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SYSTEMS STUDY 1

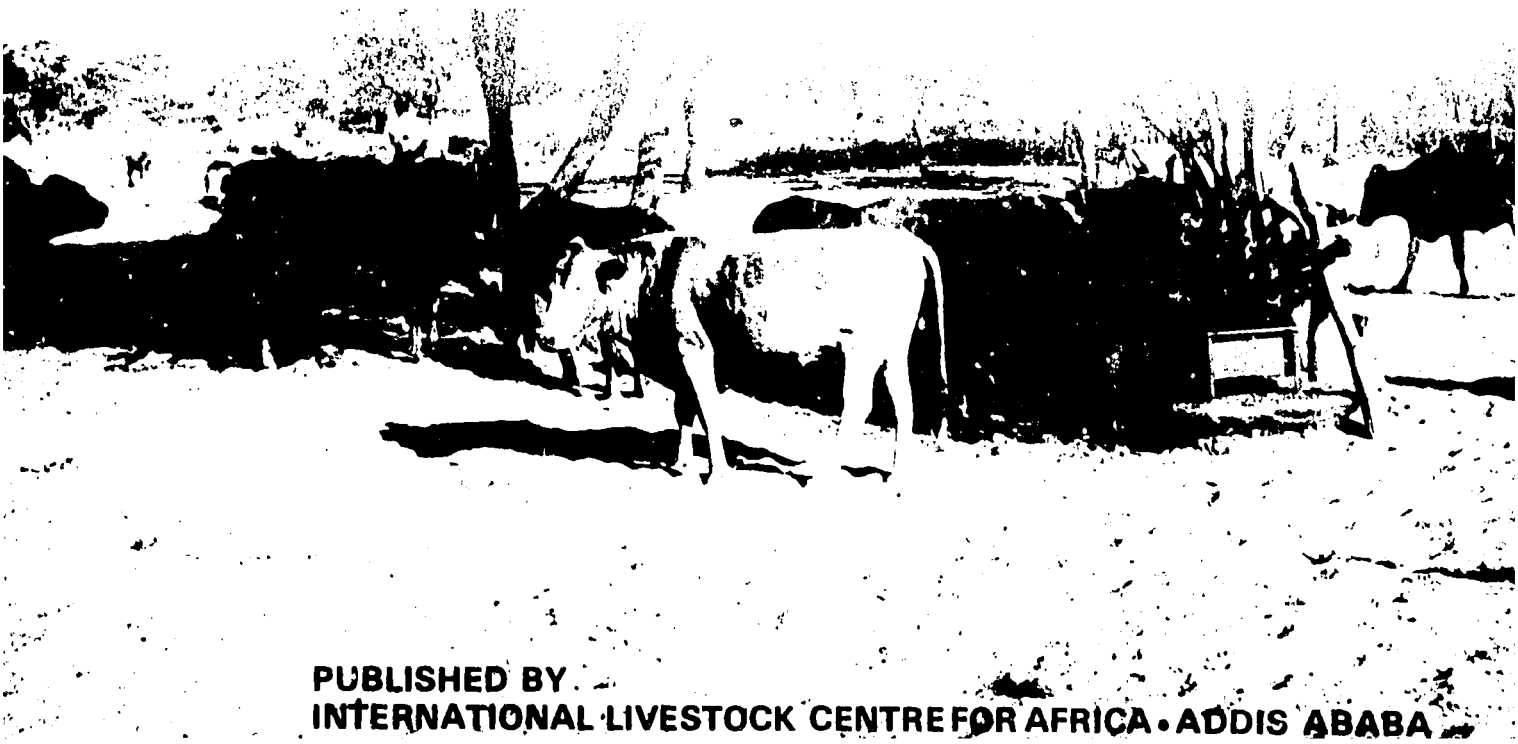
MATHEMATICAL MODELLING OF LIVESTOCK PRODUCTION SYSTEMS: APPLICATION OF THE TEXAS A&M UNIVERSITY BEEF CATTLE PRODUCTION MODEL TO BOTSWANA

UNDERTAKEN BY

INTERNATIONAL LIVESTOCK CENTRE FOR AFRICA

ANIMAL PRODUCTION RESEARCH UNIT
MINISTRY OF AGRICULTURE
BOTSWANA

WITH CONSULTATION AND TECHNICAL ASSISTANCE PROVIDED BY
TEXAS A&M UNIVERSITY ANIMAL SCIENCE SYSTEMS GROUP



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INTERNATIONAL LIVESTOCK CENTRE FOR AFRICA • ADDIS ABABA

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ABSTRACT

A beef cattle production model developed at Texas A&M University was applied to the traditional production system and an improved ranching system in Botswana. The potential contribution of mathematical modelling as an aid to livestock production research and related development problems was demonstrated and additional problems were identified where further applications of modelling techniques could assist research and development in Botswana.

KEY WORDS

Beef cattle, Botswana, mathematical model, production alternatives, semi-arid, Tswana.

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FOREWORD

There is a growing body of data on animal production systems in Africa which, although derived for the most part from isolated studies, provides increasing opportunities for the synthesis and evaluation of production systems. Nevertheless, the mathematical modelling techniques which have so far been applied to livestock production have seldom yet been applied to livestock systems in Africa, both because development of sophisticated computer-based models is beyond the capacity of most developing countries and because of the scarcity of comprehensive production data.

In early 1978, under the terms of its agreement with the Government of Botswana, the International Livestock Centre for Africa (ILCA) arranged and sponsored the application there of the beef cattle production model developed at Texas A&M University (TAMU). The study first involved joint field work in Botswana by the Government Animal Production Research Unit (APRU), the TAMU researchers and ILCA staff to establish the input data needed to operate the model for Botswana conditions and to define the feasible innovations to be examined by the model. Second, computer runs were made in Texas to validate the model and establish baseline situations against which the merits of innovations could be gauged. Third, the runs for the various interventions were carried out. Finally a workshop was held in Botswana where the results of the simulations were presented and reviewed by personnel involved in research and development in the field of livestock production. The present report describes the outcome of this joint study.

Contributors to the study from APRU were W Astle, N Buck, D Light, M Mlambo, M Montshiwa, B Muke, D Pratchett, T Rennie, T Rose, C Skarpe, C Shorrock and G Tacheba. Other Botswana livestock workers involved were B Addy, K Bingana, K Butler, D Field, A Fielding, I Fisher, O Hansen, J Jenness, R Kenneth, A Makobo and I McDonald. Contributors from TAMU were T Cartwright, T Nelsen and J Sanders and from ILCA F Anderson, J Trail and R von Kaufmann, and G Smith participated as an ILCA consultant from the USDA Meat Animal Research Center. The workshop was held under the auspices of the Botswana Ministry of Agriculture, by kind permission of the Hon E S Masisi, Minister of Agriculture, and opened by the Permanent Secretary of the Ministry of Agriculture, Mr M S P Sekgoma. This report was prepared at ILCA by F M Anderson and J C M Trail.

This publication is the first in a series of ILCA Systems Studies. As the name implies, this series will present the results of work undertaken for the better understanding and improvement of livestock production systems in Africa. Publications in this series will be produced in three major areas: concepts and methodologies, field investigations and development projects. The present report is in the concepts and methodologies category.

1. INTRODUCTION AND SUMMARY

Vast areas of Africa are used for beef cattle production systems which are often extremely complex in terms of the interactions which occur between the plant, animal and human components. The complexity of these systems is compounded by the highly variable productivities encountered at different levels. Throughout Africa, the research to date on these systems has been piecemeal, usually emphasizing a few of the key bio-technical relationships. Yet these livestock systems are now the target of substantial development activity. Research, if it is to be of value, must provide promptly the information necessary to design competently this development activity. Furthermore, research should lead to the quantification of those key aspects of production systems on which development efforts will have an impact, so that the probable consequences of development are clear and explicit.

Modelling is a research tool which can be applied to beef cattle production systems in order to use research information more effectively. While only a limited number of production systems or alternatives can be examined experimentally, modelling offers the possibility of examining large numbers of alternatives under different conditions. Prerequisites to the use of this research tool are the existence of appropriate models and sufficient quantitative information to produce valid results.

The animal science systems group at Texas A&M University (TAMU) has developed a computer-based beef cattle production model for use in tropical countries. This model can be used to predict animal and herd productivity under a variety of management regimes in diverse environments. Economic analyses can then be made, based on these predictions. Since 1970, field research in range livestock production in Botswana by a multidisciplinary team has yielded a considerable quantity of detailed information. However, the pressure on extension services for immediate advice has indicated many unanswered research questions. It is difficult to set priorities among these questions, and the resources required to conduct all the research needed are beyond the economic capacity of the national government. ILCA, therefore, sponsored the application of the TAMU model in Botswana with the objectives of introducing computer-based modelling techniques to

researchers and identifying where applications of modelling techniques would assist research and development activities. This involved field work in Botswana, computer runs and data interpretation at TAMU and ILCA, and finally a workshop held in Botswana. This was attended by ILCA and TAMU staff and workers in the field of animal production research and development in Botswana. This operation was in keeping with ILCA's mandate which stresses that it should, where appropriate, support, supplement and cooperate with national research programmes.

Chapter 2 of this report outlines the two basic systems of beef cattle production in Botswana and the principal research findings. The Animal Production Research Unit (APRU) of the Ministry of Agriculture has primary responsibility for this research. To date the APRU has concentrated its work on ranch production systems and mainly on the network of research stations it operates. Comprehensive input-output data are available from the herds on these stations for a three-year period. By contrast, research on the traditional cattle production system, the 'cattle post' system, has been limited and only incomplete productivity data are available. Chapter 2 also outlines the major research gaps remaining in regard to livestock production in Botswana.

While the data collected so far cover only a limited time span, they are adequate for the initial exploratory use of the TAMU beef cattle production model. A summary of previous applications of the model and a description of its essential features, including the key functional relationships it includes, are presented in Chapter 3. This chapter also outlines in general terms the methodology of computer-based modelling.

The TAMU model is a generalized model and most of the functional relationships embedded in it remain constant for all applications. It requires only limited input data to specify its application for a particular cattle breed and genotype in a certain location. Chapter 4 outlines the methods used and the values derived for its application to Tswana cattle in Botswana. When these values are used in the model it should be able to simulate the production levels observed in the real system. In this way the validity of the model is established. The validation procedures used in this application are given in Chapter 4. The model adequately

simulates the existing ranch production systems, but the results of the validation runs for cattle post conditions are not so satisfactory. However, since one objective of the study is to illustrate the methodology by applying it to a real system, rather than to produce results of immediate practical value, it is considered appropriate to undertake initial studies with the model on both ranch and cattle post systems.

These initial studies are summarized in Chapter 5 by presenting the results of five sets of simulation runs. Four groups of production alternatives feasible for introduction at the individual herd level in Botswana were simulated. Simulation of alternative weaning ages illustrated an innovation requiring only a change in husbandry practice; introduction of controlled breeding, weaning and use of reserve pasture illustrated a compound experiment where innovations can be examined individually and then in combination; use of Leucaena leucocephala as a dry-season forage plant illustrated the introduction of a new technology; and simulation of hand milking in a Tswana herd illustrated the examination of an area of potential development. Production under a different sequence of environmental conditions was also simulated to demonstrate the importance of assessing productiv over several years. These simulation runs demonstrate the utility of the modelling approach and the range of production alternatives which can be examined. The discussion in this chapter focusses on the biological responses of the systems to the various interventions. An economic interpretation of selected results is presented in Chapter 6.

Chapter 7 identifies further possible applications of the modelling methodology to the livestock production systems in Botswana. These additional applications are grouped according to their data requirements and the suitability of the existing TAMU model. Included are summary specifications for additional runs which follow directly from the preliminary results given in Chapter 5.

The potential contribution of mathematical modelling as an aid to livestock production research and related development problems has been clearly demonstrated for any situation in Africa where sufficient production information exists.

2 LIVESTOCK PRODUCTION SYSTEMS IN BOTSWANA AND THE RESEARCH STRATEGY

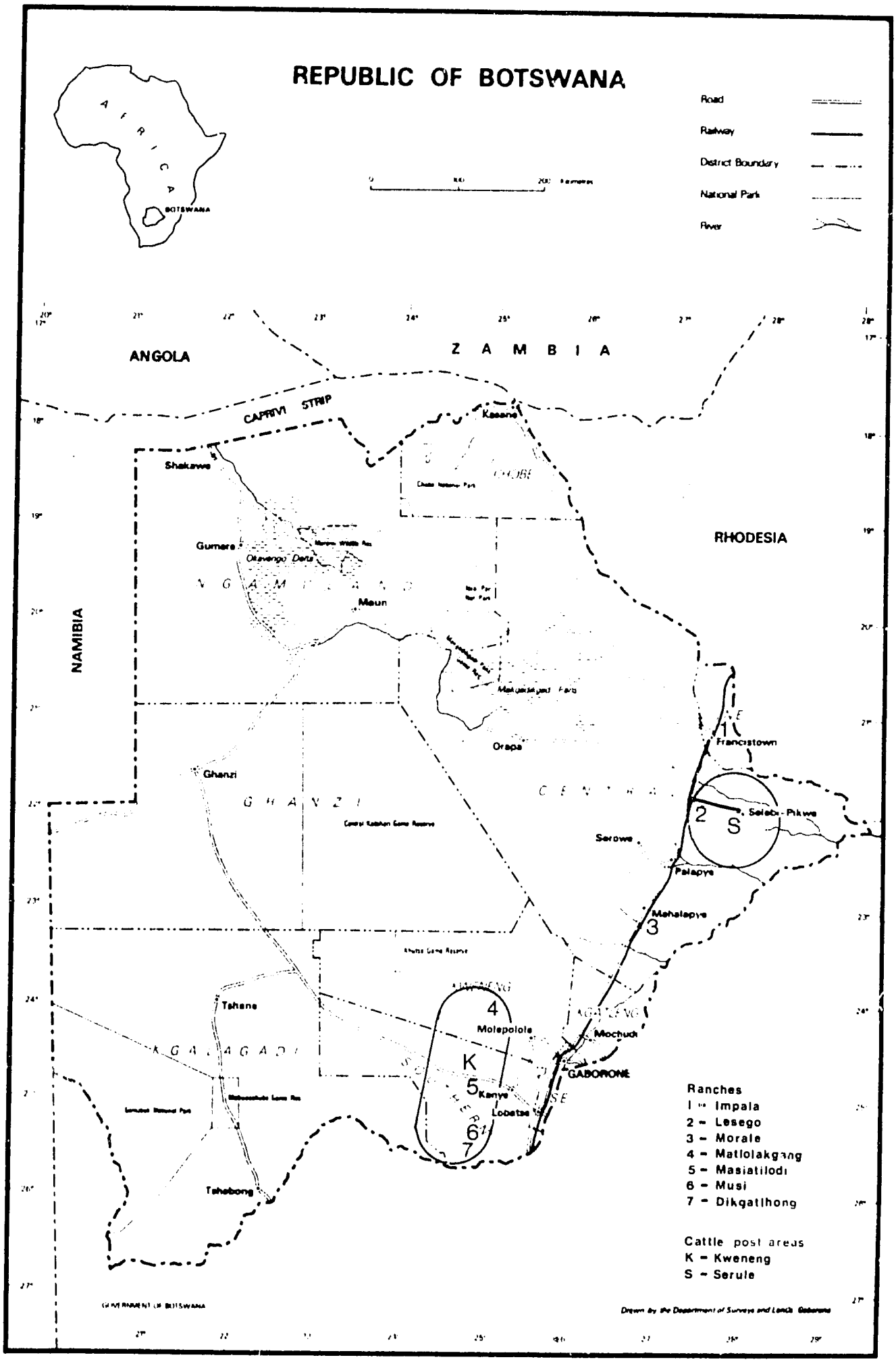
2.1 Background

Botswana occupies 572 000 km^2 of raised plateau at a mean elevation of 1 000 m; 450 000 km^2 of this area is rangeland, supporting a cattle population of around 3 million and a sheep and goat population of approximately 1.5 million. Mean annual rainfall varies from 700 mm in the north-east, dropping to 400 mm in the east and 200 mm in the southwest. The rain falls in the summer months from October to April and fluctuates widely between and within seasons. The beef cattle industry is based on the use of the natural pasture produced by this environment.

Botswana has a human population of about 800 000, giving the high ratio of cattle to human population of 3.75 : 1 which is unique in Africa. Exports of animal products from Botswana, mainly in the form of fresh meat, account for 17 percent of the gross domestic product (GDP) and almost one half of the value of exports. Before the recent expansion in the mining industry, the livestock sector was even more important to the economy.

The success which has been achieved in beef marketing is due largely to a history of effective disease control, particularly foot and mouth disease, and the absence of rinderpest and pleuropneumonia. Tsetse flies carrying trypanosomiasis are limited to part of the Okavango swamp area, and there is no limiting tick-borne disease such as East Coast fever (theileriosis).

2.1.1 Beef Cattle Production Systems. Two broad cattle production systems are practiced. The first is the traditional cattle post system where cattle are grazed on unenclosed, tribally administered land with no individual security of land tenure and a traditional right to grazing of unlimited cattle numbers. The second is a freehold farming system with fenced ranching. The traditional system has changed through time; undoubtedly there have been radical changes in the comparatively recent past, particularly due to the opportunity to exploit groundwater resources by mechanical bore-hole drilling and consequent extension of the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AFRICA
BOTSWANA
Road
Railway
District Boundary
National Park
River
ANGOLA
ZAMBIA
CAPRIVI STRIP
Kasane
Shakawe
Gumare
Maun
NAMIBIA
RHODESIA
Orapa
Francistown
Ghanzi
Selebi-Pikwe
Serowe
Palapye
Mahalapye
Tshane
Molepolole
Mochudi
GABORONE
Kanye
Lobatse
Tshabong
Ranches
1 - Impala
2 - Lesego
3 - Morale
4 - Matlolakgang
5 - Masiatilodi
6 - Musi
7 - Dikgatlhong
Cattle post areas
K - Kweneng
S - Serule
GOVERNMENT OF BOTSWANA
Drawn by the Department of Surveys and Lands Gaborone

grazing area. This process has been accelerated since the Second World War and has been responsible in part for the increase in the cattle population. The extension of grazing areas and the widely held fear of degradation of the range resources from overgrazing has led to the introduction of the national tribal grazing land policy (TGLP). The aims of tribal grazing land development are to stop overgrazing and degradation of the rangeland, to promote greater equality of incomes in the rural area, and to encourage growth and commercialization of the livestock industry on a sustained basis (Botswana, 1975).

Grazing in the tribal cattle post areas is communal, but some farmers have drilled their own boreholes and have acquired an individual right to the borehole water. Cattle are penned at night when they are near cultivated areas and when there is danger of stock losses from predators. Stock theft is rare in Botswana, hence herding is rarely practiced during the daytime. Animal management standards are low, and it is difficult to introduce innovations such as the weaning of calves or the controlled use of improved bulls.

On the ranches, fences are used to control breeding herds, to separate young stock and to retain standing hay for the dry season. Disease control measures are applied, and mineral supplementation is provided to combat phosphorus deficiency. The ranch cattle also have perennial, adequate water supplies available within a reasonable distance.

2.1.2 History of Animal Production Research. The history of animal production research in Botswana is similar to that of many former colonial territories. Government farms were established during the colonial area to investigate and demonstrate improved methods of husbandry. These were run by the Veterinary Department as the government agency responsible for animal husbandry. Much of this past research was carried out in isolation, or in separate operations which were not part of any particular production systems. Not only were the research results not adopted by cattle producers, but the research failed to provide many aspects of basic production data. In animal breeding, for example, the paucity of information on the performance of indigenous cattle throughout southern Africa has been noted even up to the present time (Maule, 1972). Experimental design was

frequently deficient, which made comparisons of the performance of different breed types impossible. In 1970, the few breeds of cattle maintained on 12 government ranches were each isolated on a different station under different conditions, rendering comparisons of breed performance impossible (Trail and Fisher, 1971).

