A SIMULATION MODEL OF THE CONSEQUENCES OF FEED ALLOCATION DECISIONS IN MIXED-SPECIES LIVESTOCK HOLDINGS (FRAME)

FINAL TECHNICAL REPORT ON PROJECT R5183

Peter Thorne

Livestock Section
Natural Resources Institute

OBJECTIVES, SUMMARY OF ACHIEVEMENTS AND RECOMMENTATIONS

The original objectives of project R5183 were:

To develop a methodology for investigating the relationships between seasonal variation in feed availability and animal responses in multi-species livestock holdings

- To use this methodology to investigate the effects of different feed allocation strategies on productivity and efficiency of feed utilisation within livestock production systems.

The limited supply of feed that is available in varying quantities at different times of the year has been identified as a major constraint to livestock production on the mixed farms of smallholders. R5183 was initiated to develop a tool for evaluating the consequences of different strategies for allocating limited, and seasonally changing, feed resources across mixed-species, livestock holdings. An interactive, simulation model (FRAME) was constructed from standard, quantitative treatments of energy and protein transactions in ruminant livestock. The model uses a simplified input data set - which describes feed quality and availability - to predict the effects of different allocation strategies on cumulative production from individual animals and from the herd as a whole. Specifically, the trade-offs between different productive outputs (meat of different types and milk) and essential functions (maintenance, provision of manure and draught power) that result from the changing priorities attached to different animals within a livestock holding at different times of year may be evaluated.

Full testing of FRAME has not been possible at this stage as this will require data from a related project (R5690) which will describe patterns of feed availability and animal performances in livestock holdings on 32 small farms in the Eastern Hills of Nepal. R5690 will be completed later in 1995. Initial indications from a limited test are that, for periods of up to 5 months, reasonable predictions of patterns of liveweight change may be made by the model. However, its lack of a metabolism component means that predictions for lactating animals in particular are likely to be less reliable. Problems were also experienced in simulating observations of liveweight changes in growing animals but unreliable test data may have been responsible for this. A more thorough test of the model will be made when all data from R5690 become available.

Initial conclusions are that the project has highlighted the shortcomings of feed evaluation and rationing systems derived for use in temperate production systems when applied to the analysis and specification of feeding systems for the tropics. Whilst the current FRAME model might be used for making predictions in relatively intensive systems, its unrestricted use for deriving practical feeding strategies for the smallholder farmer is not recommended. However, the approach taken allows the consequences of feeding decisions to be simulated in a dynamic way that is consistent with farmers' feed availability situations, production objectives and feeding practices. Thus, we believe that the model will provide a useful framework for incorporating future improvements in the evaluation of tropical feeds into practical analyses of optimum feeding strategies for a wide range of situations. It is propsed that a follow-up project should be developed (see para. 47) to allow the initial testing of the model in practical situations where its limitations apply to a lesser extent. This project would also allow the incorporation of the improved rationing system currently under development (R6282) and improved predictions of manure and compost production from project R6238.

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INTRODUCTION

1. Limited availability of livestock feeds compels farmers to make decisions regarding priorities for the allocation of those feeds to the different classes of livestock in their holdings. Their objectives in making these decisions will be, firstly, to ensure that all the essential functions of their livestock may be fulfilled (survival and draught power, for example), and secondly to optimise total outputs from the animals kept. Under these conditions, farmers need to balance the short- and long-term needs of animals with demands for outputs, and the future consequences of feeding decisions. However, their ability to make feed management decisions which will allow them to achieve this may be compromised as the effects of these decisions may not always be immediately apparent. For example, a cow fed at a low level throughout pregnancy may exhibit poor body condition at calving which is associated with low milk production, reduced calf viability and an extended *post-partum* anoestrus period. The situation may be further complicated by the changing extent of nutrient shortages over the year which results from seasonal fluctuations in total plant biomass production, labour availability and the quality of individual feeds.

2.. Clearly, animal performance in smallholders' mixed-species livestock holdings is determined by quite complex, dynamic interactions of farmer, animal and feed management factors. However, current advice to these farmers on feed resource management strategies is usually based on evaluations of short-term responses to nutritional and other interventions and may therefore be less than appropriate for their needs. At present there appears to be little information on, and no appropriate tool for, evaluating the consequences of seasonal changes in feed supply and animal "requirements" for livestock productivity and the effects of the complex interactions which relate these and other variables to herd performance. This has meant that integrating considerations of the dynamic nature of feed availability and allocation into the planning and implementation of research on feeding systems has been difficult and expensive - or, more frequently, avoided altogether. Perhaps it is not surprising that the uptake of researcher-driven technologies based on static feeding trials has been poor in the past.

3. This project was initiated to develop a computer model capable of simulating seasonality in the availability of feed resources and the consequences for productive outputs of different strategies for allocating these limited resources across a mixed-species holding. It was intended that the model

would, eventually, provide a tool for researchers and other livestock production specialists to assist them in planning optimum feeding strategies.

THE CONSTRUCTION OF FRAME

General Structure and Operation

4. FRAME is a dynamic model that simulates the consequences of feed allocations over a specified period for the cumulative performance of individual animals within a mixed-species livestock holding.

5. The structure of the model is outlined in Figure 1. The input data required to initiate a FRAME simulation (Table 1) comprise:

- A basic description of the type and chemical composition of the feeds available over the simulation period (feeds database).
- A description of the types and numbers of animals in the livestock holding at the start of the simulation (initial livestock holding).
- A series of dates on which observations and predictions will be made (at regular or irregular intervals) and the quantities of individual feeds available on each (feed calendar).

6. The progress of a simulation is determined interactively after the initial data have been entered. On each observation date further inputs are required from the user (Table 2). These include:

- Animals removed from the herd (Deaths, sales, loans etc.
- Animals entering the herd (Purchases, loans etc.)
- A work profile for draught animals
- Allocations of the available feeds across the livestock holding

7. Animals that enter the herd during the course of a simulation are described in the same way as those that are present at its start. Newborns enter the herd automatically at parturition from the mother, the user being prompted to describe the animals sex. For intervals between observations of greater than one day, it is assumed that the same availability and allocations of feed apply on each day until a

