	Tswana		Simmental x Tswana	
	Expected annual calving rate (%)	Expected monthly probability of conception(%)	Expected annual calving rate (%)	Expected monthly probability of conception (%)
2	80.0	41.5	88.0	50.7
3	80.0	41.5	88.0	50.7
4	89.0	52.1	94.7	62.5
5	92.0	56.9	97.0	68.9
6	92.0	56.9	97.0	68.9
7	92.0	56.9	97.0	68.9
8	92.0	56.9	97.0	68.9
9	91.2	55.4	96.4	67.0
10	89.0	52.1	94.7	62.5
11	85.2	47.1	91.9	56.9
12+	80.0	41.5	88.0	50.7

[a] Calving rates and conception rates are assumed equal. Expected values are for animals of normal liveweight. The expected monthly probabilities of conception have been computed assuming a 3-month breeding season.

Table A.5. *Numbers and liveweights of cows in herds used to initialize each simulation.*

Cow age (years)	No. of females in age groups	Liveweight/head of individuals in age group (kg)	
		Tswana	Simmental x Tswana
<1	12	200	210
1	8	320	330
2	8	415	425
3	7	470	485
4	5	470	485
5	5	470	485
6	4	470	485
7	4	470	485
8	4	470	485
9	3	470	485
Total	60		

Table A.6. *Random sequences of year types used in all simulation runs*[a].

Year in simulated time	Replication number									
	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1	1	1	1	1	1	1
2	3	2	4	5	3	1	2	4	3	3
3	3	3	4	2	4	4	3	3	3	3
4	2	2	2	3	2	5	5	2	2	3
5	2	4	4	3	2	3	2	3	1	4
6	1	3	3	3	3	3	3	4	2	2
7	4	3	2	2	2	4	3	2	3	1
8	2	3	1	3	3	4	2	3	2	2
9	3	4	3	5	3	4	1	3	2	4
10	2	1	3	2	4	3	5	3	4	3
11	1	4	2	4	2	2	2	1	2	2
12	1	2	3	3	2	4	3	5	2	2
13	1	4	3	4	3	2	1	2	2	1
14	2	4	3	1	2	4	1	3	3	4
15	2	3	2	3	3	4	3	3	3	2

	Year type				
	1	2	3	4	5
Overall frequency of occurence (%)	16.7	28.7	33.3	17.3	4.0

[a] Year type codes are as follows (see Table 1): 1 = good; 2 = above average; 3 = average; 4 = below average; 5 = poor.

Table A.7. *Simulated average total herd size and breeding herd sizes over the 15-year period for various supplementation levels and milk offtake rates.*

Milk offtake rate (%)	Genotype	Supplementation level (kg/head/d)					
		0.0	0.5	1.5	2.5	5.0	7.5
		Average total herd size					
0	T	122.1	125.5	126.6	127.6	126.0	124.8
	ST	120.4	126.6	130.9	131.6	131.5	130.5
20	T	118.8	124.1	126.6	127.0	124.5	123.9
	ST	122.2	119.8	127.8	130.4	131.6	131.5
40	T	114.5	120.3	124.1	124.7	123.7	122.7
	ST	118.1	118.0	125.1	128.8	131.5	130.7
60	T	100.4	106.3	108.6	111.3	112.2	111.7
	ST	107.3	114.4	119.8	125.7	127.6	128.4
		Average breeding herd size (number of cows)					
0	T	39.45	40.17	40.22	40.27	40.07	40.01
	ST	37.60	39.28	40.15	40.26	40.26	40.07
20	T	38.40	39.92	40.34	40.21	39.57	39.96
	ST	38.68	37.51	39.90	40.23	40.17	40.29
40	T	37.60	39.43	39.97	40.18	39.78	40.02
	ST	37.71	37.06	38.75	40.05	40.21	40.11
60	T	37.19	38.41	38.63	39.46	39.61	39.47
	ST	35.48	37.50	38.17	39.93	39.97	40.10