Range research was initiated in Botswana in 1936 at Morale. However, when this long-term research was reviewed there was found to be insufficient conclusive evidence to permit the formulation of management recommendations (McKay, 1968). The only other range research results available are surveys of the grazing resources (Blair Rains and Yalala, 1972; 1973).

As a result of this pattern of research, there was little concrete information available to extension advisers or economic planners when Botswana achieved independence in 1966. The advice given was essentially of an ad hoc nature, based on results and experience from other countries and from casual observations in Botswana. Much of this advice was undoubtedly sound, and the development of the cattle industry in the country is indebted to these workers, but it has been seriously hampered by the lack of more comprehensive research results.

2.1.3 Integrated Research Approach. In 1970, the Ministry of Agriculture formed an Animal Production Research Unit (APRU). Although one of the preliminary objectives was to evaluate beef cattle breeds and crosses, it was quickly realized that a multi-disciplinary approach would be necessary to cover the many aspects of beef production. The programme which has developed covers three broad areas:-

1. the measurement of animal productivity from the range areas,
2. the measurement of what the rangeland can supply to the animals, and
3. the measurement of the effects of animal productivity on the rangeland.

The objectives of this integrated programme in Botswana are to provide reliable data on which politicians, economists and planners can assess the potential value of development proposals, and to provide reliable information to extension workers and producers, demonstrated in an acceptable ongoing production system.

To these ends, the APRU plans and supervises all technical aspects of a network of 17 ranches, totalling 40 000 hectares and carrying over 5 500 cattle. It also co-operates with commercial ranches and other organizations, involving a further 10 000 cattle. As positive research results must be fed continuously into the production system for demonstration to extension workers and producers, extensive data handling facilities have been set up for rapid collection, analysis and use of beef cattle performance records (Trail and Rennie, 1974; McNamara et al., 1975).

The detailed research programmes being undertaken and the results to date can best be summarized under four main headings. These are animal productivity results from the two beef cattle production systems; range productivity and improvements; nutrition and animal productivity; and breeding and animal productivity.

2.2 Research Results

2.2.1 Productivity under Traditional and Improved Management. Studies on the two main beef cattle production systems in Botswana - traditional cattle posts and improved ranches - began in 1970 (Rennie et al., 1977). At that time, 92 percent of the cattle were maintained under a traditional management system on unenclosed grazing (on cattle posts). These herds produced approximately 85 percent of the cattle slaughtered for export. The remaining 8 percent of the cattle were maintained under a fenced system and produced 15 percent of the slaughtered animals (Botswana, Ministry of Agriculture, 1970).

In productivity studies, reproductive performance, growth and viability have been compared under the two systems over a four-year period. Calving percentages average 46.4 percent, average weight of 7-month-old calves is 122.5 kg, calf mortality averages 10.2 percent and post-weaning growth to 18 months averages 88.5 kg under cattle post conditions. Corresponding figures for cattle on the fenced ranches are 74.0 percent for calving percentage, a 7-month calf weight of 177.4 kg, 8.5 percent calf mortality and a 105.8 kg post-weaning growth to 18 months. These results indicate annual overall productivity estimates of weaner

calf weight per cow at 51 kg on the cattle posts and 120 kg on the fenced ranches, and annual estimates of 18-month-old calf weight per cow of 86 kg and 188 kg respectively.

The major objective in these studies has been to determine productivity constraints and opportunities on which future work could most profitably concentrate. The increase of over 100 percent in productivity obtained under the fenced ranch conditions illustrates the great potential for increased productivity, even without employing more sophisticated techniques of range management, animal nutrition and breeding.

2.2.2 Range Productivity and Improvement. The composition of the natural grasslands of Botswana varies considerably throughout the country, due to variations in soil type and rainfall distribution. Under highly variable rainfall conditions, efficient pasture management and utilization are difficult. In 1972, initial research objectives were to evaluate the usefulness of different range parameters for establishing limiting factors in animal production, and to indicate promising future lines of research. An initial survey has been conducted to determine the principal questions toward which future research should be aimed (Pratchett et al., 1977). Six range parameters measured monthly over an eleven-month period on nine ranches distributed throughout the main ecological zones have been related to the monthly liveweight changes of growing cattle. Clipped and oesophageal fistula samples provide estimates of crude protein (CP) content and dry matter (DM) digestibility, while available DM and grazing indices provide estimates of available herbage. Statistical analyses indicate that liveweight change is influenced primarily by the CP content of the herbage selected. The CP content of fistula samples accounts for 54 percent of the variation in liveweight, while digestibility of the same samples accounts for 32 percent. Thus, under the natural range conditions of Botswana, crude protein is the major limiting factor. Following this finding, research has been conducted to identify and encourage grasses having above-average levels of crude protein. Since April 1974, 30 different species of grass have been collected monthly over 13 ranches throughout the country's major ecological zones and screened for CP content and digestibility. The results to date indicate that certain species are superior in both CP content and digestibility

(Botswana, Ministry of Agriculture, 1978).

Large-scale grazing trials were then initiated in 1974 in an attempt to encourage the better species and to determine if improved cattle performance would follow. Four grazing treatments were examined; continuous; one-herd three-paddock; four-day grazing, 32-day resting rotation; and seven-day grazing, 56-day resting rotation. Stocking rates of 1 LSU : 10 ha and 1 LSU : 8 ha were adopted in the first and second years of the trials respectively. After two years, no significant differences have been detected among treatments in terms of total yield of dry matter, or matter of good species, botanical composition or cattle performance.[1]

Removal of bush cover by chemical treatment of cut stumps is also being examined, and the changes in the grass species composition monitored. Results three years after treatment showed significant but small increases in dry matter yields from cleared areas and a general improvement in botanical composition (Botswana, Ministry of Agriculture, 1978). Work on range fertilization has just commenced, as has the examination of introduced legume and grass species, with some promising results, although establishment costs appear formidable.

2.2.3 Nutrition and Animal Productivity. Factors of considerable economic importance in any beef production system are the reproductive performance of breeding cows and the length of time taken by growing animals to reach slaughter weight. In semi-arid areas such as Botswana, with variable summer rainfall and a prolonged winter dry season, nutritional deficiencies in the natural pasture limit both reproductive performance and liveweight gain. Deficiencies of phosphorus, crude protein and energy in the natural pastures of southern Africa have long been recognized, and the beneficial effects of phosphorus supplementation have been demonstrated repeatedly. For phosphorus supplementation, the basic recommended policy is to allow cattle access to a 1 : 1 mixture of bonemeal and salt at all times.

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1. One LSU is equivalent to one mature bovine weighing 500 kg.

As mentioned earlier, the range research programme in Botswana has determined that under natural grazing conditions crude protein rather than energy is the major limiting factor. Several supplementary protein feeds containing non-protein nitrogen (NPN), often referred to as rumen stimulatory licks, are available commercially to offset the deficiencies in the natural pasture. A series of trials has been carried out to investigate the effects of these licks on the reproductive performance of breeding cows and the liveweight gain of growing cattle (Capper et al., 1977). The trials involved 1 375 breeding cows at five artificial insemination centres, and 260 breeding cows and 269 growing stock under ranch conditions. The licks increase the percentage of pregnancies in cows under lactation stress by up to 20 percent, but have no effect on the reproductive performance of dry cows or cows with a calf older than five months. In growing animals, the provision of rumen stimulatory licks increases live-weight gain by an average of 12 percent.

2.2.4 Breeding and Animal Productivity. In Botswana there are three locally available breeds, all members of the stabilized Sanga grouping. About 80 percent are indigenous Tswana, 15 percent are Africander, mainly originating from South African imports, and a small proportion are Tuli. The Tuli breed has been developed since 1946 in the southwest of Rhodesia from Tswana types. The use of Africander, Tuli, Brahman and Simmental bulls on Tswana cows has been recommended for a number of years.

Since 1970, performance tests have been carried out on all male and female stock on a network of 13 government ranches. Superior performance-tested males are thus available as artificial insemination (AI) sires or as bull replacements for the government ranches. The remaining superior males are sold to farmers, while inferior males are castrated and eventually slaughtered. Superior females are selected for herd replacements.

The breeding programme was planned to cover three main areas:-

1. the evaluation through performance testing of major types to determine their qualities,

2. the continued performance testing of superior types for further improvement, and

3. the exploitation of heterosis effects through crossbreeding.

The ongoing breed studies are carried out mainly under fenced ranch conditions, but evaluations of crossbred cattle under traditional management conditions in the communal grazing areas have also been made. Production is entirely from natural pasture with the exception of phosphate supplementation. Sufficient standing hay is retained for dry season grazing. The traits examined are calving percentages, weights at birth, weaning and 18 months, and calf mortality.

Over a three-year period, the calving percentages of Africanders, Tswanas and Tulis were 64.5, 70.6 and 85 percent respectively (Trail et al., 1977). Mortality was higher among the Africander calves up to two years of age, at 11 percent compared to 7.5 percent for Tswana calves and 7.4 percent for Tulis. The 18-month weight of Tuli cattle was 284 kg, and of Tswanas 279 kg, both higher than the 270 kg for the Africanders. In terms of annual weight of weaner calf per cow, the Tuli is 16 percent more productive than the Tswana, which in turn is 18 percent more productive than the Africander. In terms of annual weight of 18-month-old calf per cow, the Tuli is 22 percent superior to the Tswana, which is in turn 17 percent superior to the Africander.

The results of this evaluation of the three local breeds support the use of the Tuli breed in Botswana. These findings are contrary to previous extension policy which advocated the use of the Africander. As a result the Tuli herds on government ranches for demonstration and production of breeding stock are now being expanded.

Comparisons of crossbreds produced by the use of Simmental, Brahman, Bonsmara and Tuli sires on Tswana cows show an advantage in growth to 18 months through crossbreeding. The average 18-month weight of Simmental crosses is 324 kg and of Brahman crosses 304 kg. Both are significantly higher than the average weight of pure Tswana at 279 kg. Bonsmara and Tuli crosses at 294 and 290 kg also show a significant increase over the pure Tswana.

The use of Tuli sires on Tswana cows is therefore now recommended for all

management conditions. The use of Brahman and Simmental sires on Tswana cows also produces superior growth under both ranch and cattle post conditions. An evaluation of mothering ability and reproductive performance of first cross females is now needed. The indications are that a criss-cross breeding system for Brahman and Tswana will be valuable, with the Simmental breed substituted for Brahman under improved management conditions.

2.3 Research Gaps Remaining

The critical researcher is constantly aware of the many interacting components in the beef systems under study and the difficulties of simultaneously evaluating their implications. However, even with the involvement of many disciplines, the formal research approach will only allow the examination of particular facets in isolation. Because of this, innovations which initially appear most favourable may interact with other components of the system in such a way as to significantly weaken their overall impact.

To date, the integrated research programme has been successful in indicating some specific recommendations for the extension services (Botswana, Ministry of Agriculture, 1976b). However, many further extension needs have been identified during the early implementation stages of the tribal grazing land policy. For animal production, extension recommendations are needed in the areas of animal management, nutrition, breeding, milk production and the impact of drought. These topics are outlined briefly below.

2.3.1 Animal Management. Cattle productivity levels are lower in the traditional system than on ranches, but it is still not possible to quantify the incremental advantages of adopting different components of the ranch management package. To date this problem has not been studied, as it has been assumed that piece-meal adoption of individual components of the package will have little effect. Examples are improving water supplies in the absence of grazing control, urea supplementation when forage is severely limited, and early weaning without adoption of a breeding season. However, the need to study these questions is now urgent in Botswana with the introduction of the tribal grazing land policy (TGLP) and the implementation of the Second Livestock Development Project (Botswana, Ministry of

Agriculture, 1976a). This project meets the aims of the TGLP in that it seeks to create the infrastructure needed for the development of sustained profitable production systems suitable to communal and commercial grazing areas, and for the marketing of livestock products. The development of improved management at cattle posts will, in most cases, be a gradual process, and producers will require sound advice from the extension services on the best development sequence to be followed.

The difficulties in this situation of formulating sound extension proposals for animal management on the basis of formal research are almost insurmountable. Research work on privately owned cattle posts is difficult to conduct, and research on a sufficient number of representative cattle posts to cover all environmental areas would be very expensive. Individual situations are likely to need individual evaluations and the optimal sequence of development could differ markedly among locations. Investigation of all possible combinations would require resources far beyond the value of the results which might be obtained.

2.3.2 Nutritional Supplementation. Once phosphate requirements have been satisfied, protein deficiency in pastures is the major limitation on cattle productivity. Nutrition work has therefore concentrated on the use of protein supplements in the form of NPN. The question of when and to which stock category this supplementary feed should be given, and whether this should be combined with some other management intervention such as weaning age, is indicative of the many alternatives confronting livestock producers.

In 1974, when prices were favourable, feedlot finishing of cattle appeared attractive and feedlot performance trials were conducted. Supplying sufficient cattle to the feedlots would involve the removal of significant numbers of animals from the herds. This would have an important effect on grazing pressures and would increase the grazing available to the remainder of the herds. Such effects are difficult to measure but must be estimated before the overall effect on the production system can be evaluated. This problem will assume importance if price ratios again become favourable to feedlot operations.

2.3.3 Breeding. Sound information on the value of the major indigenous

breeds is now available. The advantages to be obtained from crossbreeding have been demonstrated in terms of growth, and there is widespread interest in its adoption. The question of the optimum size of the crossbred cow for a specific environment, and the possibility that selection for maximum growth may in some cases be counter-productive, is of concern. Similarly, crossbreeding under the more rigorous environment of the cattle post may have different requirements than in the ranch situation. The optimum choice of breeding programmes in the transition from the Tswana, through Tuli-crosses and Brahman-crosses up to Simmental-crosses cannot be determined from field experimental work covering all situations.

2.3.4 Milk production. There is a total gap in research knowledge in this area. Experience suggests that milking low-yielding cows detracts significantly from beef production. However, opportunities exist for dual-purpose production which may be commercially attractive in certain localities. A research question in Botswana is whether the Tswana cow is suitable for this purpose or whether a cross with a breed such as Simmental would be more appropriate.

2.3.5 Drought. Seasonal rains rarely fail completely in Botswana. More commonly, minor seasonal differences occur in the total rainfall and in its distribution within the season and these have marked effects on forage and cattle production. The best tactical responses of producers to such situations, which are in essence droughts of various severities and durations, have not been investigated in Botswana. Formal research programmes cannot be designed to include drought situations, so research results do not lend themselves readily to the formulation of extension recommendations for times of drought. Ongoing research in Botswana will identify possible improvements in the existing systems, and the value of these improvements are related in varying degrees to their performance in drought situations. Despite the methodological difficulties involved, research must be capable of estimating this performance.

3. THE TEXAS A&M UNIVERSITY BEEF CATTLE PRODUCTION MODEL

3.1 Methodological Background

A system can be defined as a collection of elements that are interrelated and that interact with one another. All the elements which contribute substantially to its inputs and outputs are included in the system. It has physical and conceptual boundaries which vary according to the objectives of those who are studying it. A systems approach to a problem is one which defines the problem in relation to some system. It differs from a process-oriented approach which is concerned typically with understanding some process and not with how such understanding might be used to influence the system of which the process is a part.

To date, the process-oriented or analytical approach has been fruitful in many areas of research, and particularly in agriculture. However, in developing countries, where the outcome of a development process is so dependent on the interaction of many socio-economic and physical factors, this traditional approach has limitations. To overcome these limitations, emphasis on the functioning of whole systems rather than on particular processes is required. The major advantage of the systems approach to a problem is that it can synthesize the existing knowledge on components of the relevant system and permit study of their interactions and combined effects.

For research on livestock production systems, application of the systems approach will not replace traditional research, but it will assist in identifying those areas where further research would be most beneficial. The capacity of the systems approach to address this issue will assume increasing importance over time as research funds become more restricted relative to development needs. The development of holistic models of production systems is at the core of the systems approach. While quantitative models can be used to identify the appropriateness of a particular task, or the importance of a particular component in relation to a whole system, it is not necessarily appropriate that such models always be applied. In some instances it may be sufficient to prepare a descriptive model of the system.

Irrespective of the class of model which is formulated and other classes of models are possible besides quantitative and descriptive models the application of the systems approach involves a step-by-step, interactive process. The sequence of steps outlined in this section applies to the case where a quantitative model of a system is to be developed.

a. Problem definition: The objectives of a study must be defined rigorously. These determine both the boundaries of the system (i.e., those relationships and variables inside and outside the system) and the level at which the system is to be modelled (e.g. at the level of the cell, animal,herd, farm, national economy). The modelling must be conducted at a level which captures the essence of the system and with sufficient detail to meet the objectives of the study, but at the same time it must simplify the system sufficiently to be manageable.

b. Quantitative formulation of the model: A detailed mathematical representation of the model is required which accurately reflects the knowledge available. This representation must also be consistent with the objectives of the model. For example, if an objective is to examine the consequences over time of particular changes in the system, then the model will need to have the capacity to simulate time-related effects.

c. Model verification: Complex quantitative models need to be verified to ensure that what is programmed into the model corresponds with what is intended. Verification requires operating the model with key variables specified at several points covering their possible ranges.

d. Model validation: Models must be validated by comparing results from the model with experimental and other real-world data. Validation is, in part, a subjective assessment of model performance. The data used for validation must not be the data used to formulate the model.

e. Model experimentation: After a model is verified and validated it can be used to examine the system's performance under different conditions. In this way the model can simulate the performance under changed circumstances of the real system of which it is an abstraction. Usually the experiments conducted in this way will be done at lower cost and more quickly than real-world experimentation.

f. Analysis of model results: Analysis of results requires the use of analytical methods akin to those used in the analysis of actual experimental results. Methods appropriate to analysis of time-related effects will often be necessary. By contrast, the analysis of real-world experimentation data seldom requires these techniques as the time period over which experiments are conducted is seldom sufficiently long.

The outcome of the work at any of the above stages can lead to a return to earlier stages. For example, during experimentation with the model it may become apparent that the model specification is inappropriate to the task at hand, so the researchers must respecify part or all of the model. This would in turn require a repetition of the verification and validation steps before further experiments could be conducted.

3.2 Origin of the Model

In the field of animal production, measurements such as weaning weight, growth rate or mature weight usually reflect only one segment of the production system and are thus only partially related to the system's overall efficiency. Furthermore, such measurements alone do not make it possible to identify improvements in productive efficiency of whole systems. The research group at TAMU recognized the need to consider multiple inputs and outputs in evaluating beef production systems and tried to account for them on an additive basis (Joandet and Cartwright, 1969). These early models were expanded to include some variable, non-linear functions but still required a priori specification of animal performance and the subsequent computation of nutrient requirements (Long et al., 1975; Cartwright et al., 1975; Fitzhugh et al., 1975).

By 1972, the need became evident to model the interactions between genotype and environment and management practices in order to predict animal productivity. At about this same time, USAID recognized that a systematic, comprehensive approach was required to increase the productivity of tropical cattle. These common interests resulted in a USAID grant in 1972 to TAMU that helped facilitate the development of a mathematical model.

The model which was developed is based on the assumption that three characteristics account for a large proportion of the performance or productivity differences among cattle on a life-cycle basis: (1) mature size, (2) milk production and (3) maturing age. The model also recognizes the need to account for both the present and previous nutritional status of an animal. This is done by specifying both its structural size and its present weight. The growth curve for structural size specifies the mature size and the rate of increase in body weight for the genotype of the animal, but this is subject to alteration in cases of extended periods of severe nutrition stress. A typical growth curve for structural size in kg (WM) is presented in Figure 3.1. The structural size in kg at maturity is indicated by WMA. Present nutrition of the animal is a function of its nutritional requirements, as determined by age, sex, size, condition and pregnancy or lactation status, and the quality and availability of feed. Previous nutrition is accounted for by deviations in actual weight in kg (W in Figure 3.1) from the structural size for the genotype. The model can take into account a wide range of management practices, such as length of breeding season and age at weaning. Animal performance is calculated monthly and aggregated for animals of the same age, sex, size and pregnancy or lactation status.