Figure 1: Structure of the feed resources allocation model

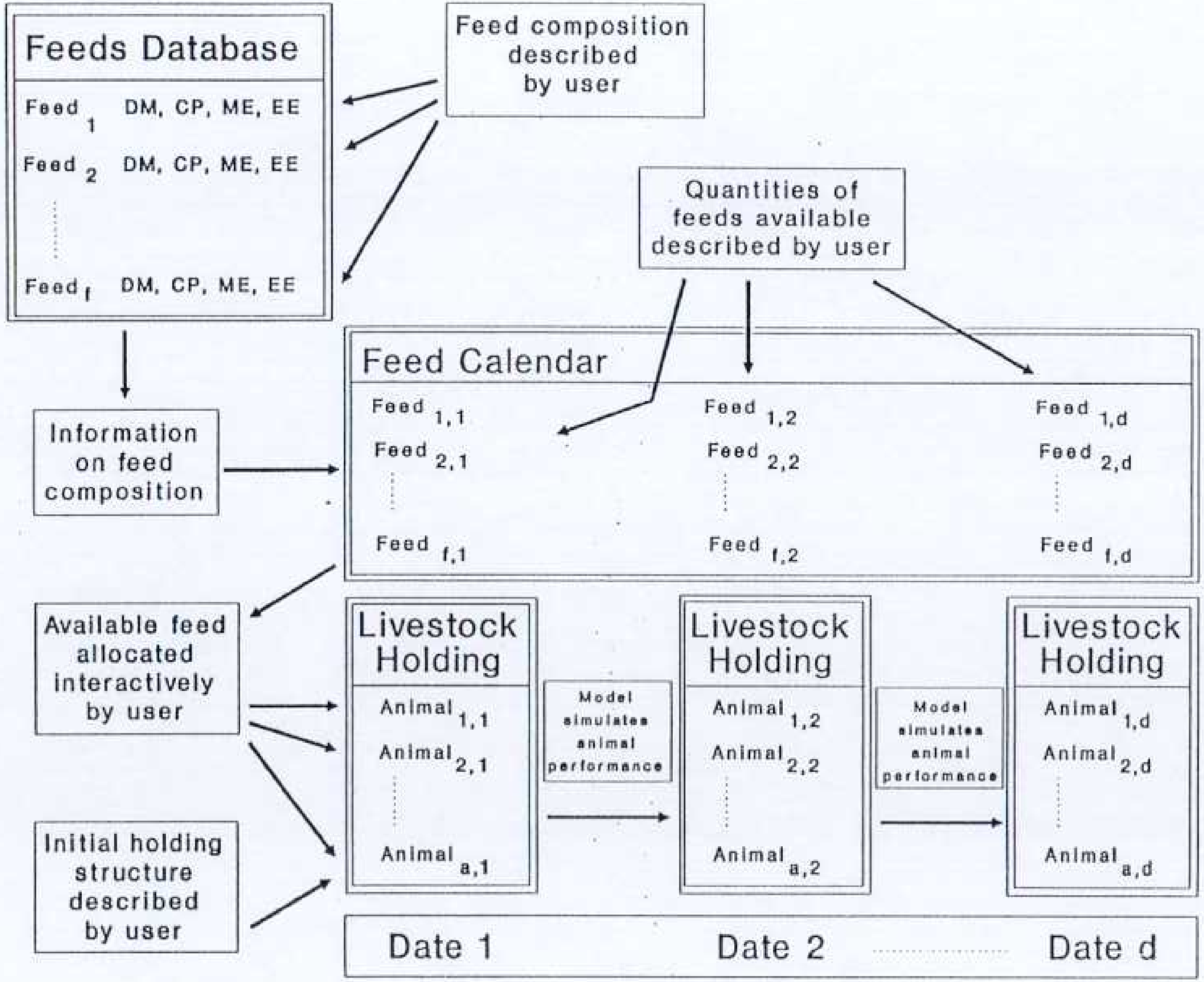

Table 1: Input data required to initiate a FRAME simulation

Variables	*Units*
Feeds Database	
Feed name	Text
Type of feed	Grass, Grass hay, Cereal crop residue, Legume crop residue, Tree fodder, Grain, Animal protein supplement, Vegetable protein supplement
Dry matter	g / kg
Crude protein	g / kg dry matter
Crude fibre	g / kg dry matter
Ether Extract	g / kg dry matter
Metabolisable energy	MJ / kg dry matter
Feed Calendar	
Date	DD / MM / YY
Feed name	Text (selected from database)
Quantity	kg as fed
Initial Livestock Holding	
Species	*Bos taurus*, *Bos indicus*, Buffalo, Sheep, Goat
Sex	Male, Female, Castrate
Class	Growing, Mature
if mature female	
Day of lactation	Positive integer
Day of pregnancy	0 .. 285
Working	Yes, no
Liveweight	kg

Table 2: Input data supplied interactively by the user at each observation date

Variable	*Units or Method of Selection*
Removals	Select from animals currently in herd
Additions	Animal description as for initial herd structure
Work Profile	
if Working = Yes	
Days worked	Integer
Time worked	hours per day
Type of implement	Traditional plough, mouldboard plough, spike-toothed harrow
Feed Allocations	
Quantity of each feed allocated to each animal	kg as fed
or	
Time grazed by each animal	hours spent grazing per day. Grazing intake (GI) is derived as: GI = 0.02 * Bodyweight * Time grazed / 24

revision is specified by the user on the subsequent observation date. Predictions of animal performance are made iteratively on this basis.

Prediction of Animal Performance from Feed Allocations

Energy and Protein Systems

8. The simulation of animal performance within FRAME is based on the treatments of nutrient and energy utilisation formulated for metabolisable energy (ME) and metabolisable protein (MP) (AFRC-TCORN, 1993). There are a number of philosophical shortcomings in this approach. These arise from the requirement-based nature of the ME and MP systems which is not well-suited to the predictive nature of FRAME[1]. However, there is no predictive system available currently that could be applied readily to a wide range of tropical feeds so the ME and MP systems were adopted for the model out of necessity rather than aptitude. The consequences of this, and the potential for improving the treatments of energy and protein nutrition used by the model, will be discussed later in this report.

9. The basic input data set required by FRAME has been minimised to allow the model to be operated in situations were available data are limited. Therefore, some of the feed parameters required by the model must be derived indirectly. These include the feed metabolisability (q = ME / Gross Energy), the acid detergent insoluble nitrogen (ADIN) content of the feed and three parameters which describe the dynamics of protein degradation in the rumen, a, b and c (Ørskov and McDonald, 1979). ADIN, a, b and c are required by the MP system. The values used are averages for each feed type.

Object Orientation

10. FRAME simulates the performance of a number of species and classes of domestic animals. Some of the equations which describe energy and protein transactions are common across species and classes whereas others must be defined

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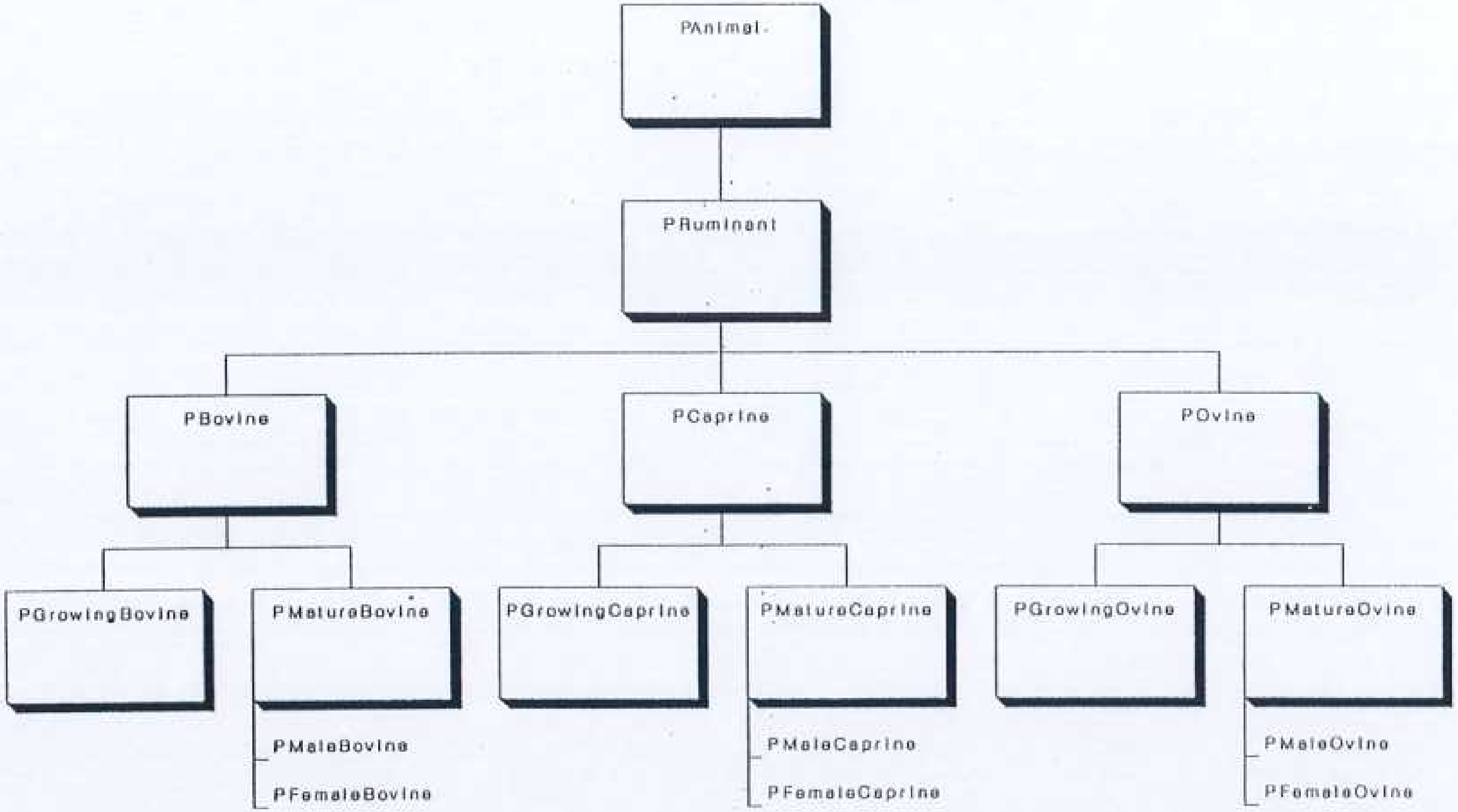
- Requirement-based systems specify the level of output and determine the nutrient inputs required to achieve this. Predictive systems attempt to predict output from a specified range of nutrient inputs.

Figure 2: FRAME Animal Object Hierarchy



specifically for each type of animal. The model employs an object-oriented construction[2]. This allows the definition of base animal types that pass attributes (e.g. liveweight) and methods (e.g. for the determination of a maintenance energy requirement from liveweight) to inheritor types in a hierarchical manner. The object hierarchy used by FRAME for simulating its different animal types is shown in Figure 2 and the attributes and methods employed by each of the model's component objects are summarised at Appendix 1.

11. The following brief example should serve to illustrate the way in which the object hierarchy has been implemented in FRAME and some of the key features of the object oriented approach.

12. The ancestor object TRuminant defines a method MP_Required which returns the amount of dietary metabolisable protein required to support a level of production predicted from the animal's current energy intake. The implementation of this method is:

MP_Required = MP_Maintenance + MP_WeightChange

(MP_Maintenance and MP_WeightChange may be defined by reference to AFRC-TCORN, 1993).

