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Preface

This study was conducted within the framework of a joint Dutch–Israeli research project "Actual and potential production from semiarid grasslands. Phase 2". It was partly funded by the Directorate-General for International Cooperation of the Dutch Ministry of Foreign Affairs.

It is based on a doctoral thesis with the same title submitted to the Senate of the Hebrew University of Jerusalem in 1984. The text and the model have been heavily revised.

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1 Introduction

There are large regions in the world with a semiarid climate and deep arable soils (Aschmann, 1973; di Castri, 1981). The dry boundary of those regions lies at the edge of the area where production of rain-fed annual crops is not possible in most years, even though steps are taken to conserve and maximize available moisture. The moisture limit lies where droughts do not substantially limit the productivity of crops in most years (Bowden, 1979). The predominant food production systems in the semiarid regions are based on small-grain crops and ruminant grazing for meat and milk. Often those are combined into agropastoral (crop and grazing) systems of various forms (Walker, 1979).

In large parts of the semiarid regions, quite remarkable food production can be achieved by full and efficient exploitation of rainfall and soil resources. The actual agricultural production is much lower than the potential, being limited by the availability of the rainfall, by low soil fertility, and by extensive systems of land-use and management that attempt to adapt to those limitations rather than to overcome them. The pathway of agricultural development and intensification is strongly subject to socio-economic and cultural factors (Grigg, 1974). After a major research project in the Sahel Region (Penning de Vries & Djiteye, 1982), Breman & de Wit (1983) concluded that the introduction of 'some major nutrients from the outside', such as phosphate and nitrogen, or 'the creation of other possibilities for gainful employment for the pastoral people' represent the only development options for that region. But as they indicate, such options are unlikely to be initiated internally but would require major intervention on the part of external agencies.

There are, however, semiarid regions where biological, socio-economic and cultural factors concur to make conventional pathways of intensification of the humid zone feasible, without major external aid. Notably, extensive agriculture is juxtaposed with an intensive agroindustrial infrastructure, inputs essential for intensification are available and developed markets are nearby.

The semiarid region of the Middle East and the Mediterranean Basin is a classic example of such an environment. Certain intensification processes occur spontaneously by the actions of individual farmers. Others may be initiated or accelerated by improving the technical knowledge and management skill of farmers, or by modest changes in government policy and support. In that situation, many new inputs and techniques become available, such as improved breeds, supplementary feeds and pasture fertilization.These can be combined into a diverse array of more intensive production systems, some of them complex. Though all increase food production, not necessarily all increase farmer income or its stability. A few of the options can be experimentally evaluated, but to examine many would be far too time-consuming and expensive. The problem then is how to select system configurations to implement in experimental or pilot projects, and how to use the information obtained in those projects for the biological and economic evaluation of other configurations that have not yet been implemented.

The methodology of mathematical modelling, systems analysis and simulation has proved an effective tool to solve problems of that kind (Dent & Anderson, 1971; Anderson, 1974; Dalton, 1975; Arnold & de Wit, 1976; Christian et al., 1978). Such a methodology is adopted in this study with a strong emphasis on a problem-oriented approach (Spedding, 1975; 1979). In this approach, the system can be described as a series of problems or, in the present context, management decisions. For several of these, one can develop decision criteria or optimization algorithms with concise and autonomous formulations that include only directly relevant biological elements of the total system.

This study examines the management problems involved in operating intensive agropastoral systems in a semiarid environment (i.e. with unpredictable and highly variable rainfall), in a region where intensification is feasible. Emphasis is placed upon management options created by integration with wheat production. With the classification scheme of Noy-Meir (1975), the system studied here can be characterized as: lamb production from a flock of sheep, of constant number of animals from year to year, reproducing once a year at fixed dates. The flock is sedentary, grazing a rain-fed area (individually farmed) consisting of annual vegetation (all species of similar growth and palatability) in a semiarid, winter rainfall zone with mild to cool winters. The pasture is fertilized and the animals are supplemented to 'optimum' production. The economic environment is characterized by a high price ratio of meat to grain. There is no limitation to drinking water. Notably, the pastoral component is integrated with small-grain production (wheat).

The region used for the quantitative characterization of the system is the northern Negev Region of Israel. The integration of wheat and sheep production has been examined over several years at the Migda Experimental Station in the northern Negev (Tadmor et al., 1974; Eyal et al., 1975; Benjamin et al., 1982). Research at Migda has aimed at determining the potential primary and secondary production in such an environment, and in designing farming systems that could be implemented widely in the region. Those systems would aim to provide a more stable income than the purely arable systems with wheat that currently predominate.

2 Theoretical framework

2.1 Classifying management decisions

It is useful to classify management decisions into two classes, strategic and tactical. Although there does not appear to be a widely accepted definition of those terms, strategy is generally taken to connote overall approach, direction and policy, whereas tactic has a more dynamic connotation, implying a response to some occurrence in a short-term context. For example, Dyckman et al. (1969) define a strategy as a decision criterion to select among actions. Riggs (1968) defines strategy as system objectives and tactics as operation objectives. A strategic decision selects the objective that makes the best use of resources in accordance with long-range goals. Tactics are the operational-level alternatives to achieve strategic plans.

Those definitions may be operationally useful in a business context, but seem less meaningful to farm management. The hierarchy of long-range goal, objective, strategic plan, strategy and tactic implicit in the definition of Riggs is not adopted here. Rather, there is assumed to be a definable objective that can be formulated in monetary terms. The purpose of strategic and tactical decisions is to direct the system towards the achievement of the defined objective. However the way decisions are best reached may differ fundamentally between them. The following discussion serves to define and clarify the significance of those two decision classes.

2.2 Strategy and tactic in farm management

The dominant factor that gives rise to integrated agropastoral systems is the unpredictability of the amount and distribution of rainfall. Variability is sufficiently high to result in extremely poor pasture production and almost zero grain yield at one extreme, and primary production of over 10 t ha^{-1} at the other. To clarify how unpredictability of rainfall affects problems of farm management, three scenarios or 'cases' are considered.