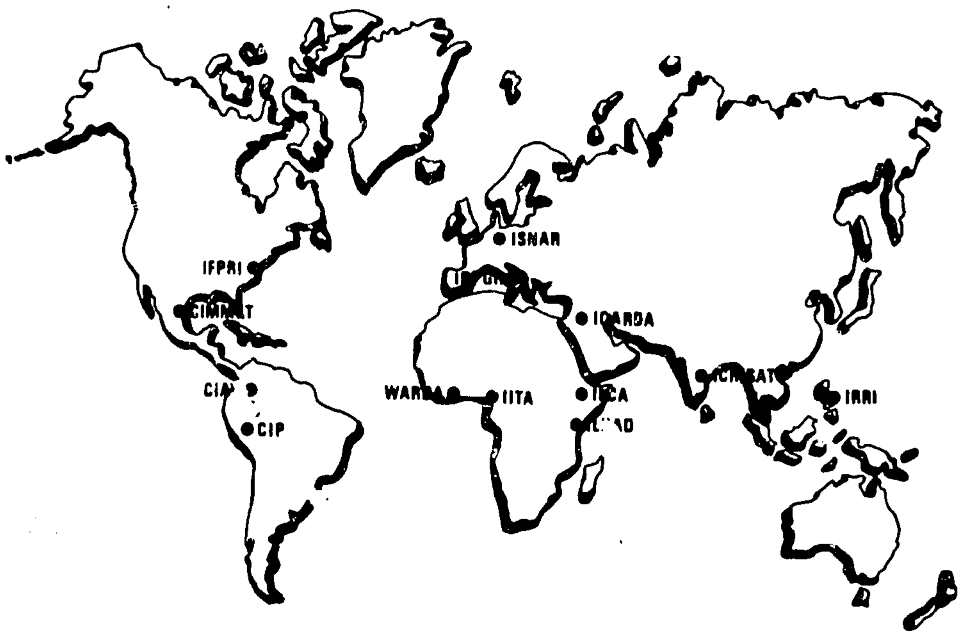
Table A.8. *Simulated average monthly supplement utilization for Simmental x Tswana cows fed 5 kg/head/d of supplements and milked at 40% offtake rate.*

Month	Monthly supplement utilization by head (kg)	Monthly supplement utilization (% of annual use)
January	1 898	5.3
February	5 667	15.7
March	5 645	15.7
April	5 638	15.6
May	5 619	15.6
June	1 906	5.3
July	531	1.5
August	–	–
September	–	–
October	3 764	10.4
November	5 147	14.3
December	226	0.6
Total	36 041[a]	100.0

[a] Total usage as per corresponding element of Table 10.

THE CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH

The International Livestock Centre for Africa (ILCA) is one of the 13 international agricultural research centres funded by the Consultative Group on International Agricultural Research (CGIAR). The 13 centres, located mostly within the tropics, have been set up by the CGIAR over the last decade to provide long-term support for agricultural development in the Third World. Their names, locations and research responsibilities are as follows :



Centro Internacional de Agricultura Tropical (CIAT), Colombia: cassava, field beans, rice and tropical pastures.

Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT), Mexico: maize and wheat.

Centro Internacional de la Papa (CIP), Peru: potato.

International Centre for Agricultural Research in the Dry Areas (ICARDA), Lebanon: farming systems, cereals, food legumes (broad bean, lentil, chickpea), and forage crops.

International Board for Plant Genetic Resources (IBPGR), Italy.

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India: chickpea, pigeon pea, pearl millet, sorghum, groundnut, and farming systems.

International Livestock Centre for Africa (ILCA), Ethiopia: African livestock production.

International Rice Research Institute (IRRI), the Philippines: rice.

International Institute of Tropical Agriculture (IITA), Nigeria: farming systems, maize, rice, roots and tubers (sweet potatoes, cassava, yams), and food legumes (cowpea, lima bean, soybean).

International Laboratory for Research on Animal Disease (ILRAD), Kenya: trypanosomiasis and theileriosis of cattle.

West Africa Rice Development Association (WARDA), Liberia: rice.

International Service for National Agricultural Research (ISNAR), the Netherlands.

International Food Policy Research Institute (IFPRI), USA: analysis of world food problems.

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3. *Evaluation of the productivities of Djallonke sheep and N'Dama cattle at the Centre de Recherches Zootechniques, Kolda, Senegal,* by A. Fall, M. Diop, J. Sandford, Y.J. Wissocq, J. Durkin and J.C.M. Trail. 1982.
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8. *Organisation and management of water supplies in pastoral Africa,* by S.G. Sandford. 1983.
9. *Economics and planning of water supplies in pastoral Africa,* by D.G. Browne. 1983.