13. The object TFemaleBovine (describing a mature female bovine) obviously shares many attributes of the object Truminant. It is, therefore, defined as a descendant allowing these attributes and the methods that may be needed to determine or manipulate them to be inherited. However, an assessment of the metabolisable protein required by an instance of TFemaleBovine needs to include the demands of pregnancy and lactation when these arise. Thus the Truminant method MP_Required must be refined for use by TFemaleBovine:

MP_Required = TRuminant.MP_Required + MP_Pregnancy + MP_Lactation

(MP_Pregnancy and MP_Lactation may be defined similarly by reference to AFRC-TCORN, 1993)

14. The binding of data and processes that is the essence of the object-oriented approach promotes simulations that are

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[2] A detailed description of the object-oriented paradigm is beyond the scope of this report. A number of standard computing textbooks are available which describe it in detail. For an example of its application in ecological modelling see Sesqueira *et al* (1991).

both more logical and more economical in programming effort. As modifications to method MP_Required in object TRuminant will also be expressed in instances of the object TFemaleBovine, it can be seen that the approach also helps to ensure consistency between types when modifications to ancestor methods are made.

15. In general terms, the object-oriented approach is more suited than traditional, procedural methods for producing simulations that are representative of real-world situations such as agricultural systems. Agricultural systems are also composed of objects - in the case of FRAME, animals with attributes and methods (the physiological processes which determine their function) - and it is a positive development to be able to represent them, conceptually, as such in simulations.

Operation of Simulations

16. The simulation of animal performance by all FRAME objects is derived initially from the difference between the ME supplied in the feed consumed and the maintenance ME requirement appropriate for each type of animal. This is calculated using the equations summarised in AFRC-TCORN, 1993. A mean, daily rate of production (milk and/or liveweight change) and total production (or liveweight loss) during a simulation period is calculated from the amount of ME in excess or deficit of the maintenance ME required. In the latter case, weight loss is calculated from the amount of body reserves mobilised to meet a shortfall in ME for maintenance (ARC, 1980).

17. The ability of an animal to achieve the level of performance predicted from ME intake depends on the adequate supply of protein for turnover and production. The protein component of the model, based on the UK, MP system, uses the same general approach described by Dewhurst and Thomas (1992) who used the system to evaluate the effects of dietary changes on urine production. Dietary MP supply is checked against the MP required to support the level of production by the energy component. If the former is found to be inadequate, a correction is made to the predicted production level on the basis of the rate of MP utilisation that the current MP intake will support. If MP supply is inadequate for protein turnover, a weight loss is calculated as specified by AFRC-TCORN (1993).

18. The MP system also allows the prediction of the partitioning of nitrogen between faeces and urine (Table 3). It is assumed that all excreted nitrogen is incorporated into

Table 3: Equations used for predicting nitrogen outputs in faeces and urine (IDWP, 1993).

Species	Faeces		Urine	
	Indigestible nitrogen (g / day)	Endogenous losses (g / day)	From protein utilisation (g / day)	Endogenous Losses (g / day)
Cattle	Acid detergent insoluble nitrogen content of the diet	$0.35 \times (\text{Weight})^{0.75}$	$MP \times K_N{}^1$ ($K_N = 0.85$ for maintenance and pregnancy, 0.59 for growth, 0.68 for lactation)	$0.13 \times (\text{Weight})^{0.75}$
Sheep + goats	As above	As above	As above + $K_N = 0.26$ for wool	$0.02348 \times \text{Weight} + 0.54^2$

K_N is the efficiency of conversion of absorbed nitrogen for different productive purposes and for maintenance.

ARC (1980)

compost together with any feeds that are rejected by animals that are not allocated and not conserved at the end of the simulation period. The current implementation of the model assumes that there is no diurnal variation in faeces or urine output.

Programming Language

19. FRAME is an object-oriented simulation, implemented using Borland Pascal (BP) with Objects 7.0™. The source code for the model is shown at Appendix 2. The interface for the current implementation of the model has been constructed from the Turbo Vision components supplied with BP with Objects 7.0™ to provide a user-friendly operating environment allowing access to the model's functions through a system of pull-down menus. The model *should* run as a stand-alone programme on any IBM-PC compatible computer with a minimum of 640K RAM although widespread testing to verify this has not been possible. The code may also be compiled into a protected mode application allowing access to any available extended memory for those users with hardware running on the Intel 80386 CPU (or above). This would greatly enhance the simulation periods and / or frequency of observations possible.

TESTING FRAME

20. FRAME is a mechanistic model, albeit at a fairly low level of disaggregation. The parameters used in its construction are related by discrete, identifiable processes that govern nitrogen and energy transactions in the animal. The scope for applying the model depends, therefore, on how generally these processes apply. The key question here is: are the standard descriptions of nitrogen and energy transactions (AFRC-TCORN, 1993) for animals under European conditions sufficiently adaptable for animals of different genotypes kept under more extensive feeding and management systems under tropical conditions?

21. This question will be addressed in more detail when the model is tested against individual animal data recorded under field conditions. Arrangements for this testing have been made under a related project entitled "Strategies for the Allocation of Seasonally Varying Feed Resources to Optimise Livestock Productivity" (R5690). R5690 has been examining feed allocation options and strategies in a hillside, crop-livestock system in the eastern hills of Nepal over a 15 month period. One of its objectives was to provide the data

set needed to test FRAME. This data set will be available when R5690 is completed towards the end of 1995.

Seasonal Feed Allocation and Livestock Performance in the Eastern Hills of Nepal

22. Data for one of the Nepalese farms monitored were analysed in more detail and used for an initial test of FRAME to be reported here. The model's ability to simulate the consequences of a real feed allocation strategy for some of the different animal types in a mixed species holding was evaluated. A relatively limited simulation period of five months (6 March to 25 July, 1994) on just one, typical farm was selected. This is normally the critical period for livestock keepers as it spans the late dry season when the availability of feed resources is said by farmers to be most restricted (Thorne, 1993).

Feed use over the simulation period

23. The farm of Chitra B. Bista was visited on ten occasions over the period used for the test simulation at, approximately, fortnightly intervals as part of the on-farm study conducted under R5690. The structure of the livestock holding on Mr Bista's farm and changes to it during the period are presented in Table 4.

24. On each visit, feeds offered to and refused by each animal or group of animals, their liveweights (estimated from body girth in the case of large ruminants) and productive outputs (including work by draught oxen) were recorded. Figure 3 shows the pattern of dry matter usage on the farm by class of feed. In setting the scene for the simulation, the main points to note are:

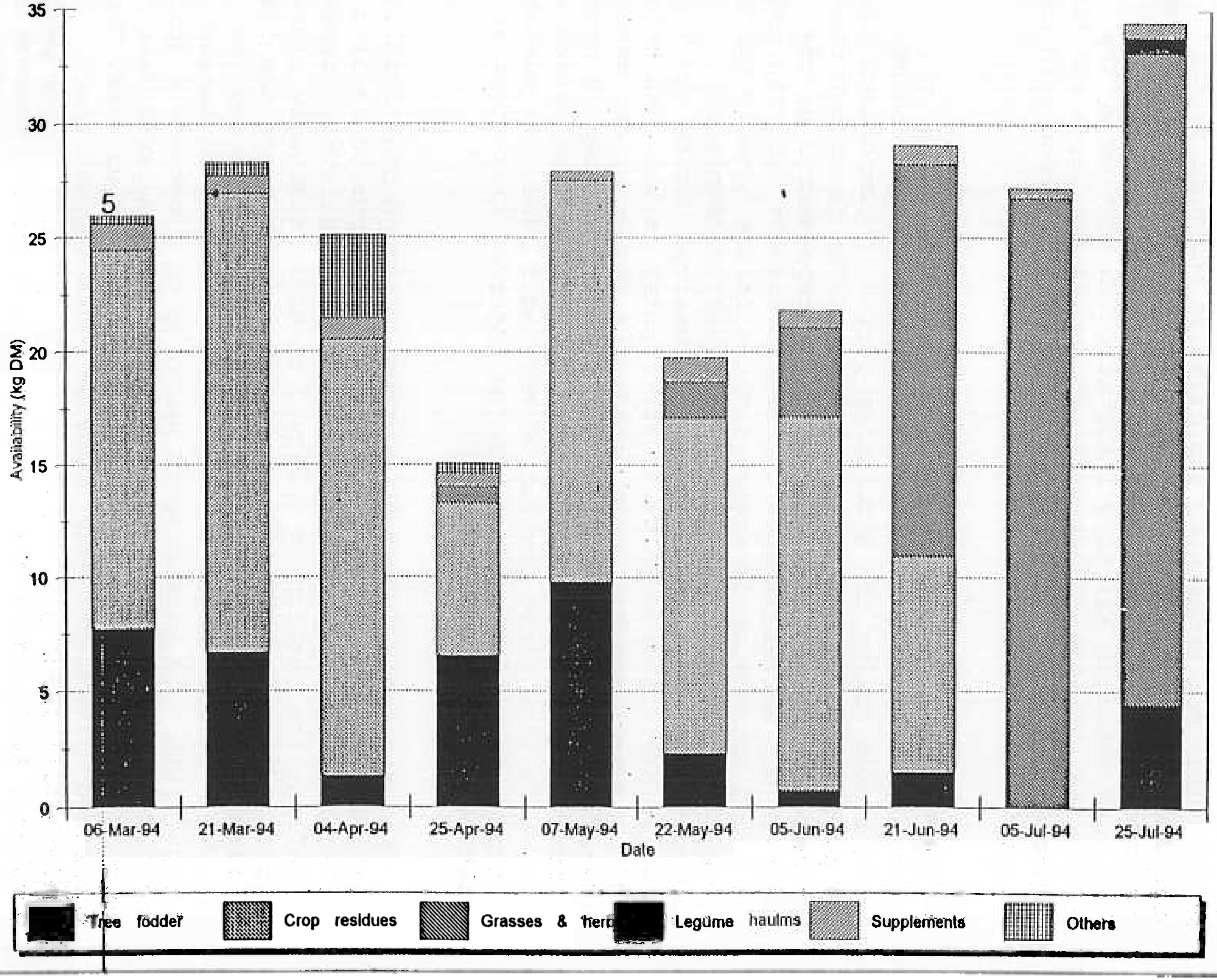
- the switch from diets based predominantly on tree fodder and crop residues during the dry period to fresh, cut and carried grasses. This change coincided with the forage flush brought about by of the onset of the annual monsoon.
- the relative shortage of dry matter available between mid-April and mid June