2.2.1 Case 1

Case 1 is defined by three characteristics.

A. All driving variables (i.e. variables across the system boundary that influence system behaviour; these usually include climate, prices, pests and diseases) remain identical each seasonal cycle.

B. The behaviour of all driving variables is known.

C. There is perfect knowledge of the biology of the system, and the ability to predict accurately the impact of any management decision.

Case 1 represents decision making under certainty. For such a system, one can, in theory, optimize management. Concepts of strategy and tactic are irrelevant. The farmer has simply to implement the optimum management solution to maximize the selected objective function. In practice, a close approximation to the optimum can probably be achieved if the biological description of the system omits detail to which the solution is expected to be insensitive. In addition, management options that recur regularly can be thinned out to reduce the number of alternatives to more manageable proportions. The impact of such condensation of the problem depends on the steepness of the response surface in the region of the global optimum.

2.2.2 Case 2

In Case 2, Characteristic A is relaxed and driving variables behave as they do in reality. Nevertheless, Characteristic B still holds and thus we are still dealing with certainty. It is still theoretically possible to optimize the management of such a system, but the magnitude of the problem is much larger than in Case 1, since seasons can no longer be taken in isolation.

Even if Case 1 or 2 existed, the package furnishing truly optimum solutions would probably not exist. Management decisions would be taken on the basis of the known outcome (there is still perfect knowledge) of various alternative options. Presumably, management would be improved by considering more options through time. A useful tool might predict the outcome of a large selection of management pathways from any given decision, and suggest the pathway most likely to contribute to the defined objectives.Even without uncertainty of driving variables (unpredictability), the manager has a formidable problem. We can now take the second step towards reality.

2.2.3 Case 3

Characteristic B is removed in proceeding to Case 3. Not only do driving variables behave as they do in reality, but they cannot be predicted either. Case 3 includes decision making under conditions of risk, where one recognizes the possible outcomes and the associated probabilities, and decision making with uncertainty, where one recognizes the possible outcomes but not the probabilities (Emory & Niland, 1968).

With risk or uncertainty, an optimum solution in the sense of a predefinable management pathway that maximizes the objective function is inapplicable. In Case 3, it is rational to base management decisions on the current state of the system and behaviour of driving variables; i.e. to create a feedback of system behaviour onto management. However one can study past behaviour of driving variables, assume that their future behaviour will show similar averages and variabilities, and on that basis formulate a long-term 'optimum strategy': 'optimum' not in the sense that the objective function will be maximized, but that the objective function has the highest probability of being in an acceptably high range; 'strategy' for those management decisions that are best taken independently of season. That is, they cannot be (or are only inconveniently or uneconomically) changed from season to season and generally cannot be determined from the present state of the system or behaviour of driving variables. Management tactics will refer to those decisions that are dependent on season, meaning they are taken on the basis of the present state of the system and behaviour of driving variables.

In practice, the type of predictive tool that would be useful in Cases 1 and 2 is similar in purpose to the tool that would aid tactical decision making in Case 3. Uncertainty in predicting future driving variables, however, adds further complexity.

2.3 Definition and application

Uncertainty of driving variables gives rise to the distinction between strategic and tactical management decisions, the distinction between them hinging on the degree of season-dependence in their execution. A strategic decision is defined as a decision taken independently of the state of the system at the time of decision as well as independently of the expected performance of that system in the short to medium term.

A strategic decision is presumably formulated on the basis of long-term experience. An example of such a decision would be the allocation of available land area between alternative enterprises. In contrast, a tactical decision is defined as a decision that is taken in response to the immediate state and environment of the system or in consideration of the expected short-term to medium-term performance of the system. An example of a tactical decision would be whether to graze green wheat when faced witha high probability of crop failure.

2.4 Case 4: imperfect knowledge

Unfortunately, Case 3 (Section 2.2.3) is still outside the realms of reality. A further step is required and that is removal of Characteristic C, since knowledge of structure and functioning of the system is incomplete or even rudimentary. The model itself is often a means of testing complex hypotheses about the biology of the system. Discussion of methodological problems of how best to apply models in a management context may seem premature. However careful integration of knowledge can constitute a significant aid to the farmer and planner, despite imperfect understanding of the components.

The definition of 'optimum' now requires further qualification which will include the uncertainty of the model structure and parametrization itself, and not just of the environment where it operates. Sensitivity analysis to both structure and parameter is the main technique used to measure the significance of that uncertainty. During the present study, a biological precision was required that cannot yet be achieved to release many management decisions from determination a priori, and thereby make them accessible to even a crude form of optimization. Two alternatives are available in such circumstances. First, to construct a best-guess hypothesis and accept the risk that any 'optimum' management recommendation grounded in that hypothesis may be highly sensitive to the structure and parametrization used, and may thus be mathematically precise but biologically inaccurate. It may be no improvement over evaluation of the farmer or extension worker whose conceptual model of the system may be more accurate, even though it is not expressed in explicit mathematical terms. Certainly as a research tool and identifier of areas for further investigation, such an approach might be regarded as the essence of modelling.

The second and more pragmatic approach is to predetermine management rules for a subsystem that is problematic to model in a more mechanistic fashion. Input–output relationships are held firmly within the range encountered under good management practice. This closes off the option of optimization of that subsystem and hence of fixing a global optimum for the system as a whole. That, perhaps, is not really of concern if the response surface of objective functions of complex agricultural systems is fairly flat in the region of the global optimum. This second approach has been adopted here for supplementary feeding of ewes.

As yet, removal of Characteristic C has been discussed in terms of imperfect knowledge about the biology of the system; knowledge in the sense of understanding. In a management context, imperfect knowledge about the state of the system can be just as significant, though here it is knowledge in the sense of information. It is inevitable that the more refined a management package becomes, the more extensive and detailed will be the concomitant data base. Given the current state of the art, it is rarely possible to determine both optimum criteria for decisions and predict when these criteria will be met on a farm. A strong feedback of information from the field is essential both to regulate the model and to know when to implement recommendations.