An overview of the major components of the model is provided by Figure 3.2. It accounts for the interactive effects of genotype, breeding system, nutrition, reproduction, growth, milk production and nutrient intake. The lack of a feedback effect from the cattle herd to the grazing resource is a major limitation of the model in its present form. However, it can still be applied with advantage to situations where this effect is important so long as the results are interpreted taking this limitation into consideration, as for example when the predicted stocking rate under a production strategy exceeds reasonable limits.

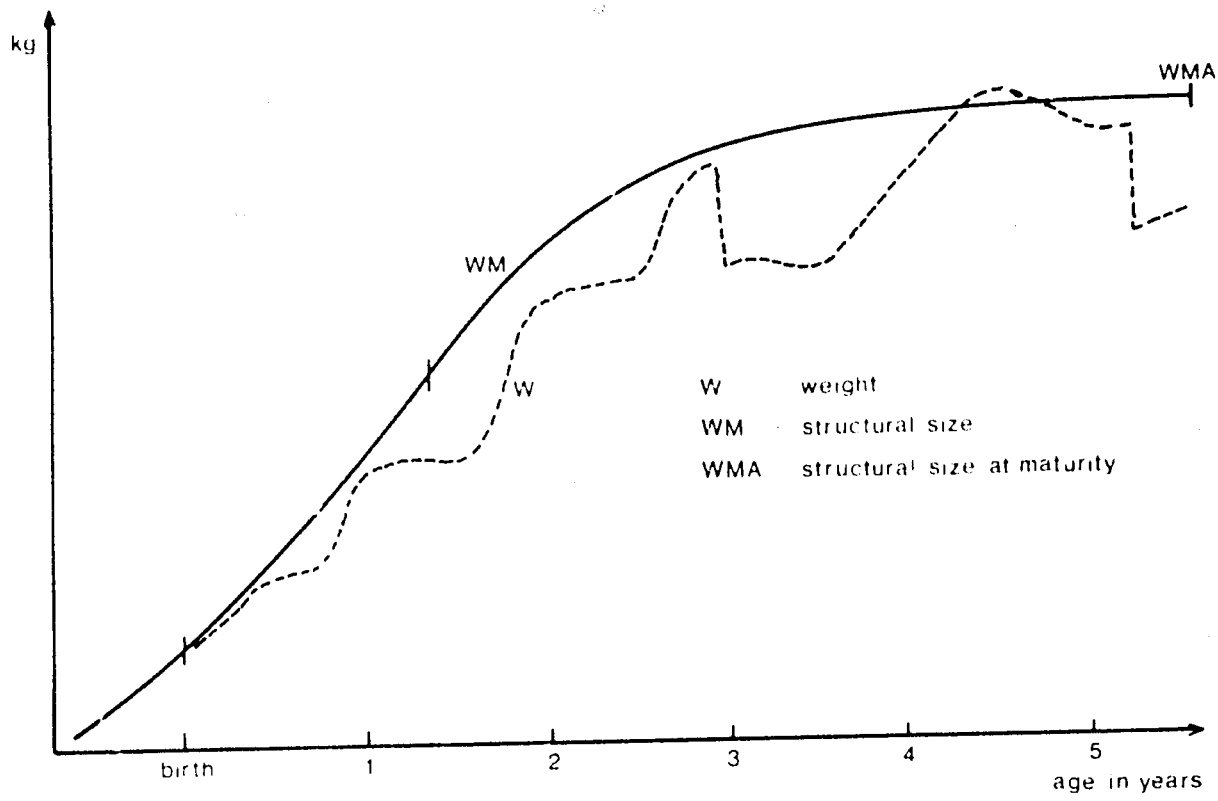

Figure 3.1. A typical growth curve for structural size.

3.3 Initial Applications

The Ebini and Rupununi areas of Guyana served as the first tropical testing grounds for the model (Davis and Cartwright, 1976). Data to characterize the resource base at both locations were limited, and it was necessary to rely on sketchy experimental results and personal obs[illegible] to describe the variation in quality of forages consumed throughout the year.

The Ebini area is an isolated part of Guyana with poor quality forage and no livestock production at present. Simulation results predicted that cattle production in this area would not be viable without supplementary feeding. This result was consistent with previous failures to establish cattle in the area. The use of improved pastures would be a practical possibility but a simulation run assuming the availability of improved pastures still did not indicate a viable situation. Detailed examination of the model output identified early calf nutrition as a major

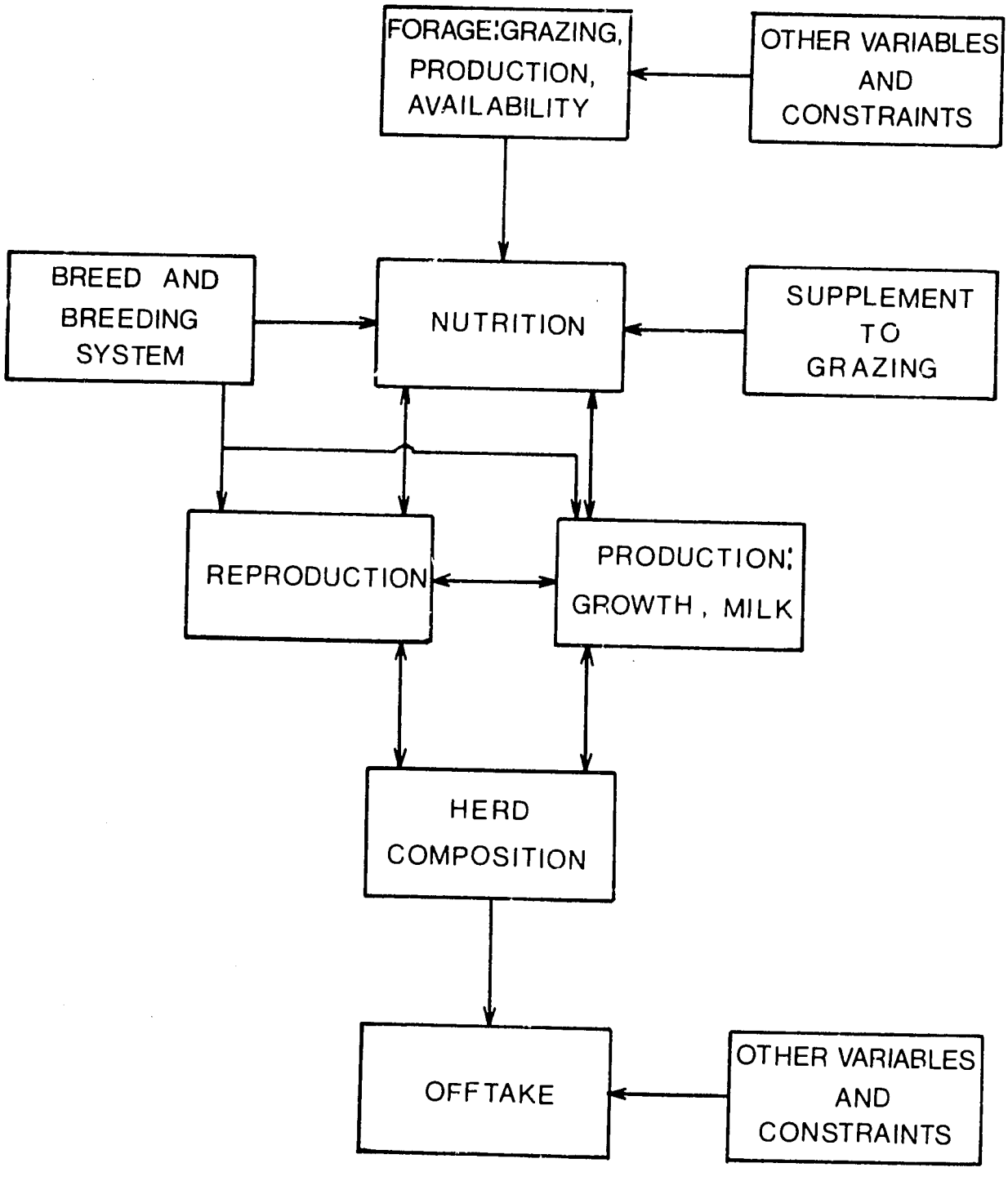

Figure 3.2. Components of the beef cattle production systems model.

limiting factor. Following this, a run was made assuming cows on a higher plane of nutrition derived from longer use of improved pastures. Under these conditions it was indicated that a productive herd could be maintained with a reasonable level of offtake.

Cattle production was also simulated for the Rupununi area which currently supports a low level of cattle production. Major floods occur periodically, causing high calf mortality. Herding cattle and controlling breeding, to restrict calvings to a time of year when there are no floods, are two ways of overcoming this production problem. The model was used to predict the consequences over time of reducing mortality by these two methods.

More recently, the model has been used to address the question of the potential productivity of dual-purpose cattle herds in the tropical lowland areas of northern Colombia (Cartwright et al., 1977). The productivity of beef cattle systems there can be increased either by adoption of different management techniques or by genetic improvement in the breeding stock. Simulation runs were made in which changes in genetic parameters were represented by different body sizes and lactation potentials, and management changes were represented by different milk extraction rates and nutritional regimes. The productivity index used to evaluate the alternatives was the total liveweight sales plus the quantity of milk sold converted to a liveweight basis per unit of dry matter consumed by the entire herd. Recommendations included the necessity of increasing the lactation potential either by selection within the existing population or by the introduction of other improved types.

The Meat Animal Research Centre of the US Department of Agriculture is an example of a national research facility whose research programme is systems oriented. Mathematical modelling is an integral part of the research activities at the centre. Primary responsibility for carrying out this modelling work rests with the management systems unit. To date the unit has relied upon adapting existing models of aspects of livestock systems, rather than undertaking original work in this area. The beef cattle production model developed at TAMU has been the basis of most of the modelling work undertaken (Sanders, 1977). This approach has proved

highly efficient. Topics researched with the model include the effects of forage quality on the productivity and profitability of cow-calf feedlot management systems and the comparative efficiencies of a number of beef cattle cross-breeding systems (Notter et al., 1978a, 1978b, 1978c).

3.4. Model Structure

The computer model, described in detail by Sanders (1974, 1977) and Sanders and Cartwright (1978a, 1978b), consists of a main segment and a number of linked subroutines. The main segment is primarily an accounting routine which keeps account of the number and status (including W and WM) of the animals in the various classes. This segment also reads the input data given to the model for a particular run and controls the output printed for each run of the model. The model places almost no limits on herd size, proportion of animals in various classes, or on management options such as selling policy, time or length of the breeding seasons and weaning policy. These options, and others, are specified to the model for each run. GRO, FERT and DIE are the designations of the three most important subroutines used to simulate animal performance. The principal function of GRO is to simulate animal growth, FERT to simulate cow fertility, and DIE to simulate mortality. The most important of the other subroutines specify when calves are weaned and the number of animals sold in any month. The three main subroutines, GRO, FERT and DIE, use generalized functional relationships which do not need respecification for the application of the model to different situations. The principal equations used in each of these three sub-routines are presented below.

3.4.1 The GRO Subroutine. Characteristics of the feed resource on offer are specified in the GRO subroutine. Lean tissue growth rate, liveweight gain or loss and, when appropriate, milk production levels are calculated for each class of animals during each month of a simulation. These performance levels are simulated as functions of genotype, animal size, level of maturity, condition (fatness), physiological state and simulated intake.

Three separate limits of feed intake are calculated from the digestibility fraction (DIG), crude protein fraction (CP) and availability in kg/head/day (AVC)

of the feed as follows:-

(1) Physiological limit $= 0.0225 \frac{WM}{DIG}$

(2) Physical limit

$$a) = \frac{0.0107\,WM}{(1-DIG)} \Bigg|_{CP \geq 0.06}$$

$$b) = \frac{0.0107\,WM}{(1-DIG)} \cdot \left[\frac{CP}{0.06}\right]^{0.6} \Bigg|_{CP < 0.06}$$

(3) Availability limit $= AVC\left[\frac{WM}{WMA}\right]$

The intake of cows more than eight years old is adjusted downward by three percent for each year of age over eight. The nutritional requirements to achieve potential levels of performance are also calculated. Intake is set at the minimum of these three limits (from equations (1) to (3)) if this minimum is below the calculated requirement. If the minimum limit is above the calculated requirement, intake is set halfway between the two levels.

Nutrient requirements (of digestible dry matter per day) for maintenance, activity, milk production, lean tissue growth and fat deposition, based on genotype, size, sex, condition, pregnancy and lactation status, are calculated for each animal in each month. The following equations are used:-

(4) Maintenance $= 0.0306\,W^{0.75} \cdot \left[\frac{WM}{W}\right]^{0.5} \cdot \left[\frac{WMA}{WM}\right]^{0.15} + AC \cdot W$

where AC is an activity coefficient particular to each situation (in the range from 0 to $8 \cdot 10^{-4}$).

(5) Lactation $= 0.3\,PM$

where PM is milk potential (in kg/day) in the month, based on genotype, age, condition and month of lactation. The derivation of PM is given in equation (9).

(6) Pregnancy $= 275 \cdot 10^{-7} \cdot WMA \cdot e^{0.522(\text{month of pregnancy} - 1)}$

(7) Lean tissue growth and fat disposition $= 0.8 + \frac{1.2232 \cdot DWM(2 \cdot WM + DWM - BW)}{WMA - BW}$

where DWM is the genetic potential for gain (kg/day) in WM (structural size) and BW is birth weight in kg.

(8) Condition $= 0.0556\,(WM - W)$

A requirement for gain in condition is calculated only if actual weight (W) is below structural weight (WM).

The nutrient requirements calculated by equations (4) to (8) are summed. If total nutrient requirements are less than calculated nutrient intake (from equations (1) to (3)), potential productivity is achieved and excess nutrients are deposited as fat. If the nutrient requirements to achieve potential productivity exceed the nutrient intake, milk production and growth of lean tissue and essential fat are adjusted downward and, if necessary, body fat is mobilized.

The maximum lactation potential in kg/day (PMA) of a mature cow of a particular genotype is specified in the model. This maximum lactation potential is adjusted for age (CFA), condition (CFX) and month of lactation (J) to determine the lactation potential (PM) at any time.

(9) $PM = CFA \cdot CFX \cdot PMA \cdot e^{-0.08J}$

where:

(10) $CFA = 1.0 + 0.01 \cdot (\text{age in years} - 7) - 0.01 \cdot (\text{age in years} - 7)^2$

(11) CFX $\quad a) = 1.0 - \left[\frac{WM - W}{0.33\,WM}\right]^{3.32} \Bigg|_{W \leq WM}$

$$b) = 1 \Big|_{W>WM}$$

3.4.2 The FERT Subroutine. Occurrence of oestrus and, when appropriate, conception rates are simulated in the FERT subroutine for all classes of open breeding females during each month of simulation. The fraction of anoestrus females that begin cycling during the current month (PEST) is calculated as follows where CFW, CFDW, CFT and CFM are correction factors for weight, weight gain, time since calving and degree of maturity in heifers.

(12) $PEST = 0.85 \cdot CFW \cdot CFDW \cdot CFT \cdot CFM$

where:

(13) $CFW \quad a) = 10^{-3} \Big|_{W<0.75WM}$

$$b) = 4\left[\frac{W}{WM} - 0.75\right] \Big|_{0.75WM \leq W \leq WM}$$

$$c) = 1 \Big|_{W>WM}$$

(14) $CFDW = 1 - \frac{100(DWM-DW)}{WM}$

(15) $CFT = 1 - e^{9 \cdot 10^{-7}(30(J-1))^{3.9}}$

(16) $CFM \quad a) = 0 \Big|_{WM \leq 0.4WMA}$

$$b) = 3\left[\frac{WM}{0.6WMA} - 0.67\right] \Big|_{0.4WMA<WM<0.6WMA}$$

$$c) = 1 \Big|_{WM \geq 0.6WMA}$$

The fraction of cows cycling in the previous month which cycle again during the current month is calculated as:-

(17) $CCYC = CFW^{0.1} \cdot CFDW^{0.1}$

The conception of cycling females is calculated as:-

(18) $PCON \quad a) = 0.75 CFT^{0.5} \cdot CFW^{0.2} \cdot CFDW^{0.2} \Big|_{\text{in breeding season}}$

$\quad\quad\quad\quad b) = 0 \Big|_{\text{out of breeding season}}$

3.4.3 The DIE Subroutine. Death rates are computed in the DIE subroutine for each class of animals during each month of simulation as functions of the time of year, age, condition and the physiological state of the animal. The death rate of cows is determined by month of year, condition, current age and age at calving. For newborn calves it is a function of the month and age of dam. For older calves it is a function of month, condition and rate of gain. The basic constant used to calculate death rates is 0.001 and is corrected by a variable, FD, a function of condition as follows:-

(19) $FD = 10^{-3} \cdot e^{140(1-W/WM)^{3.3}}$

FD is then modified according to the age class of the animals and the time of the year.

4. BOTSWANA INPUT DATA AND MODEL VALIDATION

4.1 Input Data

To apply the model to a particular breed of cattle in a certain location requires input data relating to the genetic potential of the breed, annual forage productivity and management practices. This section presents the data used to specify the model for Tswana cattle under both traditional and improved management conditions in Botswana.

4.1.1 Genetic Potential Data. Measures of potential mature cow size and potential milk production in mature females are the two parameter values provided to the model to specify genetic potential. A number of other parameters involved in simulating productivity are embedded in the model and not specified separately for each application. It is recognized that the value of these other parameters may not always be applicable or may later need to be modified for African cattle breeds. The derivation of the two specified parameters is given here.

4.1.1.1 Potential Mature Cow Size. The genetic potential mature cow size of a breed is indicated by the average actual body weight of mature dry females at the time of the year that weights tend to peak on pasture. Available values for six- to eight-year-old Tswana cows weighed on 15 May in 1975, 1976 and 1977 are summarized in Table 4.1. This date is at the end of the wet season when all animals tend to be in the best condition after several months of sustained growth.

Table 4.1. Mid-May weights for mature Tswana cows.

Category	Number of cows	Number of year/ranch groups	Average body weight (kg)
Lactating	402	24	457
Dry	140	24	495

For Bos taurus animals, the potential mature cow size lies in the range of 15 to 15.5 times the average birth weight. The APRU reports overall Tswana birth weights as 31.5 kg (Botswana, Ministry of Agriculture, 1978). This suggests a potential mature cow size of from 473 kg to 488 kg. The mid-point value of 480 kg is used to simulate the results reported in this paper. Trial runs with the model using a value of 500 kg for the mature cow size parameter overestimated growth rates to maturity. It is shown later in this section that the simulated growth curves correspond closely to those recorded in Botswana for sub-optimal production environments.

4.1.1.4. Potential Milk Production in Mature Females. No actual milked-out data for Tswana cattle are available in Botswana. An estimate of the milk yield is made by using calf growth to 90 days of age multiplied by a milk-to-liveweight conversion factor of 11.65 : 1 (Dewrey et al., 1959). Data from 394 six- to eight-year-old Tswana cows in 26 year/APRU ranch groups, covering the period 1975 to 1977, give an estimated mean daily milk yield for the first three months of lactation of 10.45 kg. Ranch production conditions in Botswana probably do not permit the expression of the Tswana breed's maximum milk yield potential, so this estimate can be taken as a lower boundary for deriving the genetic potential for yield. A series of simulation runs was made to derive the estimates of milk yield potential by simulating with progressively higher values from this lower limit until the computed pre-weaning growth curves most closely corresponded with those recorded in the field. This correspondence was best achieved using a potential milk production value of 11.25 kg per day.

4.1.2 Forage Productivity. Operation of the model requires a description of the quality and quantity of available feed resources. Feed resources are specified monthly throughout the year in terms of dry matter digestibility, crude protein content and the weight of forage dry matter available per mature animal per day.