25. It is in this context that Mr Bista's decisions regarding the allocation of feeds to different animals in his holding had to be made during the simulation period. In addition he would have had to consider the specific needs of particular animals, in particular the parturition of Cow 1 and a period of work for his two oxen between mid May and early June.

Table 4. Initial holding structure and changes observed during the simulation period (C.B. Bista, 6 March - 25 July, 1994)

Animal I.D.	Type of Animal	Changes (date recorded)
In holding at 6 March		
Ox 1	*Bos indicus*, castrated (219kg)	
Ox 2	*Bos indicus*, castrated (261kg)	
Cow 1	*Bos indicus*, female (312kg, pregnant	Gave birth to Cow 5 (25 April, 1994)
Cow 2	*Bos indicus*, heifer (117kg)	
Cow 3	*Bos indicus*, Heifer (166kg)	Loaned to neighbour (4 April, 1994)
Cow 4	*Bos indicus*, female (294kg)	Sold (4 April, 1994)
7 Goats	Total liveweight = 130kg	
Entered during observation period		
Cow 5	*Bos indicus*, heifer (40kg)	Born to Cow 1 (25 April, 1994)
1 Goat	Liveweight = 1.3kg	Born (5 June, 1994)
3 Goats	Total liveweight = 6.2kg	Born (21 June, 1994)

Figure 3: Availability and Sources of Feed Dry Matter (C.B. Bista, 6 March - 25 July, 1994)



Simulation

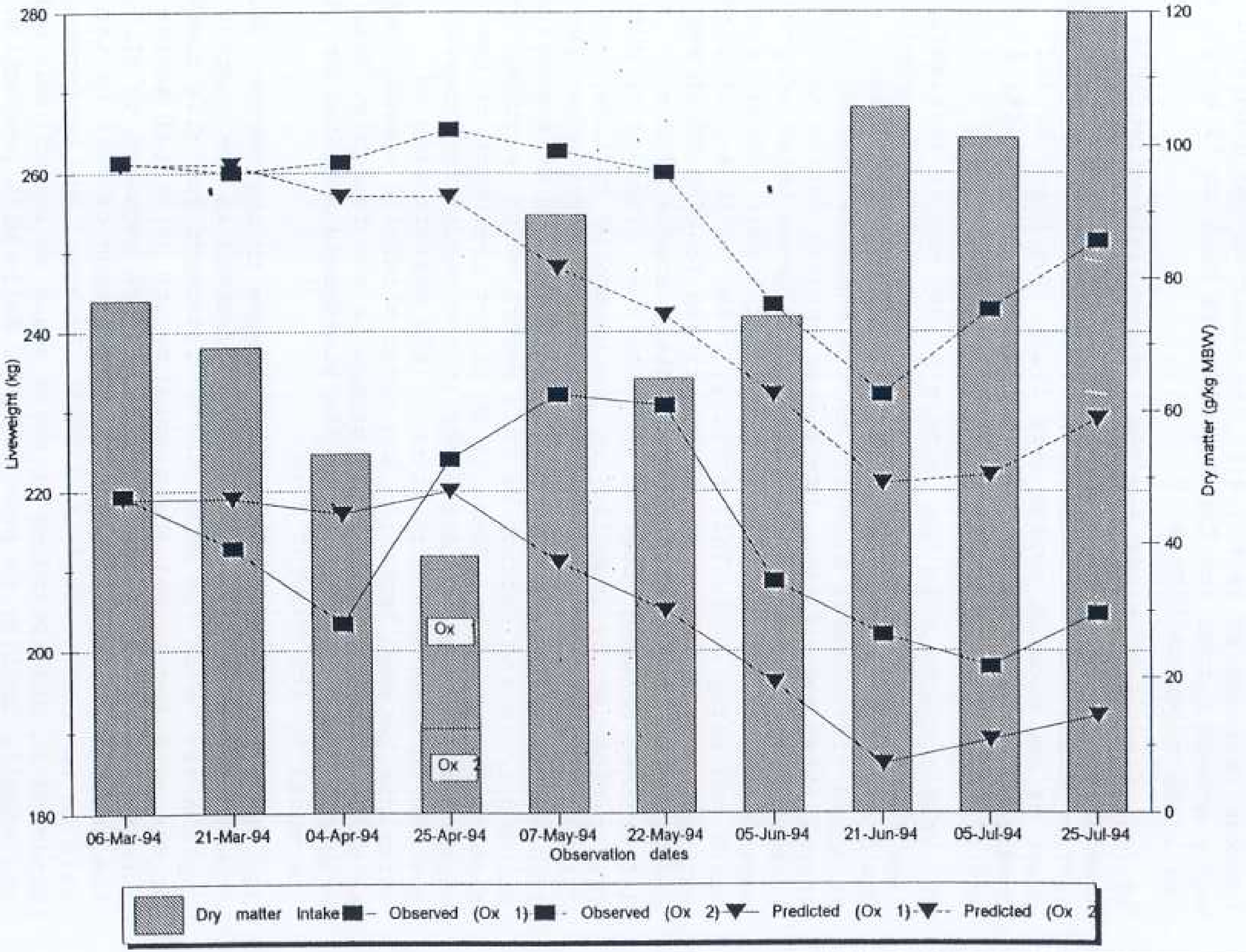
26. The data described in outline above were used as input data to establish a FRAME simulation. They included records of the quantities of feed available and consumed by each animal, the chemical composition of those feeds and the initial state of the herd. For reference, the data are shown in detail at Appendix 3. At the time of writing, chemical analyses of feeds are incomplete so it was necessary to include a number of estimates based on existing information in setting up the simulation. Simulations were not conducted for Cow 3 and Cow 4 as these left the herd during the simulation period with only 2 observations made.

Ox 1 and Ox 2

27. Figure 4 shows the liveweight changes observed in Mr Bista's oxen during the simulation period in comparison with the predictions of the FRAME simulation. The feeding strategy pursued by Mr Bista over the period is represented by the observed dry matter intakes of the two animals (protein and estimated metabolisable energy intakes follow broadly the same pattern according to the analyses currently completed). Separate feeding of the animals was observed during one visit only (22 May, 1994) when Ox 1 (the lighter animal) was offered (and consumed) approximately double the amount of dry matter offered to Ox 2. This strategy was probably adopted in order to bring the lighter animal into condition for the period of work which took place between 22 May and 5 June. Its success is indicated by the increase in the observed liveweight of Ox 1 between 4 April and 7 May.

28. The predicted liveweight changes (although quantitatively adrift at the end of the 5 month simulation period by 13kg (6.7%)and 18kg (7.9%) for Ox 1 and Ox 2 respectively) appear to reflect the pattern in observed changes reasonably closely. In particular, the simulation was able to replicate the loss in liveweight occurring during the working period and the recovery of liveweight in response to the monsoon season forage flush. The growth spurt shown by Ox 1 between 4 April and 7 May was not clearly indicated in the simulated data. It is possible that this was due to inadequate input data. The sustained liveweight gain observed would suggest that preferential feeding of Ox 1 continued for most of the period between 4 April and 7 May. However, the snapshot observation on 25 April limited preferential feeding to the period between 25 April and 7 May in the simulation.