That touches on a fundamental problem. In one direction of information flow, there is the gap from the manager's sharp intuitive sense, qualitatively monitoring and integrating over a broad base of indicators, to the exact reductionist model of low integrative facility. In the other direction, the model can sometimes provide precise thresholds for particular actions that cannot be used for lack of quantitative monitoring. A possible approach may therefore be the construction of rough-and-ready models, which require rough-and-ready information for guidance and implementation. Such an approach is exemplified by the fertilizer model DECIDE (Bennett & Ozanne, 1973). The challenge, then, is to construct such a model without its being trivial to the experienced farmer, extension worker or planner. Those considerations played a role in the development of the algorithms for tactical decisions (Chapter 5).

The approach to optimization of the two management decision classes is fundamentally different. The formulation of criteria for tactical decisions can proceed independently, partly because the relevant biological subsystem can be isolated. The optimization of strategic decisions, on the other hand, involves a high degree of interrelation between strategic decisions and the algorithms to handle within-season tactical decisions. Ideally, optimization of strategic decisions should commence only when the tactical decisions have been handled. If a global optimum is to be found, the strategic decisions can only be optimized as a whole. Thus the approach taken in this study has been first to investigate tactical decisions and formulate algorithms for their solution for incorporation into the model. Only then are the strategic decisions treated, requiring multiseason runs of the model.

2.5 Possible-outcome analysis

Possible-outcome analysis is the evaluation of alternative pathways that a system can take from a given time or decision. There appear to be two types of possible-outcome analysis. In one, the possible outcomes derive directly from unpredictability of driving variables, and a major step in the analysis is the derivation of an outcome-probability function. Ultimately it is the farmer who must decide which course of action to take since that depends on his personal profile of risk avoidance. Here, the primary function of possible-outcome analysis is to provide an information base for rational decision making. However in a model that runs autonomously, some form of built-in decision criteria must be developed. That is done in the present study in evaluation of alternative uses of green wheat.

In the second type of analysis, the possible outcomes derive directly from management alternatives. The outcome of each alternative is associated with a low uncertainty and the task is to identify which alternative is preferable. The problem here lies in defining an 'outcome' (in the sense of how far into the future it is necessary to predict) and in formulating the criterion by which to compare outcomes. That approach is applied to the problem of lamb rearing in an agropastoral system.

3 Outline of the agropastoral model

Many of the terms introduced here in defining the system, the management framework and the structure of the model will be explained in greater detail in subsequent chapters.

3.1 System

The model simulates an area of land of 1 ha that is divided between pasture, wheat and, optionally, special-purpose pasture to fatten lambs. The area of land does not include a holding paddock (which exists in all systems) nor a lamb-fattening unit (if used). Livestock consists of breeding ewes (including replacer hoggets) and lambs. Rams are not considered. Breeding stock is not bought into the system and stocking rate remains constant between years. Culling time and culling rate is season-independent and all replacers are drawn from locally produced lambs. Lambing is once-a-year only. The only sources of feed bought into the system are concentrates for ewes and lambs and poultry litter for ewes. Animal nutrition and production is based on energy balance. Supplementary feeding of ewes is target-oriented. Protein requirements are assumed not to be limiting. All prices are in dollars (US) and no inflationary effects are considered. Profit is defined as the gross margin divided by area and time.

The term 'locality' or 'nutritional locality' is used to distinguish between the physical areas of the system (pasture, wheat, special-purpose pasture, holding paddock, fattening unit) and also between different phases of use within those areas. Those distinctions are useful since management rules may differ through time for the same physical area, and they facilitate easy control over stock movements. Six possible localities are defined for the ewe:

- green pasture
- dry pasture
- early-season green wheat (not as an alternative to grain)
- late-season green wheat (as an alternative to grain)
- wheat aftermath
- holding paddock.

Eight possible nutritional localities are defined for the lamb:

- holding paddock whilst sucking
- holding paddock after weaning
- pasture (green or dry) whilst sucking
- pasture (green or dry) after weaning
- wheat (green or dry) whilst sucking
- wheat (green or dry) after weaning

- special-purpose pasture after weaning
- fattening unit after weaning.

3.2 The management decisions

Chapter 2 introduced the distinction between strategic and tactical management decisions. The following strategic decisions are treated explicitly in the agropastoral model:
- land allocation
- stocking rate
- breed
- breeding
- sowing density.

Each decision is represented by one or more parameters, which remain constant during a run. Those decisions are discussed in Chapter 4.

The tactical management decisions are as follows:
- supplementary feeding of the ewe
- the locality (grazing schedule) of the ewe
- the locality (rearing pathway) of the lamb
- baling of straw
- cutting of wheat for hay.

Determining the locality of the ewe through time involves several more specific decisions:
- for deferment of grazing on green pasture, what is the optimum time to commence grazing?
- for early-season grazing of green wheat, what is the optimum time to commence grazing?
- for late-season grazing of green wheat, is it better to graze and forfeit the expected grain yield, or to leave the wheat for grain?

Similarly, the rearing pathway of the lamb breaks down into more specific decisions:
- what is the optimum rate of supplementary feeding of the lamb at any given nutritional locality?
- which nutritional locality should the lamb be moved to?

The tactical management decisions are handled by a series of subroutines in the model. Those decisions are discussed in Chapter 5.

3.3 Structure of the model

The overall structure of the model is shown in Figure 1. The model comprises a main programme and a set of subroutines. The main programme is responsible for initialization, the issuing of calls to various biological subroutines to compute rates, the issuing of calls to various management subroutines, integration of all processes through time, output, and financial accounting.