Work carried out on a network of ranches throughout Botswana in 1972-73 (Botswana, Ministry of Agriculture, 1976b; Pratchett et al., 1977) included cattle observation studies, forage clipping and oesophageal sampling. This led to the development of techniques for comparative monthly sampling of forage on 13 of the

APRU ranches in Botswana from May 1974 to April 1976. Animal productivity parameters were also recorded over a seven-year period, including these two years. For forage quality data, monthly species collections were carried out, sampling that part of each species assumed to be eaten by cattle in that particular month (Botswana, Ministry of Agriculture, 1978). The crude protein and dry matter digestibilities of each species were obtained from monthly analyses over the two-year period. These were then combined in the relative proportions of each species estimated to be consumed monthly. These values were finally averaged to produce monthly values for one complete annual cycle for each of the locations. The quality of forage available daily per head is treated as non-limiting on ranches and for the production alternatives examined for these locations.

There is a natural division of the grassland areas of Botswana into 'sand veld' and 'hard veld'. It is appropriate to consider these two areas separately, as grasses occurring on sand veld are rarely found on hard veld and vice versa. The soils of the hard veld are classified as Limpopo soils and consist of dark reddish brown, medium textured soils of varying depth, while the sand veld falls among the Kalahari soils with yellow to reddish brown or grey sandy soils, usually deep and often underlain by calcrete.

Three pairs of APRU ranches and one single ranch were selected as representing major ecological zones in Botswana. These are Matlolakgang and Masiatilodi with Central Kalahari bush and arid sweet bush savanna on sand veld; Musi and Dikgatlhong with Southern Kalahari bush savanna on sand veld; Lesego and Impala with tree savanna with Colophospermum mopane on hard veld; and Morale with Acacia nigrescens/Combretum apiculatum tree savanna on hard veld. Observations under ranch conditions in Botswana suggest that the amount of edible bush consumed by cattle is negligible.

The monthly crude protein and digestibility values, derived as indicated above, were pooled when two ranches represented one ecological zone. The resultant values were graphed separately, and minor sampling abnormalities smoothed out and the mid-month values for crude protein and digestibility read off. These monthly values for ranches in the four zones are laid out in Tables 4.2 and

4.3.

Table 4.2. Crude protein percentages used in simulation.

Month	Ranches				Cattle posts	
	Masiatilodi-Matlolakgang	Morale	Musi-Dikgatlhong	Lesego-Impala	Kweneng	Serule
January	8.6	11.3	8.3	7.0	8.6	7.0
February	7.8	11.2	7.9	7.6	7.7	7.5
March	7.3	11.0	7.4	7.2	7.3	7.0
April	5.8	10.5	5.9	6.4	5.8	6.0
May	5.4	9.5	5.7	5.7	5.4	5.7
June	5.0	8.5	4.6	4.8	5.0	4.8
July	4.3	7.0	3.7	4.0	6.0	4.0
August	3.8	5.6	3.6	3.8	3.8	3.8
September	4.0	5.0	5.1	3.8	3.8	3.8
October	5.2	5.1	7.5	3.9	3.5	3.5
November	6.1	6.7	8.6	4.7	3.5	3.8
December	8.8	9.0	8.5	6.0	8.8	6.0

Animal productivity data were available from cattle posts in the vicinity of the APRU ranches in two of the zones: namely, in the Kweneng area in the vicinity of the Matlolakgang-Masiatilodi ranches, and in the Serule area in the vicinity of the Lesego-Impala ranches. Under cattle post conditions, herbage observations indicate that localized overgrazing increases toward the water sources. The most valuable grass species are thus generally absent in these areas and the higher quality species remaining are eaten out more rapidly as soon as the growing season is over, resulting in lower dry matter availability per head per day. Crude protein and digestibility values are lower than under ranch conditions from June to August, drop markedly lower in September, and do not start to rise until about November. This later recovery results from localized overstocking with new growth eaten as soon as it appears. No protection is afforded to the pastures on the cattle posts, in contrast to the rotational grazing system practised on the

Table 4.3. Digestibility percentages used in simulation.

Month	Ranches				Cattle posts	
	Masiatilodi-Matlolakgang	Morale	Musi-Dikgatlhong	Lesego-Impala	Kweneng	Serule
January	60.0	60.0	58.0	60.0	58.5	60.0
February	57.5	58.5	55.0	57.8	51.3	57.0
March	50.1	54.2	52.7	55.7	50.1	55.0
April	49.0	52.8	51.2	52.7	48.0	52.0
May	47.0	52.1	48.5	51.7	46.3	51.0
June	46.0	50.1	45.3	42.4	42.0	42.0
July	45.6	47.5	41.6	38.0	50.0	38.0
August	45.0	43.8	42.8	38.0	37.0	38.0
September	50.0	42.6	45.9	38.0	36.0	35.0
October	55.0	41.5	52.0	38.4	38.0	35.0
November	58.5	43.2	56.5	50.8	38.0	38.0
December	60.0	47.5	58.0	55.7	60.0	55.0

ranches. In the Kweneng area, maize crop residues are available in July each year and result in a marked increase in the digestibility and crude protein of the forage available for that month. The forage quality and quantity factors used in the model's applications to cattle posts are derived on the basis of these considerations. They are presented in Tables 4.2, 4.3 and 4.4.

4.1.3 Management. The basic management regimes adopted on ranches and cattle posts are accounted for in the model by the specifications in Table 4.5. It is not implied that all ranches or cattle posts follow these practices. For example, not all cattle posts provide bonemeal and salt without restriction. Variations from these assumptions are made in the simulations of production alternatives presented in Chapter 5.

Table 4.4. Dry matter availabilities used in cattle post simulation (kg/head/day).

Month	Kweneng	Serule
January	12.6	12.6
February	10.8	10.8
March	10.5	10.5
April	10.1	10.1
May	9.6	9.6
June	8.0	7.6
July	10.3	7.5
August	5.5	5.5
September	6.2	6.2
October	6.0	6.0
November	6.1	6.1
December	13.1	11.8

Table 4.5. Management practices on ranches and cattle posts.

Practice	Ranches	Cattle posts
Pasture management	paddocked, natural rangeland	no fenced areas, uncontrolled stocking rate
Mineral supplementation	bonemeal and salt available without restriction (i.e., phosphorus non-limiting)	bonemeal and salt available without restriction (i.e., phosphorus non-limiting)
Breeding season	three months per year from January to end March	all year round
Weaning age	seven months	ten months
Age at first breeding	heifers exposed if they weigh minimum of 272 kg (600 lbs) at beginning of breeding season	heifers exposed if more than 27 months of age
Cow culling	in April each year, 10% of 3-year-olds, 8% of 4- to 8-year-olds, 10% of 9-year-olds, 12% of 10-year-olds and 14% of 11-year-olds. All cows older than 11 years sold as they wean their calves. All remaining cows reaching 12 years of age are sold.[a]	All cows reaching 12 years of age are sold
Sales	steers and excess heifers sold at 2½ years of age, in April to June each year	steers and excess heifers sold, beginning in April each year, as they reach 2½ years of age

a. These culling percentages reflect culling due to health problems, injury, etc.

4.2 Model Validation

This section summarizes the procedures used to validate the model and presents some selected results of the validation runs made, using the input data described in the previous section.

4.2.1 Background and Procedures. Validation of a simulation model involves comparisons of field data with simulated results. Simple tabular and graphic methods are the common tools for validation, while in those cases where data are adequate, formal statistical tests can be used. For this particular validation, sufficient time-series data from the real systems are not available, which precludes the use of formal statistical techniques. Detailed input-output data are available for the real system only over a two-year period at several locations and for an above-average rainfall sequence. Additional output data are available for about a seven-year period, but are not matched by corresponding input data. For sophisticated models of complex systems, the complete data sets which would be desirable for formal validation are seldom available, and this particular model is no exception. In such cases, subjective considerations become relatively more important. When greater reliance is placed upon subjective criteria for validation, minor differences between outputs can be detected with less confidence, and this decrease in confidence becomes even more important as the number of parameters by which an output is being evaluated increases.

The model is considered to be validated for conditions in Botswana if it satisfied the following three criteria:-

(a) the solution values for key production traits correspond closely - both individually and collectively - with observations made on the real system,

(b) the growth curves for indicator classes of livestock correspond closely with recorded performance, and

(c) the changes in both the direction and magnitude of the values of both intermediate results and important summary parameters in the system are consistent with the experience and expectations of knowledgeable researchers for all the

situations examined.

4.2.2 Results. The first two criteria for validation given above are applied here to the results of the model for the APRU ranch groups and the Kweneng and Serule cattle posts. The ranches and cattle posts are treated separately. The following four key production traits need to be simulated accurately if the model is to be considered validated:-

(a) the calving rate, i.e., the number of calves born divided by the number of breeding females in the herd in mid-May (immediately after the culling of all non-lactating cows in the oldest age group); breeding females are all those which have been exposed to the bull at any time in the previous 12 months, adjusted for interim sales,

(b) the mortality of calves up to 12 months old, i.e., the fraction of calves born that die by one year of age,

(c) the weaning weight, i.e., the average weight of all calves corrected to 7 months of age under ranch conditions or 10 months of age under cattle post conditions, and

(d) the 18-month weight, i.e., the average weight corrected to 18 months of all males and females in the herd.

4.2.2.1 APRU ranches. Table 4.6 presents a comparison of actual ranch data with the simulated results for the four production parameters defined above. The data from the ranches are pooled according to the methods described in Section 4.1. The corresponding values coincide closely, with the exception of mortality at Lesego-Impala. The model accounts for mortality in relation to nutrition. The effects of infectious disease, accidents and predators may be expected to produce wider variations in the real situation, and the close approximation on all other stations suggests that mortality is adequately simulated.

Figure 4.1 presents recorded growth curves for males and females up to 24 months old on the ranches and the corresponding simulated growth curves. The

Table 4.6. Comparison of APRU ranch data with simulated results for selected parameters.

Location	Production trait			
	Calving %	Mortality up to 12 months %	Weaning weight kg	18-month weight kg
Musi-Dikgatlhong				
Actual	77	8.5	190	313
Simulated	76	6.1	191	318
Masiatilodi-Matlolakgang				
Actual	87	4.5	197	330
Simulated	86	5.5	198	348
Morale				
Actual	85	4.0	204	318
Simulated	80	6.1	193	310
Lesego-Impala				
Actual	69	12.0	184	295
Simulated	67	6.0	187	300

plotted values are the average of the weights for all calves of each sex born during the three-month calving season. Table 4.6 indicates close agreement between the actual and the simulated values of both the weaning weights and the 18-month weights. At the other intermediate ages the four figures all demonstrate the steady growth achieved every year until the onset of the dry season which is followed by a period of significantly reduced growth and even weight loss. Although the values simulated are, in most instances, slightly above the recorded weights at the corresponding age, the phasing of changes in the growth rates corresponds sufficiently well for this validation criterion to be satisfied.

The data presented here are the most important of the parameters used to

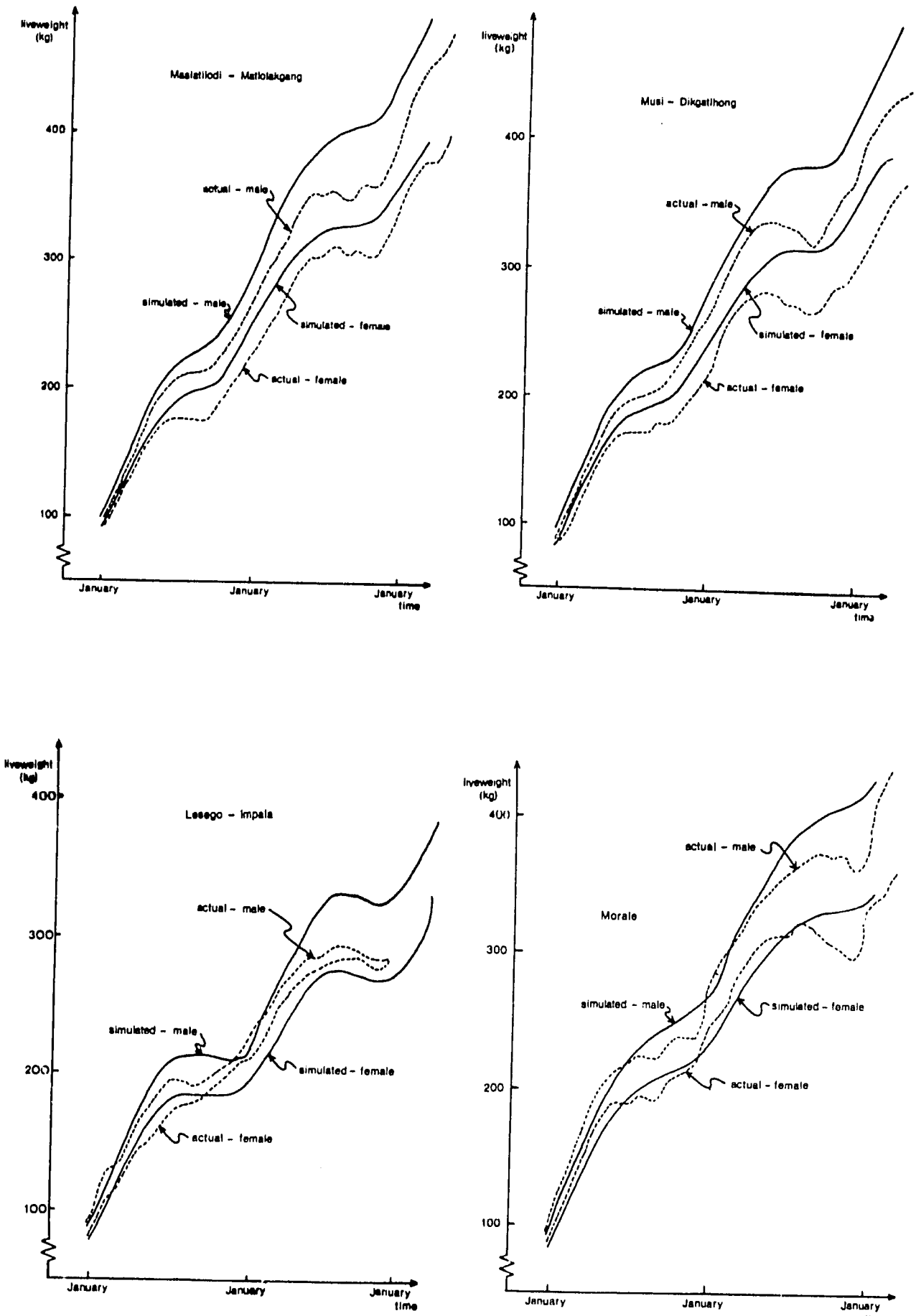

Figure 4.1. Actual and simulated growth curves to 24 months.

evaluate the validity of these applications of the model. The results of the simulation runs for the APRU ranches are summarized in Appendix 3, Table 1. Since the validation runs are simulations of existing conditions, it is the steady-state results produced in these runs which are used in Chapter 5 as the reference points for evaluating the various production alternatives for ranch conditions. The conclusions from the validation runs are that the results of the model for the three ranch locations of Musi-Dikagatlhong, Masiatilodi-Matlolakgang, and Lesego-Impala are acceptable. This permits the use of the model to investigate various production alternatives (interventions) at these locations with reasonable confidence. Actual animal production data available from Morale are based upon a small number of field observations and the modelling results produced do not correspond as closely as those produced for the other ranches. This suggests that further data collection and validation runs will be necessary before the simulations can be reliably validated and other interventions confidently simulated for that particular ranch.

4.2.2.2 Cattle Posts. Table 4.7 presents the comparisons of cattle post survey data (Rennie et al., 1977) with the simulated results for cattle posts at Kweneng and Serule. The validation runs of the model for the cattle posts are summarized in Appendix 3, Table 2. The field data available for the cattle posts are less complete than the detailed data available for the APRU ranches. Thus coincidence between the cattle post data which are available and the simulation results does not necessarily imply that the model is validated for application to these production systems. In this case, subjective factors are relatively more important in determining the acceptability of the simulation.

The model predicts higher calving percentages on both cattle posts than have actually been reported. The model assumes that phosphorus in the diet is not limiting for reproductive performance, while research results from southern Africa indicate that calving percentages are in fact very significantly reduced if the phosphorus intake is inadequate (e.g., Van Niekerk, 1974). Another factor that makes the comparison of survey data and simulated results more difficult is that in the model heifers are not joined until 28 months of age, while on the cattle posts the individual joining age is often earlier.

Table 4.7. Comparison of cattle post survey data with simulated results for selected parameters.

Location	Production trait			
	Calving %	Mortality up to 12 months %	Weaning weight kg	18-month weight kg
Kweneng				
Survey	42	10.0	130[a]	216
Simulated	56	17.5	170[b]	219
Serule				
Survey	42	10.0	145[a]	241
Simulated	55	9.3	178[c]	245

a. At 7 months.
b. At 10 months = 128 kg at 7 months.
c. At 10 months = 134 kg at 7 months.

The model predicts an average mortality rate to 12 months of age of 17.5 percent at Kweneng, as opposed to a reported 10 percent from the survey. The survey data do not identify stillbirths, abortions or early deaths of calves, but these are accounted for in the model. Identifying these deaths would be expected to raise the survey data mortality to values more comparable to the model results. Also the model does not make allowance for the impact of infectious disease such as brucellosis which may depress calving rates on the cattle posts below those predicted.

In the model, weaning on cattle posts is set at 10 months of age. At Kweneng, the model simulates a 7-month weight of 128 kg, while the survey results give an average weight of 130 kg for this age. At Serule, the model predicts a 7-month weight of 134 kg, while the corresponding survey value is 145 kg. The 18-month weights also correspond closely, which supports the conclusion that the forage parameters used in the model are similar to those on the cattle posts. No monthly production data are available from the cattle posts to correspond with the data

given for the ranches in Figure 4.1. Estimates of weights are available from the cattle posts at only two ages, 7 and 18 months. The growth rates generated by the model for the cattle posts are considered acceptable.

5. SIMULATION OF PRODUCTION ALTERNATIVES

5.1 Background

Herd productivity depends on relationships among variables whose values are determined both within and outside the system (endogenously and exogenously). The herd manager has varying degrees of control on the exogenously determined variables. For example, complete control over weaning age is a practical possibility, but only limited control is possible over the forage regime on offer to the animals, and no control is possible over the weather.

In a model, all parameters corresponding to both the endogenously and exogenously determined variables are controllable and can be set at any desired value. In this way a validated model is used to investigate the likely impact on the real system of changes in the level of any set of variables. The values of variables can be reset at particular levels and the model can then simulate operations through time and predict the changes which would occur in the real system being modelled. The model is then operating as a high speed 'if-then' calculator. In this report, when parameters have their values set at levels other than those used in the validation runs, the corresponding computer simulation run of such a production alternative is defined as an intervention. These simulation runs can be designed so that they correspond to real-world experimentation.

For any production system, it will be useful to test the impact of changes in only some of the variables. Because resources are scarce, the person undertaking modelling should restrict the interventions examined to those which have practical possibilities in the real system being modelled. However, it is not necessary for these interventions to have been tried in practice. In beef cattle systems some interventions, such as the adoption of alternative weaning ages, could be carried out at little additional cost (if a weaning policy is already being implemented). Others, such as the use of special purpose fodder in the dry season, may involve significant capital investment.

Interventions will also differ in terms of the time required for their implementation in the real world. In the model, interventions can be scheduled to

occur at any point in simulated time. For instance, the model can be programmed to depict the simultaneous introduction of controlled breeding, weaning and the use of a reserve pasture by certain classes of cattle. In practice, such management changes would usually be introduced over a period of years as husbandry skills are built up and cash for the necessary investments becomes available. Care must be taken to ensure that interventions chosen to be tested by the model are realistic, otherwise there can be little hope that results will be accepted, no matter how well the model predicts the outcome.

The interventions examined here illustrate those which are feasible for introduction in Botswana at the level of the individual herd, and thus they do not address macro-level questions such as regional or national offtake. Set 1, in which alternative weaning ages are simulated, illustrates an innovation requiring only a change in a husbandry practice. Set 2 illustrates the type of compound experiment in which innovations can be examined individually, and then in combinations of two or more, to determine their impact on herd performance. Three innovations on a cattle post are examined in this way, the introduction of controlled breeding and weaning and the use of a reserve pasture for certain classes of breeding stock. This set of interventions is relevant to the current situation in Botswana where a major component of the Second Livestock Development Project is to change existing cattle post enterprises to ranch-type operations, through the phased introduction of various husbandry practices (Botswana, 1976).