Figure 4: Comparison of observed and predicted bodyweight changes for Ox 1 and Ox 2



Cow 1 and Cow 5

29. Figure 5a shows the observed and predicted *pre-* and *post-partum* liveweight changes[3] for Cow 1 in relation to dry matter intakes observed at each visit. The observed and predicted early growth curves for Cow 5, which was born on 25 April, to Cow 1 are shown in Figure 5b.

30. The predicted values for Cow 1 demonstrate acceptable simulation of the pattern of liveweight change in the *peri-partum* period and the initiation of the growth response to the onset of the monsoon season feed flush. The observed and predicted liveweights of Cow 1 differed by 15kg (5.4%) at the end of the simulation period.

31. When compared with the pattern of dry matter availability (see Figure 3) the pattern of dry matter intakes recorded for Cow 1 over the simulation period suggest that Mr Bista attached considerable priority to the adequate feeding of this animal after parturition. Dry matter intakes during early lactation were consistently higher than those observed *pre-partum* despite the relative scarcity of fodder between mid-April and early June. This strategy resulted in a *post-partum* maternal weight loss that was restricted to 25kg which was not simulated by the model. The most likely source of the differences between observed and predicted liveweights during this period is the inability of the ME and MP systems used in FRAME's construction to predict lactation performance. The problems of using the requirement-based ME and MP systems were alluded to in the section of this report which described the model's construction. There is no direct treatment of the metabolism of absorbed nutrients in the requirement-based systems so effective prediction of the partitioning of nutrients between lactation and other metabolic demands such as maintenance and bodyweight change is not feasible. This is probably the main obstacle to the widespread application of the model in its current form.

32. The simulation of bodyweight changes in the newborn calf (Cow 5) was unacceptable. This was expected as the current implementation of the model has no treatment for milk consumed by the suckling animal which would be its principal source of nutrients at this stage. Further data are required to allow the factors which determine the consumption of milk by the calf to be incorporated into FRAME. However, any treatment based on an understanding of these would be superfluous before the model's ability to predict total daily milk production has been improved.

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[3] milk yield data are not available at the time of writing

Figure 5a: Comparison of observed and predicted bodyweight changes for Cow 1

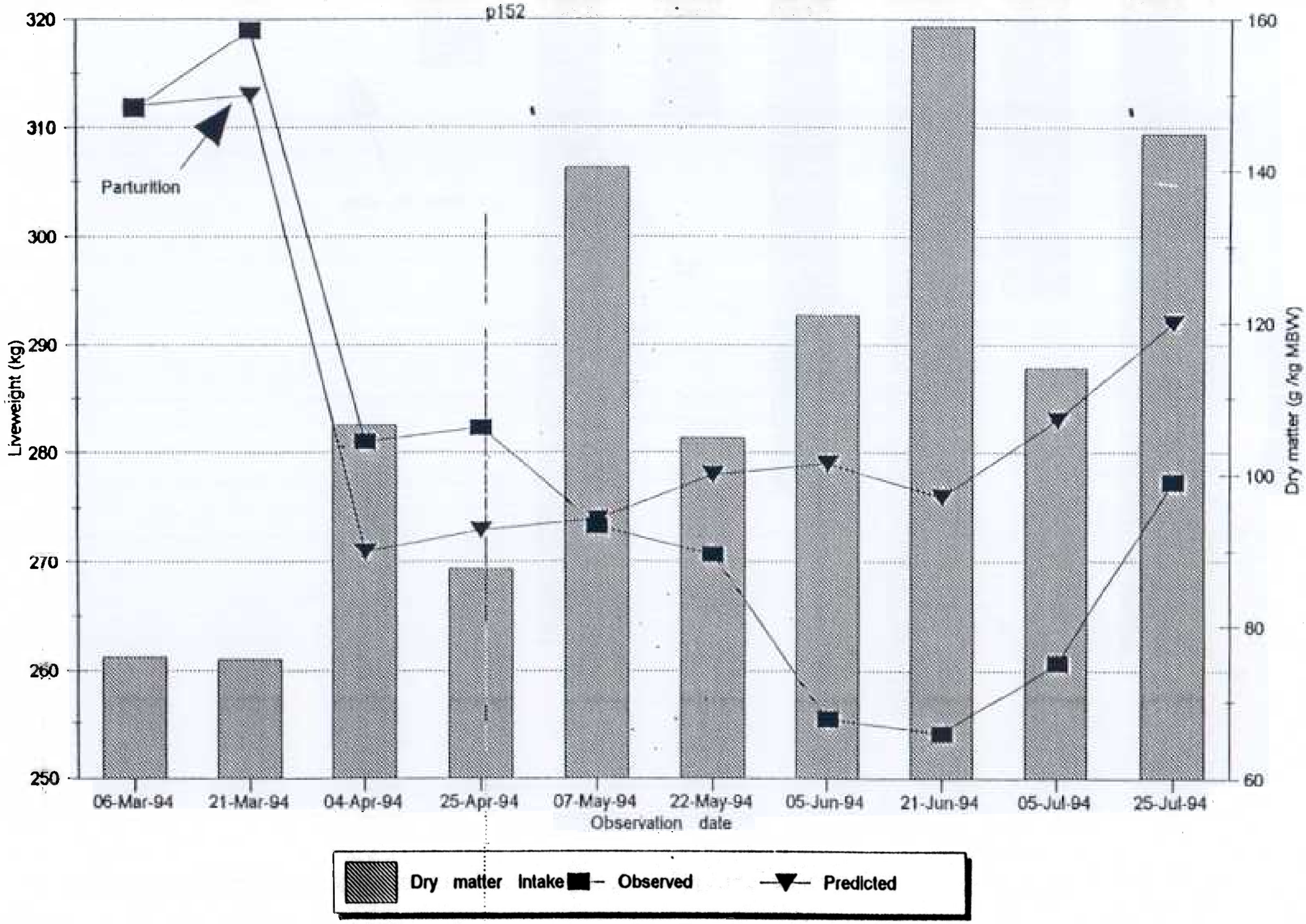
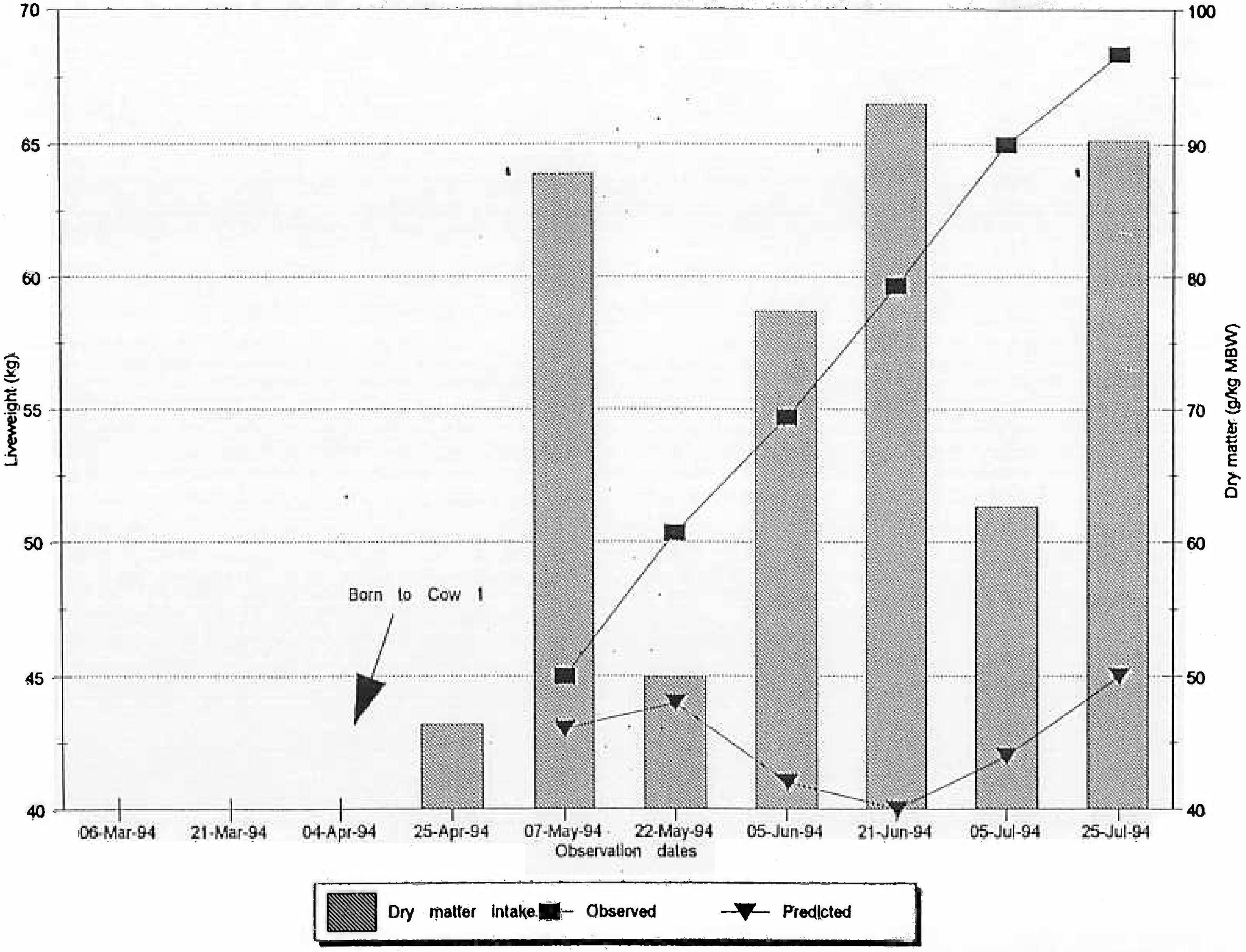


Figure 5b: Comparison of observed and predicted bodyweight changes for Cow 5.