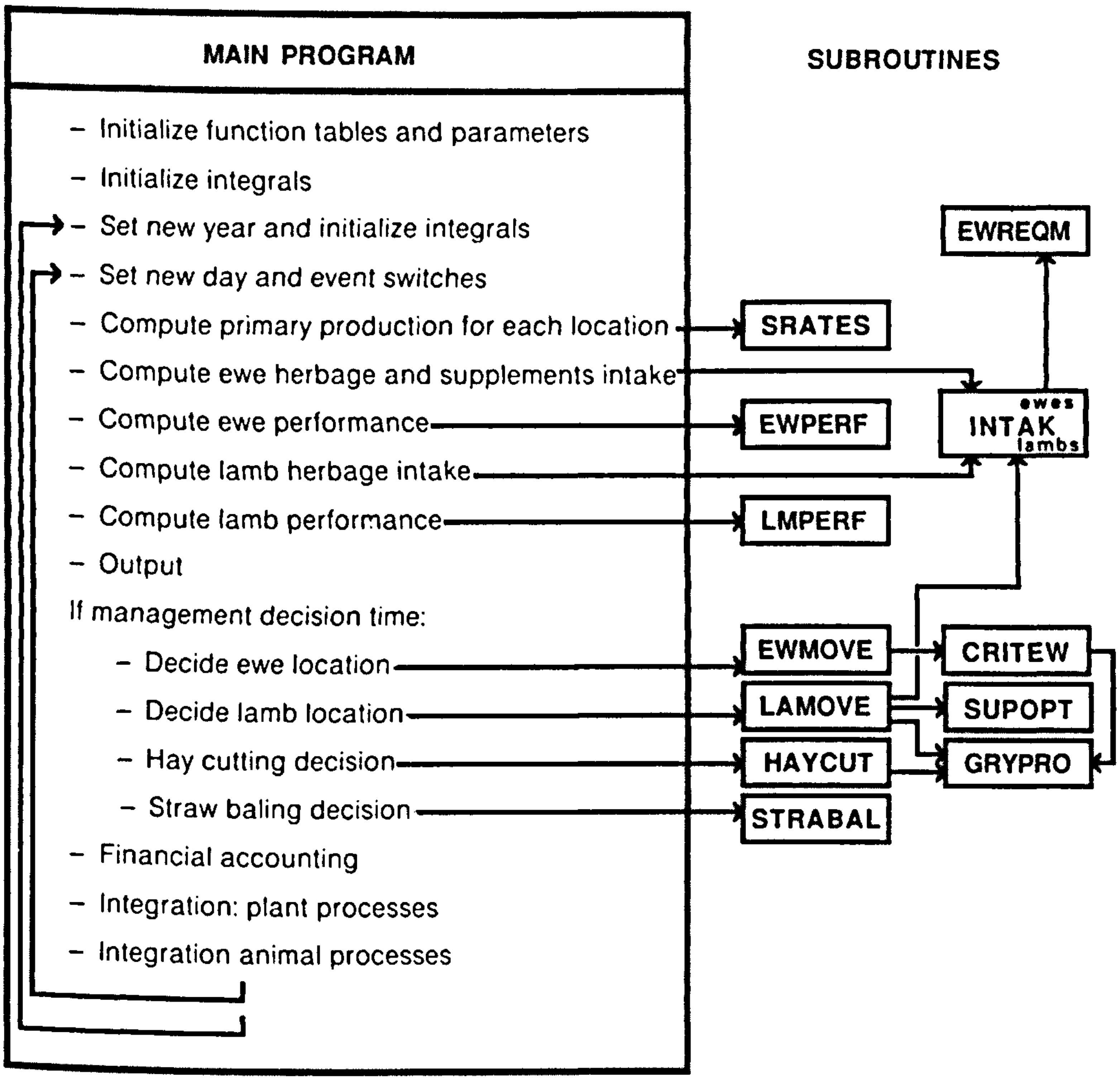


Figure 1. Overall structure of the agropastoral model. Arrows indicate connections and direction of calls between program units.

The model is coded in FORTRAN Version 5, which complies with ANSI FORTRAN 77 and has various extensions to it. The model is implemented on a Control Data CYBER Series Computer System under the NOS Version 1 operating system. Chapter 11 gives a listing of the model and Chapter 12 the model directory. Details of the model relating more directly to the programming have been placed in sections entitled 'Programming considerations'. Those sections can be skipped without loss of continuity.

3.4 Programming considerations

3.4.1 Time-step

The biological and management sections of the model can be operated with different time-steps. A time-step of one day is used in the biological sections. The time-step taken for management decisions can be any value $\geqslant$ 1 d. A 5-day time-step was used throughout this study.

3.4.2 Initialization

All values of parameters, function tables and initial conditions are read from file with the NAMELIST feature. This permits input of groups of variables and arrays with an identifying name. The file is set up similarly to a CSMP parameter file. Moisture conditions in soil are reinitialized to standard values at the beginning of each season. Values for other major state variables are carried over from one season to the next. Thus dead pasture or wheat biomass, ewe liveweight and body condition, and the hay and straw stacks are not reinitialized between seasons, and it is those variables that provide carry-over effects between seasons. So the results for a particular season can differ when simulated singly or as part of a multiseason run.

3.4.3 Meteorological data

The subroutine for primary production (SRATES) reads in daily meteorological data during the growing season from a set of disk files. The variables required are: rainfall, minimum and maximum temperature, daily total radiant exposure, daily wind run, and the dewpoint temperature at 08:00 and 14:00. Files for the period October to April of 1962 to 1982 are used.

The subroutine that computes the expected yield of wheat grain (GRYPRO) requires the historical rainfall data to be organized in 15-day totals for each season. Those data are provided in a separate file.

3.4.4 Output

Five types of output can be requested, and each is given on a separate output file:

- CSMP-style tabular output. The variables to appear in the table are part of the programme code and cannot be specified in the parameter file. Thus any change requires recompilation. The time interval between entries is defined in the parameter file.
- Summary table. At the end of each season, a set of summary statistics comprising three lines is added to that table. An overall summary is also given at the end of the run. The summary statistics include the total time spent and total feed consumed at each locality in the system. This is given separately for ewes and lambs. The amount of straw and hay put in the stack, and the gross margin for the season are also given.
- Debug output.

  All the subroutines in Figure 1, except SRATES, contain an output section that writes a selection of variable names and values to file each time the subroutine is called. An array of switch parameters, defined in the parameter file, controls which subroutines generate the detailed output and sometimes the number of variables listed.