Set 3 shows how an innovation, not as yet tried in Botswana, can be examined to establish the minimum productivity levels which would have to be reached before the introduction of the technology would be economically justifiable. The example used is the introduction of Leucaena leucocephala as a dry-season forage plant in a ranch environment.

Set 4 is presented to demonstrate how the model can be used to examine a practical development question without engaging in large-scale or long-term experimentation. The extent to which the indigenous Tswana cattle can be used as dual-purpose milk and meat animals without reducing meat production is not known. If such a dual use is possible, the importation of milk and milk products could be

reduced. This is currently seen by some as an important national goal.

The last set of interventions, Set 5, is designed to demonstrate the importance of evaluating strategies which have not been tested in the field but which appear to be favourable under different sequences of environmental conditions. At the producer level, in Botswana as elsewhere, the acceptability of a new technology or modified management practice depends upon its performance in adverse years. This can be examined by simulating adverse environmental conditions with the model.

The greatest amount of information is obtained from the simulation of production systems when the results from the runs within a set of experiments are comparable. For example, while the model predicts animal performance in response to the forage regime on offer, it does not relate performance to land area. The simulated forage quality and quantity available per animal does not decrease as the herd size increases as it might in practice for a real herd on a specific area of land.[2] Therefore, the results of a set of simulated interventions cannot be compared on the basis of a constant land area. It is also inappropriate to compare runs on the basis of constant cow numbers, as the herd composition can change markedly between runs and this would then imply substantially different areas of land required to maintain the same level of forage availability per animal. The model calculates the total amount of dry matter consumed annually by the herd, and the relevant parameters (cow numbers, calf numbers, etc.) in all solutions can be scaled to correspond to a particular total annual herd consumption. The values of ratios such as calving percentages are not altered by scaling the number of animals to a given consumption level, as the ratios are assumed to remain constant irrespective of herd size. Development plans in Botswana are based on

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2. Section 3.2 indicates that one planned addition to the model is to make animal performance and forage production interactive. This would permit the simulation of animal performance in relation to a particular unit of land and the comparison of different interventions on this basis.

herd units having access to about 6 400 hectares. Except where indicated, all solutions are scaled to a total annual consumption of 1 800 tonnes of dry matter as this quantity corresponds very approximately to the amount available from this area.[3] The actual dry matter availability will depend upon the location and the year.

The remainder of Chapter 5 focusses on the biological responses of the system to the different interventions. An economic interpretation of certain of these results is presented in Chapter 6. Additional simulations arising from the results presented below in sections 5.2.1 to 5.2.4 are outlined in Section 7.2.

5.2 Production Alternatives Examined

5.2.1 Alternative Weaning Ages. All the APRU ranches have a controlled three-month breeding season and all calves are weaned at seven months of age. Cow reproductive performance has been considered the production trait of primary importance, thus the management has aimed at giving cows the best opportunity to reproduce. Optimum calf treatment has been considered of secondary importance. Seven months was thought to be the lowest age at which calves could be weaned safely on all the ranches.

The present simulations compare five- and nine-month weaning with the seven-month standard. These are simulated under the Masiatilodi/Matlolakgang ranch conditions, as five-month weaning might well be feasible in the relatively favourable environment of this area. A summary of the simulated performance of the system under the three weaning strategies is given in Table 5.1. The values in that table are the solution values after the effects of introducing the different weaning ages are assimilated. This presentation recognizes that, while the weaning age can be changed in a particular year, the effects of such a change will be evident in the system's performance only after several years. Column 1 of this table repeats the results simulated for the validation of the model for this

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3. The scaling of the solutions to give the common basis of 1 800 tons of dry matter required the use of scaling coefficients from .78 to .88, .91 to 1.16, .86 to 1.29 and 1.02 to 1.20 for runs in Sets 1 to 4 respectively, and a coefficient of 1.2 for Set 5.

particular ranch.

Table 5.1. Effect of weaning age at Masiatilodi-Matlolakgang ranch.

Production parameter (per annum)	Age at weaning		
	7 months (baseline)	5 months	9 months
Total dry matter consumed (tonnes)	1800	1800	1800
Animal numbers as of mid-May			
Cows	259	258	288
Heifers	107	114	96
Steers	105	111	95
Calves			
Number born	222	236	216
Number weaned	212	226	204
Calving percentage	86	92	75
Weaning percentage	82	88	70
Survival to weaning (percentage)	96	96	93
Average weaning weight (kg)	198	160	226
Average cow weight in mid-May (kg)			
3-year-old	428	417	435
7-year-old	441	473	434
Total liveweight sales (tonnes)	97.1	100.8	84.7
Composition of sales			
Percentage cows	20.6	20.4	16.8
Percentage heifers	22.7	23.8	24.3
Percentage steers	56.7	55.8	58.9
Production indices			
Kg dry matter consumed/kg liveweight sold	18.54	17.86	21.25
Total liveweight sold/cow (kg)	375	391	294
Liveweight of progeny sold/cow (kg)	298	311	245

The results indicate that the effects of weaning age are retained to some extent for seven years. At five months, the average calf weaning weight of 160 kg is only 70 percent of the weaning weight under the nine-month strategy. By one

year, calves weaned at five months are 31 kg, or 13 percent lighter than one-year-old calves weaned at nine months. By two and one-half years of age, however, this difference falls to 20 kg, or four percent. At three years of age, cows that have been weaned at five months are still 18 kg, or four percent lighter than those weaned at nine months. However, the effect on the cows of suckling a calf for five months rather than nine months is such that, by five years of age, the cows under the five-month weaning regime recover this four percent disadvantage. At seven years of age, they are 39 kg, or nine percent, heavier.

The later the weaning age, the greater the number of breeding cows which can be carried when the herd size is scaled to a total herd consumption of 1 800 tons of dry matter per year. This reflects the lower number of calves produced. The calving percentage is markedly reduced by extending the weaning age, while calf survival from birth to weaning remains approximately proportional to the weaning age.

One index of biological efficiency appropriate to a grazing herd is the total amount of dry matter consumed by the herd per kilogramme liveweight sold from the system. In terms of this index, the five-month weaning regime is four percent more efficient, and the nine-month regime is 13 percent less efficient than the standard seven months. The total liveweight of animals sold - steers plus surplus heifers and cull cows - is substantially lower when calves are weaned at nine months. The total liveweight sold is 391 kg per cow in the five-month system and 294 kg per cow when the weaning age is set at nine months.

These results are simulated assuming that average forage conditions are constant from year to year. The calves under the five-month weaning regime are weaned from mid-March to mid-June at a time when the quality of the available forage is declining progressively before recovering in September-October. In years of below-average forage quality, it could be anticipated that the modest advantage of five-month over seven-month weaning might be reduced or even eliminated by inadequate fodder during this period. To test this hypothesis it will be necessary to carry out simulation experiments under a number of nutritional regimes, including random sequences of above-average and below-average years.

In the simulations of below-average years, it will also be appropriate to specify non-protein nitrogen (NPN) supplementation to calves in the early post-weaning period. Before making any extension recommendations, these simulations will need to be run under conditions corresponding to the different major ecological zones in Botswana, as there may be regional differences in the appropriate weaning strategy.

Although weaning would be the simplest form of management practice to evaluate by physical experimentation, since only a single parameter in the system is deliberately varied, such experimentation would require a considerable commitment of time and physical resources. Any conclusions from such field experimentation would only be reliable if the environmental circumstances encountered during the experimentation period included unfavourable years. For such research situations, a simulation model can be of major use, as different environmental sequences can be specified readily. Testing the hypotheses with a simulation model would be considerably less expensive than testing them by physical experimentation and the results would be available much more quickly.

5.2.2 Three Innovations to be Introduced on Traditional Cattle Posts. Productivity on cattle posts is substantially lower than on adjacent areas where the APRU ranch management regime is practised. The introduction of facilities permitting the daily watering of animals and the addition of phosphorus to the diet can raise productivity levels economically, but without the introduction of other management practices the productivity of cattle posts cannot reach that of comparable ranches. The poorer (and often overgrazed) pastures on cattle posts account for a major part of this productivity differential. Additionally, herd management differs in at least two major ways. First, on the cattle post, the calves are seldom deliberately weaned from their dams and suckle for about 10 months. This significantly lowers reproductive performance in the cattle post herds as it extends the average calving interval. Second, breeding is not controlled, which leads to a percentage of calves born in the dry season when cows are most likely to produce inadequate amounts of milk. By contrast, the recommendation for ranches is to wean all calves at seven months and allow only a three-month breeding season from January to the end of March.

Results from research on the APRU ranches suggest that controlled breeding and earlier weaning should be introduced as a package. Although specific trials have not been conducted in Botswana, researchers consider that the separate introduction of either earlier weaning or a controlled breeding season would have little positive impact on the performance of whole production systems and might even reduce overall productivity. Under ranch conditions calves are weaned onto pastures which can supply adequate nutrition. By contrast, under cattle post conditions, the introduction of earlier weaning and controlled breeding (January - March) could result in increased mortality and lower growth rates of weaned calves, because cattle post pastures are especially poor during the dry season. This effect could be exacerbated by the tendency of young stock to stay in the vicinity of the watering point and therefore to have the poorest grazing. Thus, the establishment of a reserve pasture for weaners during the dry season may well be essential if changes in the weaning and breeding regime are to lead to higher productivity.

Table 5.2 presents the summary results of simulation runs for various combinations of the two standard management practices of seven-month weaning and three-month breeding, in addition to the use of a reserve pasture for weaner calves. The simulations are for the Kweneng cattle post. The reserve pasture has the quality of the Masiatilodi-Matlolakgang ranch in this area during the months it is used. The first column in the table repeats the validation run for the Kweneng cattle post. Columns 2 to 4 give the effects of the separate introduction of the weaning and breeding strategies and the use of reserve pasture for the weaner calves. The effect of introducing both the weaning and breeding strategies without the use of the reserve pasture is summarized in Column 5. Columns 6 and 7 present the effect of introducing either the weaning or the breeding strategies in combination with the use of the reserve pasture. Column 8 presents the effect of combining the weaning, breeding and reserve pasture interventions.

Seven-month weaning, if introduced without other changes, increases the calving rate from 56 percent to 64 percent (Column 2, Table 5.2). This reflects the reduced stress on the cows and the resulting shorter average calving interval. The average calf weaning weight decreases by 16 percent to 142 kg. This weaning effect is still partially reflected in three-year old cows which are slightly lighter

Table 5.2. Effects of weaning, controlled breeding, reserve pasture and their combinations at Kweneng cattle post.

Production parameter (per annum)	Base-line	7-month weaning (W)	3-month breeding season (B)	Reserve pasture for calves (R)	Combination of (WB)	(WR)	(BR)	(WBR)
Total dry matter consumed (tonnes)	1 800	1 800	1 800	1 800	1 800	1 800	1 800	1 800
Animal numbers as of mid-May								
Cows	427	433	431	406	432	396	406	406
Heifers	142	154	96	139	97	147	91	91
Steers	144	155	97	141	97	148	91	91
Calves								
Number born	240	275	217	229	227	232	201	201
Number weaned	198	213	166	190	178	211	157	168
Calving percentage	56	64	50	56	53	59	50	52
Weaning percentage	46	49	39	47	41	54	39	41
Survival to weaning (percentage)	83	77	77	83	78	91	78	80
Average weaning weight (kg)	170	142	188	170	169	139	189	170
Average cow weight in mid-May (kg)								
3-year-old	319	298	334	336	328	325	365	355
7-year-old	401	408	403	400	410	405	403	410
Total liveweight sales (tonnes)	73.8	73.9	73.2	73.5	75.7	74.7	73.9	77.4
Composition of sales								
Percentage cows	24.5	24.6	28.2	23.4	26.4	22.1	26.2	24.2
Percentage heifers	19.6	20.7	18.6	19.7	20.6	20.6	19.1	20.6
Percentage steers	55.9	54.7	53.2	56.8	53.0	57.2	54.7	55.2
Production indices								
Kg dry matter/kg liveweight sold	24.39	24.35	24.59	24.49	23.77	24.09	24.32	23.25
Total liveweight sold/cow (kg)	173	171	170	181	175	190	182	191
Liveweight of progeny sold/cow (kg)	131	129	122	138	129	148	134	145

than those from the natural weaning regime. However the mature cows are heavier, as a result of the reduced lactation stress when calves are weaned at an earlier age. Overall, the total liveweight sold and the composition of the sales from the two systems are similar. The change in herd composition caused by introducing seven-month weaning is modest. The major difference is the increased number of steers carried as a result of the higher calving rate.

By contrast, the introduction of a three-month breeding season without any change in the weaning policy (the cattle post weaning average of 10 months being used in the simulation) reduces the calving rate from 56 percent to 50 percent (Column 3, Table 5.2). The average weaning weight increases from 170 to 188 kg, as a higher percentage of calves are born at the more favourable time of the year (October - December). Slightly more cows are carried for the total herd consumption of 1 800 tonnes of dry matter, but overall a smaller herd can be carried because average cow weights are higher. Calf survival to weaning at 10 months is slightly lower when the breeding season is controlled, as this innovation when introduced alone tends to concentrate the weaning near the end of the dry season. As fewer calves are born, the cull cows comprise a higher fraction of the liveweight sold from the herd. There is no significant change in overall biological

efficiency as given by the index of total kilogrammes of dry matter consumed per kilogramme of liveweight sold.

The third single intervention considered is the provision of a reserve pasture during the dry season for calves from weaning to one year of age (Column 4, Table 5.2). For the simulation, the reserve pasture is made available to the weaners from July 15 to December 14. Overall biological efficiency is reduced slightly by adopting this strategy. Fertility changes insignificantly and weaning rates remain constant. The average weight of three-year-old animals increases substantially, reflecting the use of the higher quality reserve pasture from weaning to one year of age. However, with breeding all through the year, a considerable fraction of the calves are weaned at a time that does not permit them to use the reserve pasture before they reach one year of age. As in the basic cattle post simulation at Kweneng, crop stover (from maize) is available to the main herd in the first month of the dry season (July). In the model, however, the weaned calves on the reserve pasture are not given access to the crop stover as this is considered likely to be outside the fenced reserve pasture area. This assumption undoubtedly reduces the impact of the reserve pasture; the results will be more favourable if the crop stover is made available to the weaners. The total dry matter consumed by the weaned calves on the reserve pasture is 2.4 percent of the total diet of the herd. This is equivalent to about 150 hectares of land for a cattle post area of 6 400 hectares.

If both seven-month weaning and three-month breeding are adopted (Column 5, Table 5.2), the results can be compared relative to the baseline run or to the runs simulating the introduction of each of these innovations singly. The introduction of seven-month weaning combined with three-month breeding gives a lower reproductive performance than the introduction of seven-month weaning alone, but a slightly higher performance than the introduction of three-month breeding alone. The combined changes produce a herd which is slightly more efficient in terms of the conversion of dry matter to saleable liveweight.

The addition of a reserve pasture for weaners, combined with a seven-month weaning period, increases average calf survival from 77 percent to 91 percent

(Column 6, Table 5.2). This is mainly due to a marked reduction in calf mortality for the younger cow groups because of their significantly higher body weights. The resultant increase in lactation stress among these younger cows in turn reduces the overall calving percentage. The reserve pasture contributes 3.7 percent of the total dry matter in the herd diet when seven-month weaning is practised, an increase from the 2.4 percent contributed when the reserve pasture is used with traditional 10-month weaning. This difference simply reflects the extra three months during which the calves are using the reserve pasture. About 250 hectares of reserve pasture are required to provide 3.7 percent of the total diet for the herd.

The combination of a three-month breeding period and reserve pasture produces the lowest calving percentage, with less than 50 percent of the cows calving each year (Column 7, Table 5.2). As calves are not weaned under this strategy until 10 months of age, the January to March mating season means that weaning takes place from August to October during the dry season. Therefore cows are put under severe stress during the dry season by the suckling calves and do not have sufficient time to recover before being exposed to the bulls again from January to March. The average mature cow weight in May does not alter but young cows are significantly heavier. Thus this strategy produces heavier young females, but lactation stress during successive lactations in the dry season eliminates this advantage. The weaning weight is approximately the same as when only the three-month breeding season is introduced to the cattle post system. The biological efficiency of combining a three-month breeding season and a reserve pasture is little different from the efficiency of either innovation introduced singly. When combined with a three-month breeding season, slightly less reserve pasture is required than when the reserve pasture is combined with a seven-month weaning strategy - 3.3 percent, versus 3.7 percent, of total dry matter consumption for the herd.

The combined introduction of a seven-month weaning period, a three-month breeding season and a reserve pasture for the weaned calves increases the overall biological efficiency of production and produces the greatest liveweight sales of all the alternatives simulated (Column 8, Table 5.2). The weaning weight of 170 kg is the same as in the baseline cattle post simulation but is achieved in seven rather

than ten months. Young cows are heavier but mature cows are approximately the same weight. The total number of animals in May is higher in the baseline run than predicted with the combination of innovations. This favours the innovative system, as the forage demand during the dry season is then lower. While 31.3 percent of the total dry matter intake is required during the five-month dry season under baseline conditions, only 27.8 percent of the total demand is during this period when the three management modifications are introduced together. This gives an increase in the ratio of wet season to dry season demand from 2.2 : 1 to 2.6 : 1.

This management regime requires that 4.8 percent of the dry matter intake is available from the reserve pasture. This is equivalent to about 300 hectares on a 6 400 hectare cattle post. Liveweight sales per cow are 10 percent higher than in the existing baseline systems but, overall, the biological efficiency of these combined interventions is only five percent greater than that of the baseline cattle post.

The interventions in this set illustrate the type of simulation experiments which can usefully be performed with a validated cattle herd model. They do not address all the issues which would be involved in actual cattle post development, such as the differential performance or changes in the ranking of these alternatives if operated in a variable environment. Nor do they indicate conclusively whether slight modifications of these interventions will not have a more favourable impact on the performance of the overall system. For example, it was suggested at the workshop that given the poor forage regime of the cattle post, a three-month breeding season from February to April might be preferable to a January-March season because during the later period the nutritional status of the cows would more likely be rising, giving higher conception rates.[4]

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4. Such alternative specifications were designed following the workshop and will be simulated. Thus the initial runs have served as an aid in formulating hypotheses about the 'best' development strategy.

None of the interventions examined lead to major changes in the productivity of the herd relative to the baseline situation. The combined introduction of all three management innovations produces the greatest improvement in biological efficiency, but it may not be warranted from an economic point of view as the gains are only modest. The economic gain would be greater if the changes in management also resulted in improvement over time in the forage quality. Thus it would be useful to test these same innovations using simulations specifying a steady improvement in the quality of the available forage over time and reaching the quality of forage available on the ranches in, say, five or ten years.

Simulation runs will also be necessary to test the impact of different sequencing of the introduction of innovations to ensure the earliest possible payoffs from the investment made. The runs will then need to be replicated using different environmental sequences, to be certain that the development strategy will be viable when implemented in the real world of uncertain climatic conditions. Such experiments with the model will help to quantify the risks undertaken by individual producers embarking on the suggested development strategy. Credit facilities and other related development activities can then be designed to help the producers meet such risks.

5.2.3 Introduction of a Dry-Season Forage Plant. In Botswana, the quality of forage for cattle drops markedly in the dry season. Providing higher quality dry-season forage will improve overall herd productivity, but whether the investment necessary to achieve the improvement will be economically justifiable is not known. On a ranch, the introduction of new fodder plants is one of several ways of alleviating a dry-season forage deficit. Although the initial capital cost of plant introduction may be considerable, it has an advantage over food supplements brought to the farm in its substantially lower recurrent costs. Research work from neighbouring Malawi suggests that a promising fodder plant to introduce in Botswana is Leucaena leucocephala. This plant has not yet been studied in Botswana to determine either the best establishment methods or yields in different areas under different environmental conditions. However, it is likely that the plant can be grown, although perhaps at considerable cost.