Cow 2

33. Observed and predicted values for the liveweight of Cow 2 differed by 5kg (3.4%) at the end of the five month simulation. However, this outcome does not reflect the apparent total failure of FRAME to predict the pattern of liveweight change in this growing heifer (Figure 6). For most of the simulation period observed growth rates are considerably greater and liveweight losses considerably less than those predicted by the model on the basis of nutrient intakes.

34. Failings in the model which might account for these discrepancies could be:

- a need for more reliable compositional data for the feeds used.
- the operation of other nutritional factors not accounted for by the ME and MP systems. These would, in any event, have to exhibit quite miraculous growth promoting properties to account for the observed effects.

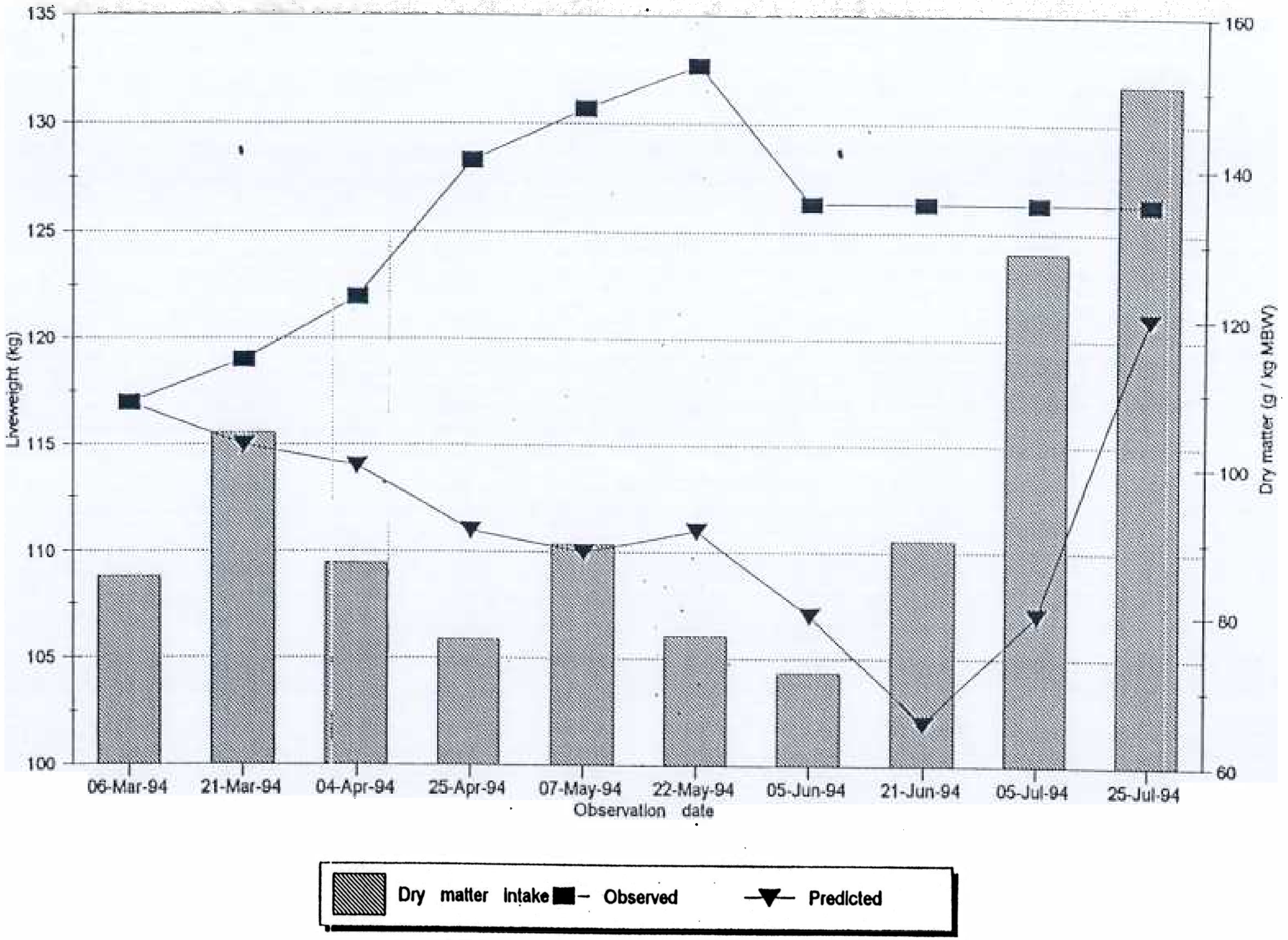
However, the feeds consumed by Cow 2 were substantially the same as those fed to the other animal types so these factors should have produced similar results in the simulations conducted with other types of animals.

34. Clearly the ability of the model to predict the performance of growing animals needs to be more widely evaluated against the Nepalese data before firm conclusions can be drawn regarding this disparity between observed and predicted values. If the problem is more widespread, the most likely explanation would seem to be that the observed liveweights are inaccurate. At relatively mild levels of under-nutrition, growing animals may continue to increase their frame size at the expense of body reserves. This would result in an increase in body girth (upon which the estimates of observed liveweight were based) but a decrease in actual weight.

Manure-Compost Component

35. The prototype for the manure-compost component of the model was developed as part of a review of the rôle of livestock in nutrient cycling in sub-Saharan Africa (Romney *et al*, 1992). The objective of the original work was to assess the feasibility of a modeling approach for investigating the rôle of livestock management in determining soil fertility in crop-livestock systems. This model was a static simulation of

Figure 6: Comparison of observed and predicted bodyweight changes for Cow 2



the effects of a limited range of livestock management decisions on the quantity and quality of organic soil adjuvants in crop-livestock systems. For integration into FRAME, the original model's description of the fate of nitrogen was improved (Thorne, 1995) and a number of adjustments made to allow the dynamic prediction required. A complete validation of the manure-compost component has not yet been undertaken because of the exploratory nature of the work.

36. For the purposes of this report, a simple comparison of FRAME predictions with experimental observations has been presented to illustrate current limitations on the predictive capacity of the model. The input data used for this simulation (Table 5) are derived from a nitrogen balance experiment conducted with indigenous Malawi goats offered a range of hay - supplement combinations (Reynolds, 1981) which was selected at random from a number of suitable, published studies. Faecal and urinary nitrogen production observed in the experiment and predicted by FRAME using the input data derived from this study are shown in Figure 7. The diets used in the study exhibited a range of nitrogen contents. Accurate quantitative prediction of the individual experimental observations was not achieved by the model as, in general, predicted values fell outside the ranges of the errors associated with the observed values. However, the direction and rates of the predicted responses to increasing dietary N were significantly correlated with those observed *in vivo* (faecal N, $r^2 = 0.676$; urine N, $r^2 = 0.981$). Similar inaccuracies were observed in the quantitative prediction of nitrogen balance (Table 6) but again, correlation over the range of treatments was significant ($r^2 = 0.959$). Growth performance data were not available for the experiment. However, weight changes predicted by the FRAME model, also shown in Table 6, were consistent with the observed nitrogen balance data - animals that were in negative N balance in the experimental study lost weight in the simulations.

37. Inaccuracies in the predictions, for urine N production at least, would appear to be errors of quantification rather than due to the general formulation of the relationships which define the model. This implies that there are inaccuracies in the data used within the simulations. It is suggested that the parameters most likely to be responsible are those which describe protein degradation in the rumen (a, b and c) and ADIN which contributes directly to faecal N levels. Values used in the model are derived means for each different class of feed but, for a, b and c, are likely to be subject to quite large inaccuracies as these parameters are highly variable

Table 5: Input data for simulation of published data (Reynolds, 1981).