- Event diary. Subroutine DIARY1 generates a one-line entry to an output file recording various discrete events that occur during simulation. The following events are recorded: changes in ewe locality, changes in the 'existence' of a locality (e.g. green pasture is 'present' from germination to full maturity), changes in 'grazability' of a locality (e.g. green pasture is 'grazable' from the time the optimum biomass for deferment is reached), lambing, weaning, ewe culling, changes in lamb locality, sale of lambs, grain harvest, baling of straw, and hay cutting. A few summary statistics are also given at the end of each season.
- Lamb rearing trace.
  Since the behaviour of the lamb-rearing algorithm is of special interest, an output file can be requested that contains the key set of variables that determine the rearing pathway.

3.4.5 Programming conventions and COMMON blocks

The following programming conventions were followed. The names of all local variables in any one subroutine (except SRATES), and only local variables, terminate with the same two alphanumeric characters. For example, all local variables in subroutine INTAK terminate with 'L8', and in subroutine EWMOVE with 'L7'. The same name is used for any variable that is accessed by more than one programme unit. With those conventions, one can build the COMMON blocks automatically with a series of simple FORTRAN programmes. The COMMON blocks are constructed such that only variables actually accessed by a programme unit appear in a COMMON block in that unit. This creates many COMMON blocks, but eliminates a potential source of errors that could be extremely hard to detect.

4 Strategic management decisions

4.1 Land allocation

Land allocation is defined broadly to include both the type of pasture and division of the area between pasture and wheat. Three pasture types are considered here: natural (non-leguminous) pasture; sown leguminous pasture; sown non-leguminous pasture (small-grain species such as barley or wheat). Other options to allocate land are the incorporation of a fallow in the grain-producing component, and a rotation between the pastoral and grain-producing areas. So including wheat, there are five options for land-use. Several ways those can be combined are shown in Figure 2. The area fraction allocated to each component is variable.

The most obvious reason to replace natural with sown pasture is to eliminate undesirable species. A sown pasture species may also be faster-growing early in the season, may yield a higher initial biomass at emergence and may be more responsive to fertilizer. Those factors are of economic significance since they may strongly influence total herbage production and the deferment of grazing re-

2-component systems					
1	W NP	2	W SP	3	W SL
4	W ↔ NP	5	W ↔ SP	6	W ↔ SL
7	W or F NP	8	W or F SP	9	W or F SL
3-component systems — all components continuous					
10	W SP NP	11	W SL SP	12	W NP SL
3-component systems — 1 component continuous					
13	W SP↔NP	14	W SL↔SP	15	W NP↔SL
16	W↔F NP	17	W↔F SP	18	W↔F SL
19	W↔NP NP	20	W↔NP SP	21	W↔NP SL
22	W↔SP NP	23	W↔SP SP	24	W↔SP SL
25	W↔SL NP	26	W↔SL SP	27	W↔SL SL
3-component systems — no component continuous					
28	W↔SP↔NP	29	W↔SL↔SP	30	W↔NP↔SL
31	W↔F ↔NP	32	W↔F ↔SP	33	W↔F ↔SL

Figure 2. Some configurations for land allocation in an agropastoral system. W, wheat; F, fallow; NP, natural pasture; SP, sown non-leguminous pasture; SL, sown leguminous pasture; ↔, rotation of any length. A holding paddock is required in all configurations.

quired at the start of the growing season. The economic value of sown pasture depends strongly on other management decisions. At low stocking rates, for example, grazing deferment may have little effect and rate of intake may be limited by availability of herbage for only short periods. At low stocking rates, the disadvantages of sown pasture may be decisive. The disadvantages are:

- cost of establishment
- a uniform decline in sward quality towards the end of the growing season
- a possibly higher susceptibility to pests and diseases than natural pasture
- poor adaptability to extreme fluctuations in seasonal conditions
- an enforced off-pasture period between cultivation and sward establishment
- the risk of not having sown before the first effective rains.

Sown legume pastures have been advocated largely to fatten lambs after weaning or as forward creep. Although growth early in the season tends to be somewhat slower than that of non-leguminous swards (though that claim is debatable), sown legume swards remain green later in the season and have a higher quality than sown or natural non-leguminous pastures. There is the obvious benefit of a leguminous component in a rotation with wheat, natural pasture or sown pasture, but costs of establishment are high and it can be difficult to maintain a sown legume sward for several years under semiarid conditions. As a special-purpose pasture to fatten lambs, sown legume may allow a higher weight at sale or replace expensive concentrates. For that purpose, a small area can be allocated to sown legume, which would be grazed by the lambs at a high stocking rate for a short period.

Systems incorporating a wheat-fallow rotation through time (i.e. on the same area; Figure 2, Configurations 7, 8 and 9) are unlikely to be managed as 2-component systems since that will result in years with no grain or straw production. The exact nature of the fallow may also be relevant. A truly bare fallow, maintained by occasional shallow cultivation, will conserve more moisture than a fallow on which naturally germinating vegetation is allowed to grow. In the latter case, however, that 'weed' vegetation can be grazed, and such use of the fallow is practised commercially. In general, the availability of cheap agricultural byproducts in the region may be a decisive factor in considering the use of a fallow.

Total dependence on regrowth of natural pasture after one or more years of wheat (Figure 2, Configuration 4) may prove expensive in supplementary feed requirements until a normal seedling density at emergence is restored.

It is not feasible to evaluate such a large range of system configurations in the field. Our understanding of some of the features that distinguish between options for land allocation (such as the effect of climate and grazing on botanical composition) is too rudimentary for quantitative analysis. But is it reasonable to expect there to be large differences in meat and grain production between alternatives? If the answer to that question is no, then the logical choice is the configuration with the lowest costs. Thus natural pasture would be chosen over sown pasture if the primary productivity and quality of the two types of sward is similar. Local pest and disease conditions may determine whether a rotation or fallow is essential for sustained grain yields. Since fallow is at the expense of grain yield, and rotation entails either sowing of pasture or suffering lower production from natural pasture, grain yields must be appreciably improved to justify such practices. For an initial quantitative analysis of agropastoral systems, the two configurations of wheat and natural pasture (Configuration 1), and wheat, natural pasture and sown legume to fatten lambs (Configuration 12) have been chosen. The sown legume is available to weaners only, and not as a forward creep.