Research in other parts of the world provides basic information on its use by cattle (Hill, 1971; USNAS, 1977). Leucaena cannot exceed 30 percent of the diet - equivalent to about 3 kg of dry matter per head per day - for an extended period without causing mimosine toxicity and its attendant problems. This upper limit on its intake can be specified easily in a simulation model. Therefore the impact of leucaena on cattle performance in Botswana can be predicted using the model. The Lesego-Impala ranch is used for the initial investigations as this area has the lowest overall forage quality so that introduction of a plant such as leucaena could be expected to be of particular value.

In the model, leucaena is specified as being available each year for the three months from August 15 to November 14. Thus it is not specified for use as drought reserve fodder, but as a routine part of the ranch's annual grazing programme. With the constraint of maximum leucaena intake, the composition of the overall diet in these months improves from approximately 38 percent digestibility and 3.8 percent crude protein to over 46 percent digestibility and 8 percent crude protein. The leucaena could, in practice, be made available to any class of cattle at any time within this three-month period. For purposes of illustration, however, only two feeding regimes are examined. The first regime provides the leucaena to all animals in the herd. The second restricts access to leucaena to cows which are lactating and/or pregnant. These are the animals under greatest stress whose performance is expected to be most responsive to the availability of high quality forage. Both these feeding regimes are practical management alternatives.

The impact of the leucaena supplementation is summarized in Table 5.3. Column 1 repeats the baseline validation run for the Lesego-Impala ranch, against which the effect of leucaena is gauged. When leucaena is provided to all animals, the weight of young cows increase by 15 percent and of mature cows by 3 percent. The overall calving rate increases from 67 percent to 83 percent in response to the improved nutritional status of the cows. Calf survival from birth to weaning does not alter significantly. Together, the increased calving rate and the higher animal weights imply a higher dry matter consumption per cow when leucaena is supplied.

Table 5.3. Effect of leucaena supplementation at Lesego-Impala ranch.

Production parameter (per annum)	No leucaena	Leucaena supplementation	
	Baseline	All animals	Pregnant and/ or lactating cows
Total dry matter consumed (tonnes)	1 800	1 800	1 800
Animal numbers as of mid-May			
Cows	313	263	280
Heifers	126	106	120
Steers	99	102	103
Calves			
Number born	211	218	222
Number weaned	201	207	210
Calving percentage	67	83	79
Weaning percentage	64	79	75
Survival to weaning (percentage)	95	95	95
Average weaning weight (kg)	187	195	194
Average cow weight in mid-May (kg)			
3-year-old	362	418	377
7-year-old	431	446	442
Total liveweight sales (tonnes)	82.0	88.6	86.1
Composition of sales			
Percentage cows	30.3	23.2	26.0
Percentage heifers	13.4	20.1	17.9
Percentage steers	56.3	56.7	56.1
Production indices			
Kg dry matter/kg liveweight sold	21.96	20.32	20.90
Total liveweight sold/cow (kg)	262	337	308
Liveweight of progeny sold/cow (kg)	183	259	228

A total of 313 cows can be supported with a herd consumption of 1 800 tonnes of dry matter in the baseline system. When leucaena is introduced and the system is again in equilibrium, only 263 of the heavier and more productive cows can be supported by the same level of dry matter consumption for the herd. Using

the weight of dry matter consumed per kilogramme of liveweight sold as an index of biological efficiency, the provision of leucaena to all animals increases efficiency by almost 7.5 percent. Total liveweight sales increase by over 8 percent while the liveweight sales per cow increase by over 28 percent from 262 to 337 kg per year. This regime requires 1 902 animal months per year of grazing on leucaena, with the special-purpose forage contributing about 9.5 percent of the total annual dry matter consumption by the herd.

The alternative specification examined is the provision of leucaena only to pregnant and/or lactating cows. Only 621 animal months of grazing on leucaena are required per year, or about one-third of the number necessary when all animals are supplemented. In this situation, leucaena accounts for 3 percent of the total herd consumption. Providing the supplement only to the cows under stress produces an increased calving percentage approaching that of the strategy of feeding the entire herd. Also, more calves are born annually under this feeding regime than with the 'all herd' feeding strategy, reflecting the slightly higher stocking rate possible when the animals are all marginally lighter.

The biological efficiency of the more limited supplementation regime is slightly lower than when fodder is provided to all animals. However, an economic appraisal of these two feeding regimes is presented in Section 6.2.1 which shows that the provision of leucaena to all animals is less favourable from an economic standpoint than providing it only to the females under stress.

5.2.4 Milking of Indigenous Cows. Botswana annually imports considerable quantities of milk and milk products. An important development question is whether the indigenous Tswana cattle can be used to substitute for these imports without impairing their performance as producers of meat. In areas with good road or rail access, milk can be taken to the consumption centres without spoilage, and at an economic price. Although such areas are of limited extent, they are considered by some to be adequate to provide substantially for the needs of the country. The simulation model is used to carry out initial investigations into this aspect of development to determine production potentials,but economic evaluation of the interventions would be necessary before final recommendations could be made.

Two milking strategies are simulated using Kweneng as the test location. Cattle posts at Kweneng have reasonable access to a milk market and cows can graze high quality crop stover during the dry season (crop stover is not available on cattle posts in the Serule area). An additional reason for basing these initial experiments on the Kweneng area is that milk sales provide a cash income which may facilitate the transition of a cattle post to a ranch-type operation. The two strategies examined are milking with and without feed supplementation for the milking cows.

Decision rules are specified in the model to determine whether an individual cow is to be milked, and the same rules are used for both milking strategies. Only cows in their fourth year of age or over are milked, and these are milked only if the calf will still gain at least 300 grammes per day if one quarter of the milk is taken. A maximum of one half of the cow's milk can be taken (by milking two quarters of the udder), if the calf is still left with sufficient milk to gain 300 grammes per day. The indigenous Tswana is specified in the model as having a milk potential of 11.25 litres per day at the beginning of lactation. Milk taken from the cows can be consumed by the herder and his family or sold.

Column 1 of Table 5.4 repeats the results of the validation run for the Kweneng cattle post. Columns 2 and 3 summarize the simulated status of the herd in the fifth year after the introduction of milking without and with supplementation respectively. The solution values for the Kweneng cattle post (as given in Column 1) are used as the starting point for these other two simulations. The initial conditions as given in Column 1 are scaled to give a total herd consumption of 1 800 tonnes of dry matter.

Although five years of milking are simulated beginning with the baseline equilibrium situation, there is evidence in the simulation results that the new equilibrium status of the herd is not reached in that time. This is most evident for the run in which milking is carried out without supplementation. In that run, the December weight of open four-year-old cows immediately post partum averages 333 kg for the first three years of the simulation, decreasing to 323 kg at the end of the

Table 5.4. Effect of milking Tswana cows at Kweneng cattle post.

Production parameter (per annum)	No milking	Milking[a]	
	Baseline	Without supplementation	With supplementation
Total dry matter consumed (tonnes)	1 800	1 500	1 671
Animal numbers as of mid-May			
Cows	427	430	435
Heifers	142	48	132
Steers	144	123	135
Calves			
Number born	240	242	262
Number weaned	198	166	182
Calving percentage	56	56	60
Weaning percentage	46	39	42
Average weaning weight (kg)	170	132	153
Average cow weight in mid-May (kg)			
3-year-old	319	278	300
7-year-old	401	402	415
Total liveweight sales (tonnes)	73.8	52.7	62.9
Composition of sales			
Percentage cows	24.5	34.7	29.6
Percentage heifers	19.6	16.6	18.0
Percentage steers	55.9	48.7	52.4
Milk production (kg)			
Calves	-	90 457	129 017
Saleable	-	70 598	95 816
Total	-	161 055	224 833
Production indices			
Kg dry matter/kg liveweight sold	24.39	28.47	26.53
Total liveweight sold/cow (kg)	173	122	145
Liveweight of progeny sold/cow (kg)	131	80	102
Total milk produced/cow (kg)	-	375	517

a. Values in Columns 2 and 3 are from the fifth year of simulation starting from the baseline conditions summarized in Column 1.

fourth year and to 307 kg at the end of the fifth year. This time series, and others which can be taken from the model output, indicate that the effect on the cow herd only becomes evident in the last two years of the run when the calves born within the milking system themselves reach maturity. This overall decline in herd productivity can be expected to continue for some years before the new equilibrium status of the herd is reached. Emphasis in this discussion is on the performance of the herd in the fifth year after milking is introduced.

When the cows are milked and not given supplementary feed, the total dry matter consumed by the herd decreases from 1 800 to 1 500 tonnes by the fifth year (Column 2, Table 5.4). This mainly reflects the reduced numbers of herd followers (steers and surplus heifers) due to increased calf mortality and the lower weights of the young cows being introduced to the herd in the later years of the simulation. Whereas there are 142 replacement heifers in the herd in the baseline situation, this number is reduced to 48 after five years of milking. Fewer heifers are available for sale when calf survival is reduced by the milk deprivation of the calf caused by milking, and the same number is needed to replace the cow herd after mortalities and culling. While 198 calves are weaned annually in the baseline run, only 166 are weaned in the fifth year of milking. The herd status indicated by Column 2 is for a transition year between two equilibrium states, with herd performance declining. This gives the upper limit for survival of calves born in the fifth year of 69 percent (calculated as 166/247).[5] By the fifth year of milking, the total liveweight sales from the herd are reduced from 73.8 to 52.7 tonnes. This is equivalent to a drop in liveweight sales per cow from 173 kg in the baseline situation to 122 kg in the fifth year with milking. The liveweight sales per cow of steers and surplus heifers fall from 131 kg to 80 kg per year. Cull cow sales comprise 24.5 percent of all sales in the baseline situation, increasing to 34.5 percent in the fifth year under the milking regime.

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5. The 242 calves born in that year will be weaned partly in the year and partly in the next year of the simulation. This is a 10-month weaning system with year-round breeding. Some of the 165 calves weaned on the fifth year are born in the fourth year, which has a marginally more favourable maternal environment than the fifth year. The sixth year will be even less favourable, resulting in still lower calf survival.

Without supplementary feeding of cows, the average weaning weight of calves declines from 170 kg to 132 kg, a reduction of 22 percent from the baseline value. Correspondingly, the average weight of three-year-old cows is 278 kg in the fifth year, versus 319 kg in the baseline situation. Liveweight sales are reduced by almost 29 percent through the introduction of milking. Milk is a joint product under this regime, and 70 598 litres are extracted. This is 44 percent of the total milk produced, with the remainder consumed directly by the calves. The amount extracted is 165 litres per cow in the herd, or 286 litres per cow which calves in the year.

The index of biological efficiency, expressed in total kilogrammes of liveweight sold per kilogramme of dry matter consumed, drops by over 16 percent when milking is carried out without feed supplementation, compared with the baseline situation. When the quantity of milk extracted is converted to liveweight equivalents using a conversion factor of 9 : 1 (constructed from values given by Dewry, et al., 1959), the index of efficiency of this milking strategy improves from 28.47 to 24.78. This approaches the baseline index value of 24.39.

An important aspect of this milking strategy is that the producer loses some flexibility to respond to drought conditions by manipulating stocking rates. The herd (as indicated by the mid-May inventory) is composed predominantly of cows, so the producer has only a limited number of non-breeding stock which can be sold in below-average or drought years. One alternative to manipulating stocking rates in this way is to sacrifice herd productivity (particularly fertility) in poor years and compensate for this loss by improved productivity in the above average years. Such alternatives can readily be investigated by the appropriate specification of experiments with the cattle herd model.

Table 5.5 presents the distribution of milk production at Kweneng over the year during the fifth year of the simulation. The highest monthly production in January is 7.3 times the lowest monthly production in September. Monthly yields show a steady decline from January through June, with an increase in July when the cows graze on maize stover. The milking decision rule specified for this simulation limits milk offtake to 50 percent of the production in any month, but this

maximum offtake is achieved only in January when all lactating cows are milked. More than 40 percent of the milk is extracted every month from December through May. The proportion extracted is lowest in September when 23.9 percent is taken. The monthly milk offtake is more variable over the year than the total monthly milk production. The minimum offtake is 789 litres in September and the maximum is 12 067 litres in January, giving a maximum to minimum ratio of 15.3 : 1. An economic appraisal of milking without feed supplementation is presented in Section 6.2.2.

Table 5.5. Milk production at Kweneng cattle post in the fifth year after introduction of milking without supplementation.

Month	Milk production (kg)			Saleable/total
	Calves	Saleable	Total	%
January	12 067	12 067	24 134	50.0
February	10 895	10 480	21 375	49.0
March	10 512	9 947	20 459	48.6
April	9 313	8 572	17 885	47.9
May	8 584	6 460	15 044	42.9
June	6 600	2 780	9 380	29.6
July	7 859	4 999	12 858	38.9
August	2 763	1 033	3 796	27.2
September	2 517	789	3 306	23.9
October	3 119	1 474	4 593	32.1
November	3 946	1 860	5 806	32.0
December	12 282	10 137	22 419	45.2
Total	90 457	70 598	161 055	
Minimum	2 517	789	3 306	23.9
Maximum	12 282	12 067	24 134	50.0

Column 3 of Table 5.4 presents a summary of herd performance when the same milking decision rule is applied, but all cows milked are provided with one kilogramme of a proprietary feed supplement daily. While the system is not in

equilibrium after five years, the output from the model indicates that the equilibrium level of production under this strategy will be closer to the baseline situation than when the milking cows are not given a supplement. In practical terms, this means that the adoption of milking with supplementation on a cattle post will not affect the herd as markedly as when the cows are not given a supplement.

With milking and supplementary feeding and the same culling policy, the number of cows in the herd after five years increases from 427 to 435. The numbers of steers and surplus heifers are also only slightly different from the baseline situation. The calving percentage increases from 56 percent to 60 percent, but calf survival is lower than the baseline because of relative milk deprivation. Only 182 calves are weaned in the fifth year (262 are born) versus 198 weaned (240 born) in the baseline situation. Lower calf survival to weaning is accompanied by a lower average weaning weight of 153 kg in the fifth year, down from the baseline of 170 kg. The effect of the poorer maternal environment is still evident in the three-year-old cows which are 19 kg, or six percent, lighter than their counterparts under baseline conditions. The higher average weaning weights when supplementation is given with milking will ensure higher calf survival during poor forage years than when the cows are not supplemented.

Total dry matter consumption by the herd decreases by seven percent, from 1 800 tonnes to 1 671 tonnes, while the total liveweight sales decrease by almost 15 percent, from 73.8 tonnes to 62.9 tonnes. Again as with milking without supplementary feeding, the reduction in liveweight sales is due almost exclusively to the reduced number and weights of the steers and surplus heifers. Cull cow weights remain almost unaltered.

The provision of a feed supplement to lactating cows increases the total milk yield to 224 833 litres, of which 57 percent is used by the calves. This represents an average annual yield of 517 litres for each cow in the herd, or 858 litres for each cow calving during the year. Assuming that cows are milked for approximately 150 days and that about 50 percent of the cows are in milk at any time for a 60 percent calving and 42 percent weaning ratio, then giving each milking cow one kilogramme of supplement per day requires about 32.6 tonnes of supplement

for the 435-cow herd.

Table 5.6 presents the distribution of milk supplies throughout the year when milking cows are supplemented. At the peak of the season, in January, the total milk produced is 4.6 times the minimum monthly production occurring in October. The yield of extracted milk is more variable across the year, with the peak offtake in January 12.6 times the lowest offtake in September. More than 45 percent of the milk is extracted for each of the six months from December through May and also in July. Only 13 percent of the milk produced in September is extracted. Dividing the dry matter plus feed supplement consumed by liveweight sales plus milk extracted converted to its liveweight equivalent gives this strategy a revised index of biological efficiency of 23.16. This compares favourably with the baseline value for this index of 24.39.

5.2.5 Impact of Late Rains. Considerable variability occurs at the herd level in both forage and animal productivity in Botswana. For this reason, many of the possible developments in cattle production cannot be investigated under controlled experimental conditions without using large-scale trials to ensure statistically reliable results. Such trials are expensive as they would need to be replicated over time to ensure that the conclusions are not conditional upon particular environmental circumstances. Environmental variability is an important consideration as producers will hesitate to adopt a new technology or management practice if it does not have a clear advantage over their current practice, particularly in poorer production years. Furthermore, when an intervention is considered likely to have a substantial effect on the system, it may be necessary to follow its impact over a number of years to avoid drawing conclusions based only on short-run gains, as undesirable consequences may occur in the longer term. Properly specified simulation experiments with a validated model can overcome these particular difficulties. As many different environmental sequences as necessary can be specified, and the model can run for sufficient simulated time to make clear the long-term changes

Table 5.6. Milk production at Kweneng cattle post in the fifth year after introduction of milking with supplementation.

Month	Milk production (kg)			Saleable/total
	Calves	Saleable	Total	%
January	13 572	13 572	27 144	50.0
February	12 789	12 734	25 523	49.9
March	13 345	12 629	25 974	48.6
April	13 203	11 698	24 901	47.0
May	11 981	10 410	22 391	46.5
June	12 012	6 164	18 176	33.9
July	12 192	10 260	22 452	45.7
August	10 419	1 992	12 411	16.1
September	6 935	1 081	8 016	13.5
October	4 071	1 814	5 885	30.8
November	4 784	2 194	6 978	31.4
December	13 714	11 268	24 982	45.1
Total	129 017	95 816	224 833	
Minimum	4 071	1 081	5 885	13.5
Maximum	13 714	13 572	27 144	50.0

caused by any intervention.[6]

This section illustrates the impact on herd performance of variables out of management control, using a change in the forage regime as an example. The onset of the annual wet season is assumed to be delayed by two months, reducing the length of the growing season by the same period.[7] The runs are conducted with the model for Serule cattle post.

Table 5.7 gives the assumed monthly crude protein, digestibility and availability values for the forage in a year with a late growing season. The model is run for five years of simulated time (referred to here as Year 1 to Year 5) and gives outcomes on a calendar-year basis. The first 10 months of Year 1 have standard forage values. The rains at the end of Year 1 are late, with the forage values specified accordingly, and a late onset of the rains is specified again at the end of Year 2.

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6. The present model is deterministic but it can be modified to a stochastic mode by specification of distributions for key parameters which are variable in the real system. An example of such a parameter is the quality of forage on offer each month. In the stochastic mode the model would produce distributions of outcomes through simulated time as repeated runs are made with the same initial conditions and randomly selected values of the stochastic variables. The deterministic formulation of the model is used in this report as the objective is to illustrate the modelling methodology rather than to provide operational answers to research questions.

   Interpretation of output from a stochastic model is more difficult. Furthermore, where, say, 50 repeats of each particular intervention are necessary, the cost of operating a stochastic model is much greater. A composite approach is therefore often advantageous. The deterministic model is first used to identify promising interventions, and then this subset of interventions is investigated using the model in a stochastic mode.

7. The impact of drought would be specified by a much more severe reduction in forage supply and quality.

Table 5.7. Forage parameters for average and late seasons at Serule cattle post.

Month	DM availability kg/head/day		Crude protein percentage		Digestibility percentage	
	Average season	Late season	Average season	Late season	Average season	Late season
January	12.6	11.8	7.0	6.0	60	55
February	10.8	10.8	7.5	7.5	57	57
March	10.5	10.5	7.0	7.0	55	55
April	10.1	10.1	6.0	6.0	52	52
May	9.6	9.6	5.7	5.7	51	51
June	7.6	7.6	4.8	4.8	42	42
July	7.5	7.5	4.0	4.0	38	38
August	5.5	5.5	3.8	3.8	38	38
September	6.2	6.2	3.8	3.8	35	35
October	6.0	6.0	3.5	3.5	35	35
November	6.1	6.0	3.8	3.5	38	35
December	11.8	6.1	6.0	3.8	55	38

The forage seasons starting at the end of Years 3 and 4 are normal, as is the season beginning just before the end of the run in the fifth year simulated. This phasing of normal and late forage seasons is presented schematically in Figure 5.1, and the results of the run are summarized in Table 5.8. Columns 1, 2 and 3 are from the first, third and fifth years of the simulation respectively.