Feed	Feed Type	Dry matter (g/kg DM)	Crude Protein (g/kg DM)	Crude fibre (g/kg DM)	Ether Extract (g/kg DM)	Metabolisable Energy (MJ/kg DM, estimated)
Chloris gayana hay (1)	Grass hay	895	59	427	8	7.40
Chloris gayana hay (2)	"	920	53	435	10	7.40
Chloris gayana hay (3)	"	900	59	362	9	8.15
Chloris gayana hay (4)	"	932	58	445	8	7.40
Concentrate (1)	"	927	100	60	90	11.75
Concentrate (2)	"	908	230	100	65	11.44
Concentrate (3)	"	913	347	99	69	11.29

Animal details: One 30kg mature castrated goat

Figure 7: Comparison of observed and predicted values for N excretion by indigenous Malawi goats consuming different levels of nitrogen (observed values from Reynolds, 1981)

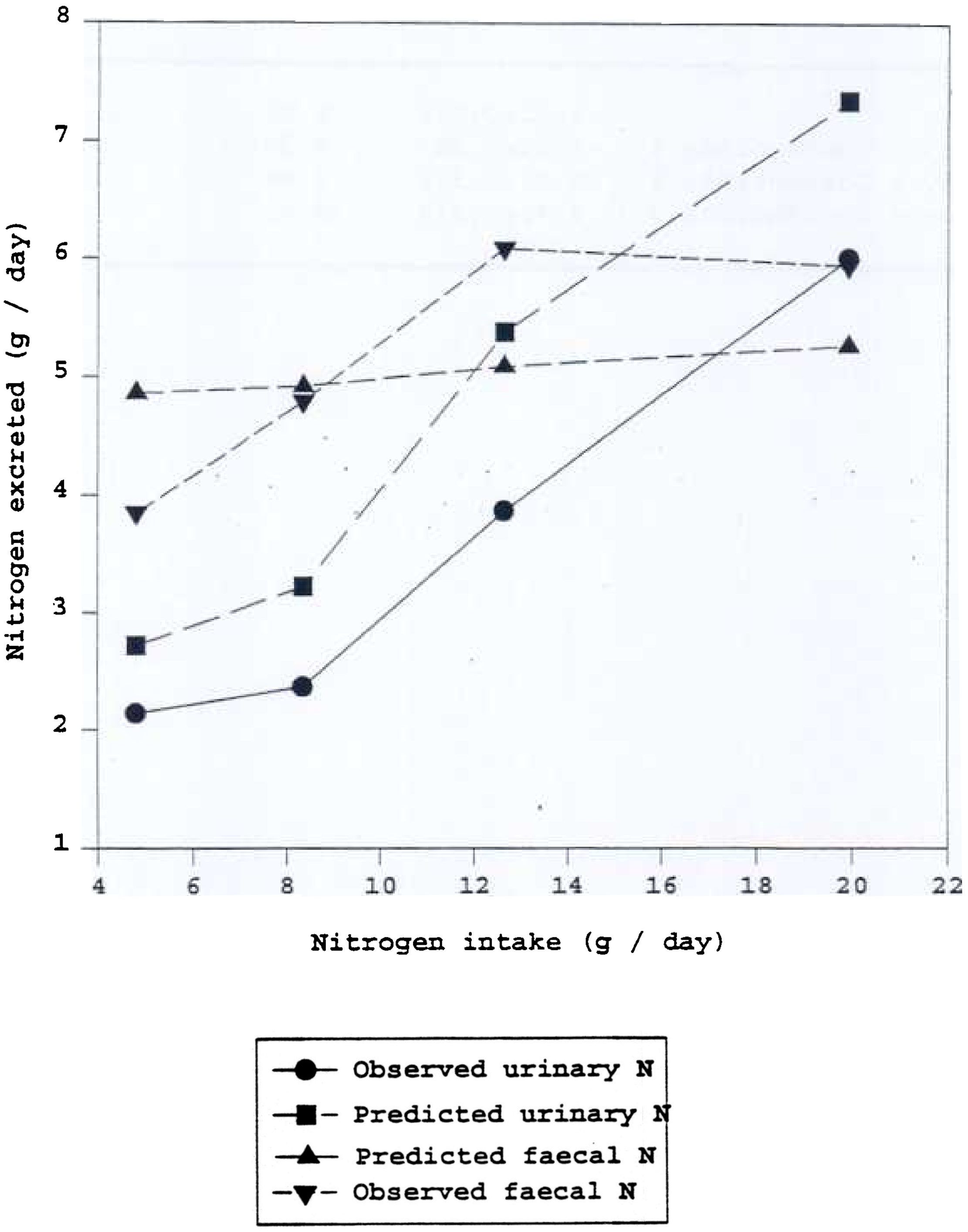


Table 6: Predicted and observed nitrogen balances and predicted growth rates based on data from Reynolds (1981)

Treatment	Nitrogen balance		Predicted weight change (g / day)
	Observed	Predicted	
Hay	-1.81±0.394	-1.85	-94
Hay + Concentrate 1	-1.20±0.357	0.00	-31
Hay + Concentrate 2	1.11±0.312	3.98	35
Hay + Concentrate 3	7.45±0.378	9.61	17

(Webster, 1993) even when determined for the same samples at different laboratories. The use of ADIN to represent undegradable, undigested nitrogen has been adopted relatively recently, therefore, only limited data are available on which to base model predictions. Thus, increasing the accuracy with which a, b, c and ADIN are quantified is likely to be the most significant barrier to improving the quantitative predictive capacity of the model in future. Direct input of these parameters for feeds used in simulations could be expected to increase accuracy of prediction. However, these data are not widely available for practical situations and insistence on their use would probably compromise the utility of the model.

Arrangements for Further Testing

38. Analysis of the data set from Nepal will be completed under an extension to project R5690 during the latter part of 1995. This work will include a detailed evaluation of the predictive capacity of FRAME when applied to the animals on the 32 livestock holdings monitored by the study.

39. A key requirement for potential FRAME users is likely to be the model's ability to test the following:

- alternative allocations of feeds across species;
- optimum timing of the use of feed supplements;
- alternative interventions under particular conditions of feed availability;
- interactions of feed availability and allocation with other aspects of herd dynamics (by manipulation of calving dates and selective culling for example).

40. As the testing of the model described here was relatively limited in its scope, it was not considered appropriate to illustrate the use of the model in this way. However, a full evaluation of FRAME as a tool for effecting this kind of analysis will be conducted as part of the full scale test of the model

41. Further testing of the manure-compost component will not be undertaken on the current implementation of the model. Work under a new Project entitled "Implications of Livestock Feeding Management for Long-term Soil Fertility in Smallholder Mixed Farming Systems" (R6238) will include refinement of the approach adopted in FRAME. This project will also examine the scope for integrating the model's manure-compost outputs with soil nutrient models for predicting the consequences of

feeding management for the maintenance of soil fertility The modeling phase of this study will be undertaken in collaboration with soil scientists from Wye College, University of London and field studies in Nepal will generate data for testing the model.

CONCLUSIONS

42. The work conducted under project R5183 has demonstrated the general suitability of the simulation modeling approach adopted for analysing the feeding systems operated by smallholder farmers with mixed-species livestock holdings. However, a number of shortcomings in the current version of the model have been identified as the work has progressed. These relate broadly to the different nature of smallholder feeding systems (when compared with more intensive systems) and a lack of specific information on the productivity of tropical breeds of livestock from tropical feeds. The most serious aspect is the indication that the ME and MP systems used to construct the model are not ideally suited to the predictive nature of FRAME. In particular, the lack of a treatment for the metabolism of absorbed nutrients restricts the model's applicability. It is acknowledged, therefore, that FRAME's use at present would be limited to more intensive production systems where outputs may be "pre-specified" to allow a more requirement-based approach.

43. Currently, there are a number of opportunities which could support the further development of FRAME to address these deficiencies. This further work will not require specific funding as it can be effected as part of two new projects.

44. Project R6282 entitled "Development of a Practical Dairy Feed Rationing System Appropriate for Use in Developing Countries" will provide a predictive system for rationing dairy cattle in the tropics. In principle, it will be possible to extend the system for use with other classes of livestock and use it as a complete replacement for the ME and MP systems currently used by FRAME. This should address the model's difficulties in partitioning of absorbed nutrients that compromise its use with lactating animals.

46. Project R6283 will reassess the requirements for an animal model which can be used to analyse the rôle of livestock in nutrient cycling in mixed farming systems.

The manure-compost component of FRAME will be used as a starting point for this work and the outputs of R6283 will ultimately enhance the model's capacities in this area.

47. A follow-up project will be required to allow the initial testing of the model in practical situations where the limitations discussed in para. 42 apply to a lesser extent. This project would also support the incorporation of the improved rationing system currently under development (R6282) and improved predictions of manure and compost production from project R6238. The future version of FRAME incorporating these innovations would then be tested for its suitability for the following applications:

- pre-testing improved treatments for researchers conducting experiment on improved feeding strategies;
- analysing potential nutritional interventions by planners and designers of development projects;
- support to extension staff planning recommendations on practical feeding strategies;
- training of livestock officers and extension staff.