4.2 Stocking rate

Stocking rate is defined here as the number of breeding ewes (including replacement hoggets) divided by area of system. Stocking rate is treated as a long-term management decision; purchase and sale of breeding stock in response to seasonal conditions is not considered, though such an option may be rational under certain conditions. The question of stocking rate in the context of maximization of gross margin with reference to area is essentially related to the balance between nutrient requirement of the flock and nutrient supply from primary production, and the cost of covering nutrient deficits with purchased feeds. Other factors may play a large role in determining optimum stocking rates when the objective function includes goals at the whole farm or regional level.

4.3 Breed

Breed selection for ewe and ram is a fundamental management decision in that it determines the potential meat output, and strongly influences the labour requirement per ewe. Many factors are brought into consideration in determining breed, and these will generally include:

- adaptation to local climatic and topographic conditions
- prolificacy and seasonality of breeding
- intensity of care required by ewes and lambs
- sensitivity of productive performance of ewes (reproduction and lactation) to adverse conditions and nutrition
- performance characteristics of lambs
- susceptibility to disease and metabolic disorders.

For economic analysis, the effect of prolificacy is the least problematic to quantify, though defining prolificacy as a function of breeding time is generally hampered by lack of information. Sufficient data are often available to characterize the lactation curve of different breeds, but differences in persistence or responsiveness to improved nutrition are much harder to quantify. We have defined the milk curve according to Wood (1967):

Table 1. Parameters for strategic management decisions in the agropastoral model. The value is for the standard run of the model.

Parameter	Value	Acronym
– parameters for land allocation		
area fraction of system to pasture (1)	0.5	AREA(1)
area fraction of system to wheat (1)	0.5	AREA(2)
area fraction of system to special-purpose pasture (1)	0	AREA(3)
– parameter for stocking rate		
stocking rate of ewes + hoggets (ha^{-1})	5.0	NEWES
– breed-related parameters for the German Mutton Merino		
minimum body condition score (1)	0	BCP1
maximum body condition score (1)	5.0	BCP2
acceptable body condition score (1)	3.0	BCP3
liveweight of mature ewe (kg)	60.0	BCP4
difference quotient of liveweight change to body score change (kg)	5.0	BCP5
gestation period (d)	150	GEST
birth weight of single lambs (kg)	4.5	LBWS
birth weight of twin lambs (kg)	3.5	LBWT
mortality of single lambs (1)	0.06	LMORTS
mortality of twin lambs (1)	0.12	LMORTT
lambing rate of hoggets[1], if tupped (1)	0.6	LPH
lambing rate of mature ewes[2] (1)	0.9	LPM
litter size of hoggets, if tupped (1)	1.15	LSH
litter size of mature ewes (1)	1.40	LSM
mass fraction of solids in ewe's milk (1)	0.2	MDMC
content of metabolizable energy in ewe's whole milk ($MJ\ kg^{-1}$)	4.6	MEWM
– parameters in milk yield function (Equation 1)		
M (1)[3]	400.0	MF1
b (1)	0.35	MF2
c (1)	0.01	MF3
mass fraction of fat in ewe's milk ($g\ kg^{-1}$)	70.0	MFC
increase factor for milk yield with twins (1)	1.4	MIFT
body condition threshold for supplementation (1)[4]	Figure 4	MNEBCT
maximum liveweight of lambs at sale (kg)	45.0	SLVWT
– parameters in breeding regime		
switch for breeding system. 1 = conventional, 2 = early (1)	2	BSYS
culling rate of mature ewes (1)	0.2	CULBS
time of joining from 31 December (d)	210	JOIND
– agrotechnical aspects		
earliest time of wheat harvest from 31 December (d)	150	EWHD

Table 1 (continued)

Parameter	Value	Acronym
time of applying fertilizer from 31 December (d)	295	FERTD
initial aerial biomass of pasture at full emergence (kg ha^{-1})	50	IBIOM(1)
initial aerial biomass of wheat at full emergence (kg ha^{-1})	50	IBIOM(2)
initial aerial biomass of special-purpose pasture at full emergence (kg ha^{-1})	40	IBIOM(3)
time of ploughing from 31 December (d)	290	PLOWD
time of sowing from 31 December (d)	300	SOWD

1 Hoggets are defined as lambs retained for replacement of ewes at about 6 months of age at tupping and 11 months of age at lambing.
2 Ewes are defined as such from about 18 months of age.
3 Initial value at start of each season. This parameter varies somewhat with plane of nutrition; details are given in Section 6.2.3. If constant, yield of ewe's milk over 120 days, for a single lamb, would be about 100 kg.
4 Function table.

$$Y_t = Mt^b \exp(-ct) \qquad \text{Equation 1}$$

where
Y_t is rate of production of whole milk
t is time post partum
M,b, c are constants.

Throughout this study, the model is parametrized for the German Mutton Merino. The parameters used to characterize breed are given in Table 1 together with assumed long-term average values for the German Mutton Merino (breeding once a year). Since ewe nutrition is target-oriented, those performance parameters represent targets that must be matched by adequate nutrition.

4.4 Breeding

It is convenient to define alternative strategies for breeding schematically (Figure 3). For simplicity, we assume that events in the breeding schedule occur simultaneously for all animals involved. Each uniformly managed group of animals is represented by a separate pathway.

System 1 represents the essential features of what might be termed the 'conventional' breeding system. There is one breeding season per year; replacement hoggets are drawn from the lamb crop some time after weaning, and they are first put to the ram at about 18 months old. By that age, the hoggets can attain the necessary minimum weight with small inputs of supplementary feeds, and may be grouped separately until they join the breeding ewes before first mating.