After two late wet seasons, average mature cow weight drop from 420 to 403 kg, and average three-year-old cow weight from 344 to 310 kg. Cow numbers remain relatively constant through the third year of the simulation as cow mortality is little affected and recruits to the cow herd are born before the two relatively deficient years. By the third year, the number of calves born increases slightly from 219 to 230, and calvings are more concentrated in the earlier half of the year.

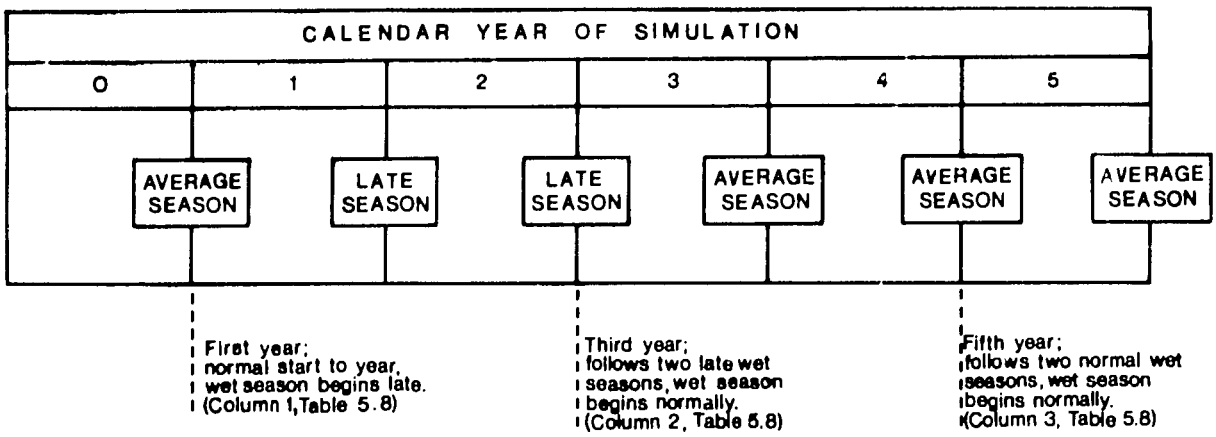

Figure 5.1. Phasing of normal and late forage seasons in Kweneng cattle post simulation.

Only 151 calves are weaned during the third year, or 76 percent of the number weaned in the first. In the third year a higher fraction of calves die in the first month after birth, releasing more cows from the stress of suckling their calves for the full 10-month period. The subsequent improved capacity to re-breed is reflected in the increased numbers of calves born in the second recovery year (Year 5).

After two normal seasons the reproductive capacity of the herd is largely restored, with the numbers of calves born and calves weaned in Year 5 approximating those of Year 1. However, the effects of the two poorer forage years are not eliminated from the system, as the total liveweight sales in Years 3 and 5 are considerably below the level of Year 1. These sales are strongly affected by the lower average sale weight of steers born and raised during the period of below average forage conditions. Similarly, the average weight of young cows is still well below the level of Year 1. By the second recovery year (Year 5), cull cow sales account for 32 percent of total liveweight sales, compared with only 22 percent in Year 1.

Table 5.8. Impact of late rains at Serule cattle post.

Production parameter (per annum)	Calendar year of simulation[a]		
	1 (Baseline)	3 (After 2 late seasons)	5 (After 2 av. seasons)
Total dry matter consumed (tonnes)	1 800	1 577	1 607
Animal numbers as of mid-May			
Cows	397	392	389
Heifers	149	143	146
Steers	150	144	148
Calves			
Number born	219	230	208
Number weaned	199	151	195
Calving percentage	55	59	54
Weaning percentage	50	39	50
Average weaning weight (kg)	178	132	173
Average cow weight in mid-May			
3-year-old	344	310	294
7-year-old	420	403	414
Total liveweight sales (tonnes)	77.0	68.0	54.6
Composition of sales			
Percentage cows	22.1	22.6	31.9
Percentage heifers	21.5	21.5	18.3
Percentage steers	56.5	55.9	49.8
Production indices			
Kg dry matter/kg liveweight sold	23.38	23.09	29.48
Total liveweight sold/cow (kg)	194	174	140
Liveweight of progeny sold/cow (kg)	151	135	96

a. See Figure 5.1.

These results show that even modest changes in the forage supply have important lagged effects, even when followed immediately by two normal years. The impact of this modified forage regime will still be evident in the performance of the system several years later. Furthermore, the changes in the forage regime

specified for these runs are modest compared with the changes which do occur from year to year in Botswana. At present the model does not allow for tactical responses to such factors as the impact of disease, different environmental circumstances or the condition of the herd in relation to the forage supply. For example, to examine the impact of a drought on the herd it will be necessary to include a decision module to simulate the actions of producers when confronted with such a situation. Such a decision module could be incorporated into the model to take account of the herd status in absolute terms and in relation to environmental circumstances.

6. ECONOMIC INTERPRETATION OF SIMULATED RESULTS

6.1 Background

Chapter 5 presents some examples of the simulation runs conducted with the model, focussing on the biological responses of the system to changes in the production environment. Several of the interventions produce biologically favourable responses, but it does not necessarily follow that the interventions are favourable from an economic point of view.

A partial economic analysis is now made of two of the sets of interventions discussed in chapter 5 from the viewpoint of the individual producer. No attempt is made to aggregate the results to the regional or national level, although from a policy standpoint such analyses are essential for the appraisal of these interventions. The objective here is to demonstrate the utility of simulation models and the results they can produce in addressing development questions at the level of the individual herd. The major objective of the workshop was to introduce the basic principles of computer-based simulation modelling to researchers working mainly in the biological and technical sciences. Such professionals are best acquainted with the analyses of systems under assumed steady-state conditions, and their research is usually focussed on processes within systems rather than upon major sub-systems or whole systems. Thus it was considered appropriate that the results discussed at the workshop be presented in the form most familiar to these workers. For this reason two of the interventions presented in chapter 5 are compared on the basis of their equilibrium or steady-state performance.

Comprehensive economic analyses of development at the herd level ideally include the time flows of benefits and costs associated with the development under consideration. The analysis presented in section 6.2.1 assumes that equilibrium conditions apply, while section 6.2.2 introduces some aspects of the time flows following from the introduction of an intervention.

The two sets of interventions appraised here are the introduction of leucaena as a dry season forage plant (cf. section 5.4) and the introduction of milking to a herd of indigenous Tswana cattle (cf. section 5.5). Both these sets of

interventions are predicted to have a strong impact on the biological performance of the herd.

6.2 Economic Evaluation of the Interventions

6.2.1 Introduction of a Dry-Season Forage Plant. The introduction of leucaena as a special purpose dry-season forage plant raises the productivity of ranch-managed herds at Lesego-Impala. Of the two management regimes specified, feeding leucaena to all animals results in higher cow weights, calving percentages, total liveweight sales and biological efficiency than providing it to pregnant and lactating cows only. However, it must be kept in mind that numerous alternative management regimes could be specified for the use of leucaena and neither of the above two regimes specified here is certain to achieve the maximum biological efficiency.

Both leucaena feeding strategies increase meat sales from the ranch. At a price of 0.70 pula per kg cold dressed weight (CDW) and assuming a 50 percent dressing out percentage, the ranch yields total sales of 28 700 pula for 82 000 kg liveweight without the special purpose forage (cf. Table 5.5).[8] Providing the forage to all animals increases total liveweight sales by 6 600 kg per year and farm revenue by 2 310 pula. Supplementing only pregnant and/or lactating cows, a more restrictive feeding strategy, raises revenue by 1 435 pula for the extra 4 100 kg liveweight sold. The grade of meat sold is assumed to be the same in all cases. However, extra annual costs are incurred if leucaena is used. Since the area must be well fenced, a fence maintenance cost must be included. Maintenance of the leucaena is also necessary. The annual fence maintenance cost is estimated to be 10 percent of the capital cost of the fencing, while maintenance of the leucaena is costed in the budgets at 10 pula per hectare per year.

Based on experience elsewhere in the world, the annual yield of leucaena under Botswana conditions can be expected to range from two to eight tonnes of d --

8. All calculations assume meat prices constant across years and months within years and across all classes of cattle.

matter (DM) per hectare, with the most likely average yield in the region of five tonnes. Under favourable conditions, the cost of establishment for nursery propagation might be as low as 120 pula per hectare, but if the plant proves more difficult to establish the cost per hectare may be as high as 260 pula.[9] Table 6.1 gives a breakdown of these estimated costs. At this time, researchers in Botswana consider that the plant will be difficult to establish and, therefore, that the cost of establishing it will likely be high. Propagation from a nursery is budgeted, as seed germination is expected to be poor even in prepared seed beds.

Table 6.1. Estimated costs of establishing leucaena on cleared ranch-land in Botswana.

Input	Lower limit pula/ha	Upper limit pula/ha
Land preparation	20	50
Fertilizer		30
Young plants (nursery charge)[a]		
Nursery preparation	5	5
Seeds, plastic bags, soil	20	60
Labour	30	60
Water	5	5
Planting cost	25	50
TOTAL	120	260

a. Although establishment from seeds is possible, more successful establishment will follow if young plants are propagated in a nursery.

The internal rate of return (IRR) is commonly used to evaluate the economic merit of development alternatives.[10] The IRR is the discount rate which makes the present value of a stream of benefits equal to that of the costs.

9. 1 pula = approximately US $1.20.

10. For the evaluation of mutually exclusive development alternatives to be financed from a given budget the use of present values is formally the correct method. Since in this case no budget optimization is necessary this complication can be neglected.

Six assumptions are common to all the following IRR calculations:-

a. Leucaena is an incremental investment. The revenues and costs which apply on the ranch before the leucaena is introduced are unaltered by its introduction. The opportunity cost of the land used for growing the leucaena is zero, as the area of land used for it is a trivial fraction of the entire ranch.

b. The investment has a life of 10 years and has zero salvage value (Year 1 is defined as the first development year).

c. All costs and revenues occur at the end of the year. For example, the investment in fences and plant establishment is charged as if it is made at the end of Year 1 and is discounted accordingly.

d. The capital expenditure on fencing and plant establishment is made in Year 1.

e. The fence and plant maintenance costs begin in Year 2 and continue at the same level until Year 10.

f. The leucaena is first grazed in Year 3. The full benefit of grazing is achieved in that year and all subsequent years.

For purposes of illustration, Table 6.2 presents the data necessary for calculating the internal rate of return for an incremental investment in leucaena if it is fed to the whole herd, if the annual dry matter yield is 6 tonnes per hectare, and if the establishment cost per hectare is 120 pula. The leucaena is used for 1 902 grazing months, with each animal consuming 3 kg of leucaena dry matter per day. Thus the area of leucaena must be sufficient to produce 171 tonnes of dry matter per year. Assuming an annual yield of 6 tonnes per hectare, this area will be 28.53 hectares. The total capital costs of fencing and plant establishment given in Table 6.2 are calculated on the basis of this area. This feeding strategy produces an incremental revenue of 2 310 pula annually from the third year onwards. Both fence and plant maintenance are charged from the second year onwards. The last line of the table gives the incremental net revenue flows for each of the ten years.

For this feeding strategy and yield and investment cost, the incremental investment in leucaena yields an annual IRR of 17.9 percent.

Table 6.2. Data for calculation of internal rate of return for investment in feeding leucaena to whole herd (6 tonnes DM/ha/year, establishment cost 120 pula/ha).

	Development year			
	1	2	3	4-10
Incremental revenue[a]	0	0	2310	2310
Incremental costs				
Capital items				
Fencing[b]	1712	0	0	0
Leucaena establishment	3424	0	0	0
Annual maintenance				
Fencing[c]	0	171	171	171
Leucaena[d]	0	285	285	285
Incremental net revenue flows	-5136	-456	+1854	+1854

a. 6 600 kg liveweight at 0.35 pula/kg liveweight.

b. For this feeding strategy 1 902 grazing months are required. At 3 kg per head per day this is equivalent to 171.18 tonnes of DM. Dividing this quantity by the yield of 6 tonnes per hectare gives an area required of 28.52 hectares. This requires 2.14 km of fencing costing 800 pula per km.

c. Annual fence maintenance cost is 10 percent of the capital cost.

d. At 10 pula per hectare per year.

Table 6.3 gives the IRRs calculated for the likely range of annual DM yields (two to eight tonnes per hectare) and establishment costs (120 pula to 300 pula per hectare) for the two strategies of feeding leucaena to the whole herd and to pregnant and lactating cows only. The calculations for the more restrictive feeding strategy are based upon leucaena providing 621 livestock grazing months annually at 3 kg of DM per head per day. (The herd sizes and composition differ for the two feeding

strategies, cf. Section 5.2.3.).

Table 6.3. Internal rates of return for investment in leucaena for various yields and establishment costs for the two feeding strategies.

	Establishment cost (pula/ha)				
	120	150	200	260	300
Feeding to whole herd (1 902 grazing months p.a.)					
2 tonnes/ha/yr	neg.[a]	neg.	neg.	neg.	neg.
4 tonnes/ha/yr	9.1	6.3	2.7	neg.	neg.
6 tonnes/ha/yr	17.9	14.9	10.9	7.3	5.3
8 tonnes/ha/yr	24.3	21.1	16.9	13.0	10.9
Feeding to pregnant and lactating cows (621 grazing months p.a.)					
2 tonnes/ha/yr	6.0	3.6	0.3	neg.	neg.
4 tonnes/ha/yr	20.5	17.7	14.0	10.5	8.6
6 tonnes/ha/yr	29.4	26.4	22.4	18.6	16.5
8 tonnes/ha/yr	35.8	32.8	28.7	24.7	22.5

a. This indicates a negative internal rate of return.

As shown in Table 6.3, if leucaena is fed to the whole herd each year and the dry matter yield is two tonnes per hectare per year, the internal rate of return is negative over the range of investment costs considered. At a yield of four tonnes the IRR is about nine percent at the lowest establishment cost considered of 120 pula per hectare, but is negative if the establishment cost is higher than about 260 pula per hectare. Under the most favourable, but unlikely, circumstances of an annual yield of eight tonnes of DM per hectare and establishment cost of only 120 pula, the IRR is 24 percent. If an establishment cost of 200 pula per hectare applies and the opportunity cost of money in Botswana is in the region of 10 percent per year, then a sustained annual yield of more than six tonnes per hectare is necessary for this investment to be economic.

If only pregnant and/or lactating cows are fed with leucaena the internal rates of return are more favourable. For example, at an establishment cost of 260 pula per hectare and a four tonne yield, the IRR is about 10 percent. For these same cost and yield conditions the IRR is negative if the leucaena is fed to the whole herd. Under the most favourable circumstances of a 120 pula establishment cost and an annual yield of eight tonnes of DM per hectare, the IRR for the restrictive feeding strategy is 36 percent, an increase of about 12 percent over the IRR for the whole-herd feeding strategy under the same conditions.

The willingness of producers to undertake forage development by introducing leucaena will depend upon both the internal rate of return (which must be greater than the opportunity cost of money) and the availability of investment funds. For this reason it is appropriate to estimate the total investment costs for the various yield and establishment cost combinations for the two feeding strategies. These are given in Table 6.4 for those combinations which yield a positive IRR.

Table 6.4. Capital inputs for leucaena development given various yields and establishment costs and the two feeding strategies.[a]

DM yield	Establishment cost (pula/ha)				
	120	150	200	260	300
Feeding to whole herd					
4 tonnes/ha/yr	7 870	9 154	11 294	n.c.[b]	n.c.[b]
6 tonnes/ha/yr	5 592	6 448	7 872	9 586	10 727
8 tonnes/ha/yr	4 410	5 052	6 122	7 406	8 262
Feeding to pregnant and lactating cows					
2 tonnes/ha/yr	5 491	6 330	7 727	n.c.	n.c.
4 tonnes/ha/yr	3 136	3 556	4 254	5 092	5 651
6 tonnes/ha/yr	2 285	2 565	3 031	3 590	3 963
8 tonnes/ha/yr	1 842	2 052	2 401	2 820	3 100

a. Investment in first year plus working capital for fence and maintenance in the second year.

b. Not calculated if the IRR is negative.

Leucaena is a deep rooted plant and its yield losses in below-average rainfall years will be less than for other pasture species. Thus, over several years the internal rate of return calculations presented here will tend to underestimate its average contribution. The simulation model can be specified to examine the incremental benefit due to this differential performance in dry years. This benefit will depend, of course, upon the relative frequencies of years with above-average and below-average rainfall.

The calculations in this section illustrate a method of evaluating the economic desirability of introducing leucaena to livestock production units when only limited cost and productivity data are available. These preliminary results suggest that additional simulation runs should be made to investigate the contribution of leucaena to both ranch and cattle post systems in Botswana. Also it would be desirable to augment these computer-based studies by field trials directed toward the determination of yield and establishment cost.

6.2.2 Milking Indigenous Cows. The summary of the simulation runs to examine two alternative milking strategies in the Kweneng cattle post area is presented in section 5.5. That discussion indicates that substantial quantities of milk can be extracted from a cattle post herd when cows are milked both with and without supplementary feeding. This section discusses the economic merit of milking without supplementary feeding.

Farmers in this part of Botswana receive a farm-gate price for milk of approximately 0.15 pula per litre, with on-farm milking costs of 0.05 pula per litre, giving a net price of 0.10 pula per litre. Although the price varies through the year, rising in the dry winter months, an average price of 0.10 pula per litre is used here, as the objective is to illustrate the method of economic analysis rather than to be prescriptive. When cows are milked without supplementation, the producer does not need to purchase any additional inputs other than those already accounted for in the net price assumed above.

It was indicated in section 5.2.4 that five years of milking is not a sufficient time for the impact of milking to be fully expressed in the system's performance.

In the fifth year the herd is still in transition from one equilibrium state to another. The interest here is in the economic evaluation of the milking intervention from the viewpoint of the individual producer. The changes in herd performance over time following from the introduction of an intervention are important in such an evaluation, as economic gains or losses can result in the short or long term. The phasing of these gains and losses is a key determinant of the attractiveness to the producer of an intervention. If the herd performance is simulated for a short time, say five years, and the equilibrium status is significantly different from the initial conditions, these conditions will influence the outcome. The influence diminishes as longer-run simulations are made. This parallels the performance of the real systems being modelled where the status of the herd at any time can only be related confidently to immediately prior events. Different initial conditions will thus produce different time paths of variables as the status of the simulated herd moves toward the equilibrium state. The initial conditions used for the simulation run of the milking strategy are the baseline values for the herd at Kweneng cattle post when no milking is carried out.

Defining Year 0 of the simulation as the last year before milking is introduced, the model then simulates performance for five years, defined as Years 1 to 5. Table 6.5 gives the livestock and milk sales from the herd for the five-year period. Assuming a meat price to the producer of 0.70 pula CDW (equivalent to 0.35 pula per kg liveweight for a 50 percent dressing out ratio), livestock sales in Year 0 total 25 832 pula. When milking is introduced, livestock sales increase to 26 782 pula in Year 1, and then fall to 18 437 pula by Year 5. Correspondingly, milk sales (total production less consumption by calves) are valued at 7 662 pula in Year 1, falling to 7 060 pula by Year 5. If milking is not introduced, the Year 0 (steady-state) income of 25 832 pula will continue to be received. By Year 4 of the milking regime without supplementation the combined revenue from livestock and milk sales is below the baseline value. The major cause of the reduction that year is the lower average weights of the livestock sold. This reflects the lower weight gains made by calves raised in Year 1 when milking is introduced, as calves born in that year are sold in Year 4. Table 6.5 also gives the total dry matter consumed by the herd through simulated time. It falls to 1 500 tonnes in Year 5 from 1 800 tonnes in Year 0. Thus the effective stocking rate on the cattle

post is reduced by one sixth after five years of milking (calculated as: (1800 - 1500)/1800). Herd consumption of dry matter increases in Year 1 to 1 826 tonnes because calves are deprived of milk and they compensate by consuming relatively more forage than if the full milk supply were made available to them.