A concept note describing the proposed follow-up project will be submitted for livestock production programme funding in due course.

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DISSEMINATION

Reports, Publications and Seminars

Thorne, P.J. (1993) Strategies for the Allocation of Seasonally Varying Feed Resources to Optimise Livestock Productivity. Seminar presented at Pakhribas Agricultural Centre, Nepal. 30 May, 1993.

Thorne, P.J. (1995) Modeling the effects of livestock on nutrient flows in mixed crop-livestock systems. In: Proceedings of an International Conference on Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems of Sub-Saharan Africa held at ILCA, Addis Ababa, Ethiopia, 22 - 26 November, 1993. Eds. J.M. Powell, T.O. Williams and S. Fernandez Rivera. Addis Ababa, Ethiopia, International Livestock Centre for Africa. (In press).

Publications in Preparation

Thorne, P.J. Modeling the consequences of seasonal changes in feed availability and farmers' feed allocation decisions on production from mixed-species livestock holdings. Poster to be submitted for the Fourth International Symposium on the Nutrition of Herbivores, Clermont Ferrand, France.

Arrangements for Further Dissemination

Two further publications describing the model's construction and its testing against the Nepalese data will be prepared. These will be submitted to a refereed journal such as Agricultural Systems.

Further dissemination funding will eventually be sought for the preparation of a user manual to accompany a final version of the model to be distributed on disc.

Table A1: Chemical compositions of available feeds (C.B. Bista, 6 March 25 July, 1994)

Feed	Type	Dry matter	Crude protein	Crude fibre	Ether extract	Estimated metabolisable energy
		(g/kg)	(g/kg DM)			(MJ / kg DM
Bamboo	Tree fodder	448	134	212	6	7.66
Banmara	Tree fodder	143	181	121	34	8.21
Bean bark	Legume residue	307	116	216	15	4.96
Chamlayo	Tree fodder	155	142	240	24	8.94
Chayote		92	102	86	18	13.50
Chilaune	Tree fodder	285	124	210	15	8.87
Dudhilo	Tree fodder	358	113	172	27	9.45
Gogun	Tree fodder	300	99	164	18	9.17
Kaiyo	Grass	247	115	218	35	8.77
Maize bran	Grain	914	116	33	56	11.76
Maize flour	Grain	842	90	75	30	14.52
Maize grass	Grass	180	75	312	19	9.92
Mixed grass (1)	Grass	292	102	302	16	8.86
Mixed grass (2)	Grass	292	92	302	16	9.04
Mixed grass (3)	Grass	292	92	302	16	8.92
Mustard cake	Vegetable protein	898	385	35	107	13.67
Nebharo	Tree fodder	283	140	180	19	9.67

Table A1: continued

Feed	Type	Dry matter	Crude protein	Crude fibre	Ether extract	Estimated metabolisable energy
		(g/kg)	(g/kg DM)			(MJ / kg DM
Painyu	Tree fodder	245	125	192	17	8.45
Patle	Tree fodder	307	116	216	15	9.28
Pumpkin fruit		92	101	88	9	13.50
Rice bran	Grain	854	114	256	38	12.55
Rice straw	Crop residues	780	25	315	9	5.87
Salt		100	0	0	0	0
Sweet potato vine		87	219	150	34	12.04
Titepati	Grass	215	179	281	11	8.21
Wheat straw	Crop residues	840	21	535	15	5.22

Table A2: Availability of feeds during the simulation period (C.B. Bista, 6 March 25 July, 1994)

Feed	Quantities available (kg as fed)									
	06 / 03	21 / 03	04 / 04	25 / 04	07 / 05	22 / 05	05 / 06	21 / 06	05 / 07	25 / 07
Bamboo		10.2	3.0							
Banmara				5.0		3.0		8.7	22.5	
Bean bark										1.6
Chamlayo						4.9		9.7		
Chayote			3.0							
Chilaune					1.9					
Dudhilo					20.1	2.6				
Gogun				16.0						
Kaiyo							10.7			
Maize bran	0.3	0.8	1.0							
Maize flour				0.4			0.4		0.5	
Maize grass							7.0	3.0	11.5	
Mixed grass (1)								53.5		
Mixed grass (2)									74.8	
Mixed grass (3)										98.3
Mustard cake				0.3	0.4					
Nebharo	23.0									
Painyu	5.1	8.7		1.0						
Patle				4.9	6.8	2.0	2.3			14.5
Pumpkin fruit	4.0	4.0		3.7						

Table A2: continued

Feed	Quantities available (kg as fed)									
	06 / 03	21 / 03	04 / 04	25 / 04	07 / 05	22 / 05	05 / 06	21 / 06	05 / 07	25 / 07
Rice bran	1.0					1.2	0.5	0.9		0.7
Rice straw	21.4	26.0	24.6	8.7	13.6	11.1		10.5		
Salt	0.3	0.3	0.2	0.2	0.1	0.2	0.1	0.5	0.2	0.6
Sweet potato vine		2.7	39.0	1.2						
Titepati						5.5				
Wheat straw					8.5	7.3	19.6	1.5		

Table 3: Feed allocations during the simulation period C.B. Bista, 6 March - 25 July, 1994)

06-Mar-94	*Cow 1*	*Cow 2*	*Cow 3*	*Cow 4*	*Ox 1*	*Ox 2*
Maize bran	0.04	0.09	0.06			
Nebharo	2	5.5	4		3.19	3.31
Painyu						
Pumpkin fruit	0.56	1.25	0.08			
Rice bran	0.07	0.16	0.1		0.23	0.27
Rice straw	2.02	4.1	3.2		3.19	3.21
Salt	0.03	0.06	0.04		0.046	0.054

21-Mar-94	*Cow 1*	*Cow 2*	*Cow 3*	*Cow 4*	*Ox 1*	*Ox 2*
Bamboo	1.3	3.3	2.4			
Maize bran	0.13	0.33				
Painyu						
Pumpkin fruit	0.66	1.67				
Rice straw	2.6	4.5	3.5		4.05	4.95
Salt	0.05	0.13				
Sweet potato lahara	0.48	1.13				

04-Apr-94	*Cow 1*	*Cow 2*	*Cow 3*	*Cow 4*	*Ox 1*	*Ox 2*
Bamboo		3				
Chayote					3	
Maize bran					1	
Painyu						
Rice straw	2.8	6.1	3.8		2.94	3.67
Salt					0.2	
Sweet potato lahara	3.4	10	4.6		4.89	6.11

25-Apr-94	*Cow 1*	*Cow 2*	*Cow 3*	*Cow 4*	*Ox 1*	*Ox 2*
Banmara						
Gogun	2	4.26		0.74	2.29	2.71
Maize flour		0.4				
Mustard cake		0.3				
Painyu						
Patle						
Pumpkin fruit		3.7				
Rice straw	3.3	4.6		0.8		
Salt		0.15				
Sweet potato lahara		1.2				

07-May-94	*Cow 1*	*Cow 2*	*Cow 3*	*Cow 4*	*Ox 1*	*Ox 2*
Chilaune						
Dudhilo	2.5	10		1.79	1.08	1.22
Mustard cake		0.4				
Patle						
Rice straw	2.3	4.33		0.77	2.91	3.19
Salt		0.1				
Wheat straw	1	2.72		0.48	2.01	2.29

22-May-94	*Cow 1*	*Cow 2*	*Cow 3*	*Cow 4*	*Ox 1*	*Ox 2*
Banmara						
Chamlayo						
Dudhilo		2.6				
Rice bran		1.2				
Rice straw	2	3.4		0.7	2.35	2.65
Salt		0.15				

05-Jun-94	*Cow 1*	*Cow 2*	*Cow 3*	*Cow 4*	*Ox 1*	*Ox 2*
Kaiyo						
Maize flour		0.4				
Maize grass		5.533		1.467		
Patle						
Rice bran		0.5				
Salt		0.1				
Wheat straw	3.2	6.402		1.698	3.79	4.51

21-Jun-94	*Cow 1*	*Cow 2*	*Cow 3*	*Cow 4*	*Ox 1*	*Ox 2*
Banmara						
Chamlayo	1.5				1.03	1.17
Maize grass (green)		3				
Mix 1	8.7	21.68		5.109	8.4	9.6
Rice bran					0.19	0.21
Rice straw	1	3.48		0.82	2.43	2.77
Salt		0.1			0.07	0.08
Wheat straw		1.5				

05-Jul-94	*Cow 1*	*Cow 2*	*Cow 3*	*Cow 4*	*Ox 1*	*Ox 2*
Banmara						
Maize flour					0.22	0.28
Maize grass (green)		11.5				
Mix 1	16.1	20.56		5.14	14.8	18.2
Salt					0.07	0.08