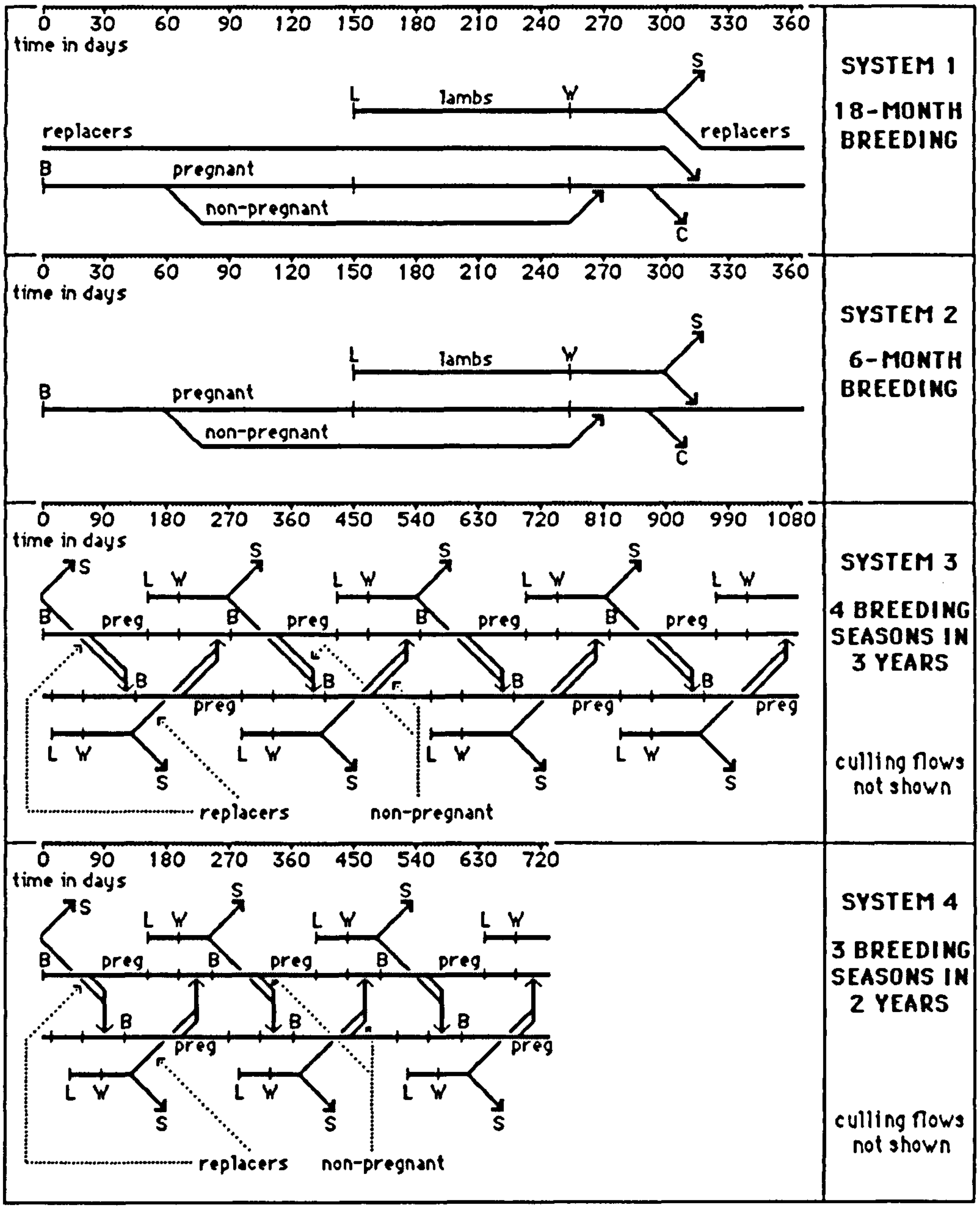


Figure 3. Schematic representation of various breeding systems. Time proceeds from left to right. Each line represents a relatively homogeneous group of animals distinguished by its physiological state or management. The breeding systems are referenced by number in the text. B, breeding; C, ewe culling; L, lambing; S, lamb sale; W, weaning.

In System 2, replacement hoggets are put to the ram at about 6 months old. The question of age at first mating seems most interesting if there is a possibility of gaining an extra lambing by advancing the first mating by one year. This would require a nutritional regime equivalent to fairly intensive fattening if hoggets are to reach the required weight in time for the tupping season. A simple calculation indicates that this extra cost can be justified with even a low proportion of hoggets lambing. However if early tupping reduces reproductive performance in subsequent years, it is questionable whether early mating is preferable.

Systems 1 and 2 represent the ewe lambing once a year. Even with hormones, high-quality feedstuffs and artificial rearers, there is a limit to the output that can be achieved in such systems. Further increases in output require accelerated breeding where each ewe has the opportunity to lamb more than once a year on average. There is no limit to the complexity that such systems can reach as concurrent staggered breeding cycles are added.

Systems 3 and 4 are examples of accelerated breeding employing two concurrent cycles. Accelerated breeding is difficult to manage. Excellent records are essential to the success of such systems. Those systems can easily degenerate into virtual year-round breeding and lambing, with breeding seasons slipping, expanding and overlapping.

The reproductive performance of accelerated breeding systems, when poorly managed, might be little better than once-a-year breeding systems. Nevertheless, there is a clear discontinuity in management complexity and overall input (system 'intensity') between them. Furthermore, in the context of agropastoral systems in the semiarid region, we would expect the role of pasture in flock nutrition to be greatly diminished in accelerated breeding. Even without quantitative analysis, such systems are more sensitive to price ratios of meat to feed than the more extensive once-a-year breeding systems.

The standard run of the agropastoral model is based on lambing once a year with 6-month breeding of hoggets (System 2 in Figure 3). For simplicity in the programming, there is no time distribution of lambing in the flock.

The timing of breeding is treated as a strategic decision. Three primary factors influence the choice of breeding season:

- the effect of time of mating on reproductive performance
- the synchronization of ewe and lamb nutritional requirements with the quality and amount of nutrient supply from pasture
- the meat price curve.