Table 6.5. Livestock and milk sales on Kweneng cattle post through five years of milking without supplementation.

Year simulated	Total DM consumed (tonnes)	Livestock sales		Milk sales[b]		Total output (pula[d])
		kg lwt	pula[a]	kg	pula[c]	
0	1 800	73 805	25 832	-	-	25 832
1	1 826	76 520	26 782	76 616	7 662	34 444
2	1 716	75 674	26 486	74 048	7 405	33 891
3	1 590	67 448	23 607	74 490	7 449	31 056
4	1 527	51 629	18 070	73 929	7 393	25 463
5	1 500	52 676	18 437	70 598	7 060	25 497

a. At 0.35 pula per kg liveweight = 0.70 pula per kg CDW.

b. Total milk produced minus milk to calves.

c. At 0.10 pula per kg.

d. Value of livestock plus milk sales.

While Table 6.5 indicates that an increase in income is achieved in the first three years of milking, this is obtained at some expense in terms of the value of the livestock (herd) capital used in production. Table 6.6 summarizes the weights and values of the various age classes in the herd before and after five years of milking. Excluding calves less than one year old, the herd biomass (calculated at the end of December) decreases from 222.7 tonnes before milking is introduced to 185.4 tonnes at the end of Year 5. Assuming the market values of livestock are based upon their liveweight, at a price of 0.35 pula per kg liveweight the total value of the herd decreases over the five-year period by over 16 percent from 77 958 pula to 64 887 pula. While the weights of mature cows are not markedly different at these two times, the weights, and therefore the market values, of young females in

the breeding herd and steers and surplus heifers are substantially reduced. Together, the inventories of two- and three-year-old females decline in value from 9 740 pula to 8 796 pula over the five-year period, a drop of almost 10 percent. The value of the steers and excess heifers together drops by 45 percent from 25 360 pula to 13 869 pula. While there is some reduction in the numbers of animals in these two classes, most of the fall in the value of the inventory is attributable to the lower average weights.

Table 6.6 Livestock numbers and values in December at Kweneng cattle post.

(a) Baseline, no milking or supplementation

Livestock class	Number in herd	Av. wt per head (kg)	Total wt. of class (kg)	Total value of class (pula[a])
Breeding females				
2 yrs	54	244	13 176	4 612
3 yrs	50	293	14 650	5 128
4-8 yrs	232	366	84 912	29 719
9-11 yrs	97	387	37 539	13 139
Others				
Steers	197	274	53 978	18 892
Surplus heifers	88	210	18 480	6 468
Total	718		222 735	77 958

(b) After five years of milking (starting from baseline), no supplementation

Livestock class	Number in herd	Av. wt per head (kg)	Total wt. of class (kg)	Total value of class (pula[a])
Breeding females				
2 yrs	52	204	10 608	3 713
3 yrs	53	274	14 522	5 083
4-8 yrs	234	358	83 772	29 320
9-11 yrs	96	384	36 864	12 902
Others				
Steers	171	171	29 241	10 234
Surplus heifers	67	155	10 385	3 635
Total	673		185 392	64 887

a. At 0.35 pula per kg liveweight.

The results suggest that cattle post owners can initiate milking in their herds and secure short-term gains. Over the first three years of milking total income is increased by almost 21 900 pula. However one danger of adopting this strategy is that poor forage years may mask the longer-term deleterious effect of milking on the herd and encourage its continuation. The breeder may then incorrectly attribute the poor performance of his herd to the poor forage years and not to the effects of milking, and thus fail to maximize the long-run productivity of his herd. Continuing milking beyond five years is expected to further reduce the capital value of the herd and the annual income from livestock and milk sales. Cows are milked only if the milking calf still gains at least 300 grams per day. Raising the required minimum gain will reduce the quantity of milk available for sale but will also substantially reduce the negative impact of milking on the herd in terms of animal weights and reproductive performance. A series of simulation experiments to investigate these dual-purpose production possibilities is warranted as the question is of importance in Botswana and it is unlikely that observation of existing field systems will cover the entire range of feasible management strategies.

7. UTILIZATION OF MODELLING IN BOTSWANA

7.1 Introduction

Chapter 5 presents a summary of the results of the initial applications of the TAMU beef cattle production model to livestock research and development problems in Botswana. The applications were designed to demonstrate the types of questions which can be addressed by a validated time-dynamic simulation model. Principal objectives of the workshop were to introduce modelling techniques to researchers in Botswana, determine further applications of the TAMU model, and identify livestock production problems where the application of modelling techniques would assist research and development activities in the country. Four groups of applications were defined:-

a. applications which can be made by the present model and do not require collection of additional field data,

b. applications which can be made by the present model but require collection of additional field data,

c. applications which can be made after some additions to the present model and which require additional field data, and

d. applications which cannot be made with the present model (in some cases requiring completely different models) and also those which require substantially different data from those collected at present by agencies in the country.

7.2 Applications

7.2.1 Applications with the Existing Model and Data. Five sets of interventions are presented in chapter 5, and four of these are illustrative of the types of management changes which can be introduced on ranches and cattle posts. The simulations of these four sets of changes were not designed to produce final answers to the topics they addressed. Rather they were expected to provide the basis for designing subsequent runs with the model. It would have been possible

initially to simulate many more runs in each of these sets but, as with real-world experimentation, the examination of a system's performance for each additional variable incurs extra costs. It is usually more cost-efficient to conduct runs with the model in a stepwise manner, with the results from each set of runs used to identify subsequent simulations. The specifications for a second series of runs requiring no additional field data are as follows:-

a. Alternative weaning ages. The preliminary runs made to examine the ranch performance under different weaning regimes indicated that a change from seven-month to five-month weaning may be warranted as it improves reproductive performance (Section 5.2.1). In this situation, post-weaning supplementation given to calves during the dry season, and particularly in drier than average years, could be advantageous. The series of five runs shown in Table 7.1 addresses this question. All parameters not included in the table are set at the values used in the baseline validation run.

Table 7.1. Specification of a second series of simulations to examine the impact of alternative weaning ages at Matiatilodi-Matlolakgang ranch.

Run number	Run specification		
	Weaner age (months)	NPN supplementation to weaner calves, August to end November	Year sequence[a]
1	5	No	5 years; 1 dry, 4 normal
2	7	No	5 years; 1 dry, 4 normal
3	9	No	5 years; 1 dry, 4 normal
4	5	Yes	5 years; all normal
5	5	Yes	5 years; 1 dry 4 normal

a. All runs to begin with the same baseline conditions.

b. Three innovations on traditional cattle posts. The first series of runs made for the Kweneng cattle post suggested that a more realistic baseline run would result if, in the model, heifers were bred according to their physiological

condition instead of restricting breeding to only those heifers older than 27 months (Section 5.2.2). Two other runs will be compared with this new baseline. One run is identical to the baseline except that a three-month breeding season from March to May is adopted, giving cows a longer period to recover breeding condition.

The correct phasing of management changes appears crucial to successful development on cattle posts. The second run specifies the following sequence of innovations: pasture is reserved for weaners from July to the end of October each year; an initial six-month breeding season (November to April) is introduced, reduced by one month every two years to a three-month season (January to March) from the seventh year onwards; heifer breeding at the weight of 272 kg (600 lbs) is introduced in the fifth year; and the forage quality of the pasture outside the weaning paddock is improved to the level of a ranch (at a compound rate) by the tenth year. The simulation is run for 15 years.

c. Introduction of a dry-season forage plant. Supplementation of pregnant and lactating cows with leucaena during the dry season was predicted in the first series of runs to improve performance at Lesego-Impala ranch (Section 5.2.3). The specifications of four follow-up runs are summarized in Table 7.2.

Table 7.2. Specification of a second series of simulations to examine the impact of introducing leucaena at Lesego-Impala ranch.

Run number	Run specification		
	Leucaena supplementation	Year sequence	Cows mated in second dry year
1	No	10 years: 2 dry, 8 normal	Yes
2	No	10 years: 2 dry, 8 normal	No
3	Yes	10 years: 1 dry, 9 normal	Yes
4	Yes	10 years: 2 dry, 8 normal	Yes

d. Milking of indigenous cows. Preliminary runs with the model (Section 5.2.4) suggested that short-term gains can result from milking but, in the longer term, it may be disadvantageous because of adverse effects on reproductive performance, calf survival and capacity of the herd to withstand drought. The specifications of additional runs are given in Table 7.3.

Table 7.3. Specification of a second series of simulations to examine the effect of milking Tswana cows at Kweneng cattle post and Masiatilodi-Matlolkgang ranch.

Run number	Run specification			
	Location	Minimum calf liveweight gain (gm/day)	Milking cows supplemented (1 kg/day)	Year sequence
1	Cattle post	300	No	10 yrs: all normal
2	Cattle post	450	No	10 yrs: all normal
3	Cattle post	300	Yes	10 yrs: all normal
4	Cattle post	300	No	10 yrs: 1 dry, 9 normal
5	Cattle post	450	No	10 yrs: 1 dry, 9 normal
6	Cattle post	450	Yes	10 yrs: 1 dry, 9 normal
7	Cattle post	300	No	10 yrs: 2 dry, 8 normal
8	Cattle post	450	No	10 yrs: 2 dry, 8 normal
9	Cattle post	450	Yes	10 yrs: 2 dry, 8 normal
10	Ranch	450	No	10 yrs: all normal
11	Ranch	450	Yes	10 yrs: all normal
12	Ranch	600	Yes	10 yrs: all normal
13	Ranch	450	No	10 yrs: 1 dry, 9 normal
14	Ranch	450	Yes	10 yrs: 1 dry, 9 normal
15	Ranch	600	Yes	10 yrs: 1 dry, 9 normal
16	Ranch	450	No	10 yrs: 2 dry, 8 normal
17	Ranch	450	Yes	10 yrs: 2 dry, 8 normal
18	Ranch	600	Yes	10 yrs: 2 dry, 8 normal

7.2.2 Applications with the existing model and additional data. The results of the runs with existing data are evaluated principally on the basis of the steady-state attributes of the different systems. This method of evaluation is not concerned with either the initial conditions or the interim values occurring before the steady-state is achieved. However, both the initially conditions and the interim values are critical to the success of any development venture undertaken by individual livestock producers and must be considered when extension recommendations are devised. Thus it would be inappropriate to encourage a producer to adopt a particular regime if in the long run it is not attainable because of almost certain financial failure in the interim. Additional field data need to be collected in Botswana before the existing model can be used as an aid to formulating extension recommendations.

Cattle post development is a priority activity of government but the development options on cattle posts are more complex and less is known about animal performance than on ranches. This favours the use of modelling to screen alternatives more rapidly and at less expense than through survey or field experimentation procedures. However, additional field information is required to model cattle post development efficiently. First the population of cattle posts has to be classified on the basis of criteria such as herd size, proportion of adult females in the herd, available range resources, etc. Surveys to obtain these data would allow the classes of cattle posts to be ranked in priority for study. This would avoid the application of the model to cattle post situations which are either atypical or of low priority for development. Evaluation of feasible development strategies for these classes of cattle posts would then follow.

7.2.3 Applications with additions to the model and to the data. The consequences of management decisions taken by producers in Botswana are uncertain, mainly due to variability in the quantity and quality of the forage supply. The present model simulates herd performance based upon a complex set of biological relationships. The addition of the ability to account for tactical decisions made by producers based upon the relationships between the status of the herd and the production environment would allow even more realistic predictions of herd performance. These predictions would be more appropriate for development planning

as the risks involved in adopting various production strategies would be quantified. Additional data required would cover classification of the production units (Section 7.2.2) and determination of the basic decision rules used by producers.

7.2.4. Applications requiring major changes in the model and the data input. There are important research and development problems in livestock production which cannot be addressed by the current model but which, in principle, are well suited to examination using computer-based simulation techniques. The most important of these are outlined below.

a. Where exogenous forces are important, livestock systems may never reach and maintain an equilibrium state. In this situation a deterministic model cannot produce probabilistic estimates on the future state of the herd, whereas this can be done by an appropriately specified stochastic model. Incorporating stochastic elements into the present model is straightforward. Time series data on the production systems in Botswana are not extensive, but continued collection of particular input-output data, such as are presently recorded by APRU, will permit eventual validation of a stochastic model. The development of such a model should be attempted, as it will, in the longer term, be able to provide more realistic answers to development questions.

b. In the present model there are no feedback loops from animal to forage production, although in practice these have a significant effect on productivity in pasture-based livestock systems, both in the short and long term. Time series data on forage and animal production at the same location are scarce Thus modelling and validating linkages between them will be most difficult. It is likely that an adequate forage model will require at least two man-years to develop and interface with the animal production model.

c. Sheep and goats are important in Botswana. Research to date has focussed on cattle production, but the research effort expended on smallstock is increasing. A model incorporating the most important of the animal-level biological processes could assist in identifying research priorities and making research more efficient. While many of the processes in smallstock production closely parallel those in beef

cattle production, there are sufficient important differences to warrant the separate development of a smallstock model.

d. The present model accounts in only a general way for the effects of disease and parasites on productivity, and mineral nutrition is assumed to be non-limiting. This is not a major limitation for the application of the model to cattle production in Botswana, as mineral deficiencies can be profitably overcome and disease is well controlled through effective veterinary measures. However the inclusion of interactive mineral and disease components in a smallstock model for Botswana would be essential.

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APPENDIX I WORKSHOP PROGRAMME

Monday 13th March		
9.00	Opening of Workshop	Mr. M Sekgoma, Permanent Secretary, Botswana Min. of Agric.
	Response	Cartwright, Texas A&M University
9.40 - 12.30	Overview of collection of range and animal production data and the present status of animal production systems in Botswana	Buck, Light, Rennie, Pratchett, Rose, Montshiwa, Jenness and Addy
2.30 - 3.15	Present animal production systems research programme in Botswana and the gaps remaining	Buck and von Kaufmann
3.30 - 4.30	Systems analysis techniques and their application to beef cattle production	Cartwright
Tuesday 14th March		
8.30 - 10.15	Systems analysis techniques and their application to beef cattle production (continued)	Cartwright and Anderson
10.30 - 12.30	The USDA Meat Animal Research Center as an example of the systems approach	Smith
2.30 - 4.30	The Texas A&M cattle production model	Cartwright and Nelsen
Wednesday 15th March		
8.30 - 12.30	Validation of the Texas A&M cattle model in Botswana	Cartwright and Nelsen
2.30 - 4.30	Results of alternative management strategies examined in traditional and modern animal production systems	Cartwright, Nelsen, Smith and Trail
Thursday 16th March		
8.30 - 12.30	Utilization of modelling results in Botswana	
	(a) Economic interpretations	Rose and von Kaufmann
	(b) Utilization in research planning	Buck and Smith
2.30 - 3.00	Roundup	Addy
3.00 - 4.00	Critique and discussion on possible further utilization of modelling techniques	Discussion

APPENDIX 2 WORKSHOP MEMBERS

NAME	AFFILIATION
B L Addy	Anim. Prod. Division, Min. of Agric.
F M Anderson	ILCA, Nairobi
W Astle	APRU, Min. of Agric.
A A Motlhalawadira	Anim. Prod. Division, Min. of Agric.
J F Barker	University of Botswana and Swaziland
N Buck	APRU, Min. of Agric.
K Bingana	Ministry of Agriculture
K E Butler	Livestock Project Management Unit
T C Cartwright	Texas A&M University
D I Field	Land Utilization Division, Min. of Agric.
I L Fisher	Anim. Prod. Division, Min. of Agric.
R F Frary	Ag. Inf., Min. of Agric.
O J Hansen	APRU, Min. of Agric.
J Jenness	Min. of Finance & Dev. Planning
D B Jones	Ministry of Agriculture
J Kana	Anim. Prod. Division, Min. of Agric.
R von Kaufmann	ILCA, Botswana
J Kendrick	Huntings Technical (Botswana)
R Kenneth	APRU, Min. of Agric.
H B Kgosidintsi	National Development Bank
D Light	APRU, Min. of Agric.
T F Machacha	Anim. Prod. Division, Min. of Agric.
I McDonald	Anim. Prod. Division, Min. of Agric.
L M McNamara	Govt. Computer Bureau
A D Makobo	Anim. Prod. Division, Min. of Agric.
J T Masokwane	Anim. Prod. Division, Min. of Agric.

NAME	AFFILIATION
P K Matzen	Anim. Prod. Division, Min. of Agric.
Y Merafe	Planning and Statistics, Min. of Agric.
L Mhlanga	Anim. Prod. Division, Min. of Agric.
M L Mokone	Planning and Statistics, Min. of Agric.
M Montshiwa	APRU, Min. of Agric.
G L Motseme	Planning and Statistics, Min. of Agric.
Z Mpetsane	National Development Bank
T Nelsen	Texas A&M University
P G Niseane	Rural Sociology, Min. of Agric.
K Oland	Agricultural Research, Min. of Agric.
D Pratchett	APRU, Min. of Agric.
S D Ramahobo	Livestock Project Coordinating Unit
O Ramasia	National Development Bank
T Rennie	APRU, Min. of Agric.
T J Rose	APRU, Min. of Agric.
A J H Rutherford	Botswana Livestock Development Corporation
R M Ryman	Planning and Statistics, Min. of Agric.
M S P Sekgoma	Ministry of Agriculture
G M Smith	US Dept. of Agric.
G Seitshiro	Range Ecology, Min. of Agric.
G Tacheba	APRU, Min. of Agric.
J M Tshelwanew	National Development Bank
J C M Trail	ILCA, Nairobi
T J Willcocks	Agricultural Research, Min. of Agric.

APPENDIX 3. SUMMARY OF BASELINE VALIDATION RUNS

Appendix Table 3.1. Summary of baseline validation runs for the ranches.

Production parameter (per annum)	Ranch location			
	Musi-Dikgatlhong	Masiatilodi-Matlolakgang	Morale	Lesego-Impala
Total dry matter consumed (tonnes)	1 800	1 800	1 800	1 800
Animal numbers as of mid-May				
Cows	232	259	212	313
Heifers	119	107	116	126
Steers	164	105	158	99
Calves				
Number born	177	222	170	211
Number weaned	168	212	161	201
Calving percentage	76	86	80	67
Weaning percentage	72	82	76	64
Average weaning weight (kg)	192	198	193	187
Average cow weight in mid-May (kg)				
3-year-old	412	428	408	362
7-year-old	435	441	445	431
Total liveweight sales (tonnes)	82.5	97.1	81.4	82.0
Composition of sales				
Percentage cows	21.2	20.6	20.4	30.3
Percentage heifers	20.4	22.7	21.1	13.4
Percentage steers	58.4	56.7	58.5	56.3
Production indices				
Kg dry matter/kg liveweight sold	21.82	18.54	22.11	21.96
Total liveweight sold/cow (kg)	356	375	384	262
Liveweight of progeny sold/cow (kg)	280	298	306	183

Appendix Table 3.2. Summary of baseline validation runs for cattle posts.

Production parameter (per annum)	Cattle post location	
	Kweneng	Serule
Total dry matter consumed (tonnes)	1 800	1 800
Animal numbers as of mid-May		
Cows	427	397
Heifers	112	149
Steers	144	150
Calves		
Number born	240	219
Number weaned	198	199
Calving percentage	56	55
Weaning percentage	46	50
Average weaning weight (kg)	170	178
Average cow weight in mid-May (kg)		
3-year-old	319	344
7-year-old	401	420
Total liveweight sales (tonnes)	73.8	77.0
Composition of sales		
Percentage cows	24.5	22.1
Percentage heifers	19.6	21.5
Percentage steers	55.9	56.5
Production indices		
Kg dry matter/kg liveweight sold	23.39	23.38
Total liveweight sold/cow (kg)	173	194
Liveweight of progeny sold/cow (kg)	131	151