No attempt is made to quantify the first of those factors since there is limited information about the breed and environment used in this study. Furthermore, a constant meat price is assumed. Thus the model can only investigate the supply and demand for nutrients in the decision about time of breeding.

Decisions about culling and replacement policy are essentially long term, though some flexibility can be introduced in response to flock performance in a particular season. The selection of individuals to cull is criteria-based, and the sophistication of those criteria depends on the quality of the flock records. In the absence of flock records, age is often the sole criterion for culling.

4.5 Sowing density

The agrotechnical aspects of wheat production and sown pasture management are not treated explicitly in this study. Such management questions can usually be answered on the basis of field experience or field trials. Interactions with other management decisions are extremely weak, if any. Sowing density, however, may be one agrotechnical option that is related to other aspects of integration of wheat and sheep.

For wheat, work at Migda indicates that sowing rate can be doubled without detrimental effect on grain yield but with a large effect on accumulation of biomass early in the season (Yanuka et al., 1981). That is relevant if the green wheat might be grazed at some stage.

For pasture, initial biomass and early-season accumulation of biomass are major determinants of pasture dynamics and of the deferment of green grazing needed to ensure continued pasture productivity. Although systems with sown pasture are not analysed quantitatively in this study, the effect of initial biomass of natural pasture on system performance can be used to estimate the influence of sowing density.

4.6 Fertilizer

Nitrogen supply limits primary production in the semiarid region in all but drought years. Application of nitrogen to non-limiting rates can double or triple primary production. That might be a rational management strategy at medium to high stocking rates where additional primary production replaces purchased feedstuffs. Furthermore, research at Migda indicates that a high proportion of soil nitrogen not used one year through low rainfall remains available for the next season (Feigenbaum et al., 1983).That fact tends to strengthen the case for non-limiting application of N.

The agropastoral model uses a primary production module based on the simulation model ARID CROP (van Keulen, 1975). That model assumes N not to be limiting and so the model cannot be used to investigate other fertilizer strategies. The system is charged for N application according to the mean annual rate of application that would maintain soil N at a non-limiting level.

4.7 Standard values of parameters

The parameters related to the strategic decisions are given in Table 1 together with the values taken in the standard run of the model. All those parameters are defined in the parameter file, which is read by the program during initialization.

5 Tactical management decisions

5.1 Supplementary feeding of the ewe

5.1.1 Introduction

The problem of supplementary feeding of the ewe is to find the economically optimum rate of supplementary feeding through time. That is problematic given present limitations to understanding of animal nutrition and physiology. To explain that, it is useful to distinguish between the determination of feed input and the prediction of animal performance.

The feed input that supplies the nutrient requirements for a given performance is determined by a conservation approach and can be fairly accurate. That holds for any production mode, be it maintenance, pregnancy, lactation or liveweight change. However predicting the productive performance of an animal from knowledge of its feed inputs is only straightforward for the open dry animal, i.e. where there is only maintenance and liveweight change. Since maintenance requirements must be met, an energy balance approach can be applied to calculate liveweight change. Thus supplementary feeding of lambs can be treated in terms of output prediction, and that allows the development of optimum feeding for lambs. Once other productive modes are included, the accuracy of prediction is more restricted. For example, it is difficult to predict the effect of a reduction in energy intake during lactation. At the extremes, the animal may reduce milk production but maintain liveweight, or draw on body reserves (liveweight loss) in order to maintain milk yield. The problem is complicated by the dependence of the current physiological response of the animal on previous nutritional history. Significantly, however, the precision with which the relationship between nutritional history and reproductive performance can be defined is low relative to its importance. The derivation of output-prediction equations is hampered seriously in pasture-based systems for lamb production since variables such as intake of pasture by ewe and lamb, production of ewe's milk, and even liveweight are difficult to measure accurately.

5.1.2 Target-oriented feeding

The difficulty in predicting performance is one reason for adopting a 'target-oriented' management. Target-oriented feeding is based on input determination, since feeding is adjusted to ensure the achievement of specified production targets. These are generally set close to the animal's potential. Thus supplementation policy for ewes is based upon meeting performance targets during pregnancy or lactation; that is, outputs for those productive functions are driving variables. Nevertheless, ewe bodyweight is allowed to fluctuate at times during the reproductive cycle when that is not expected to have a detrimental effect on productive performance.

In the agropastoral model, the minimum acceptable body condition over the physiological cycle of the ewe is defined. The function is adjusted according to the target reproductive performance of the ewe (Figure 4). The ewe is supplemented whenever body condition falls below the minimum acceptable value, and during lactation if herbage intake provides less than half the total energy requirements.

The adoption of a target-oriented approach to animal performance in a deterministic model necessitates care in interpreting the computed between-season variability of economic performance. In the field, the meat output per animal is unlikely to be constant from year to year even if a target-oriented approach could be strictly implemented. One would therefore expect the variability of economic performance in farming practice to be greater than the computed values.

5.1.3 Programming considerations

Supplementary feeding of the ewe is computed together with herbage intake in subroutine INTAK (Chapter 11, Lines 856-1182). That subroutine is described in Section 6.3, and computational details and values of parameters for supplementary feeding of ewes are given there.

5.2 Grazing schedule of the ewe

5.2.1 Approach

Six localities for ewes are defined in the agropastoral model:
- green pasture
- dry pasture
- early-season green wheat (not as an alternative to grain)
- late-season green wheat (as an alternative to grain)
- wheat aftermath
- holding paddock.

There are three stages in determining the locality of the ewe at any time of decision:
- determine which localities are 'present' (only the holding paddock exists at all times)
- determine which of the 'present' localities are deemed 'grazable'
- determine which 'grazable' locality to choose.

Determining which localities are 'present' is straightforward. The development stage (DVS) serves as the plant's phenological clock in simulating primary production, and is used to determine whether pasture and wheat are green ($DVS < 1$) or dry ($DVS \geq 1$). Early-season green wheat is distinguished from

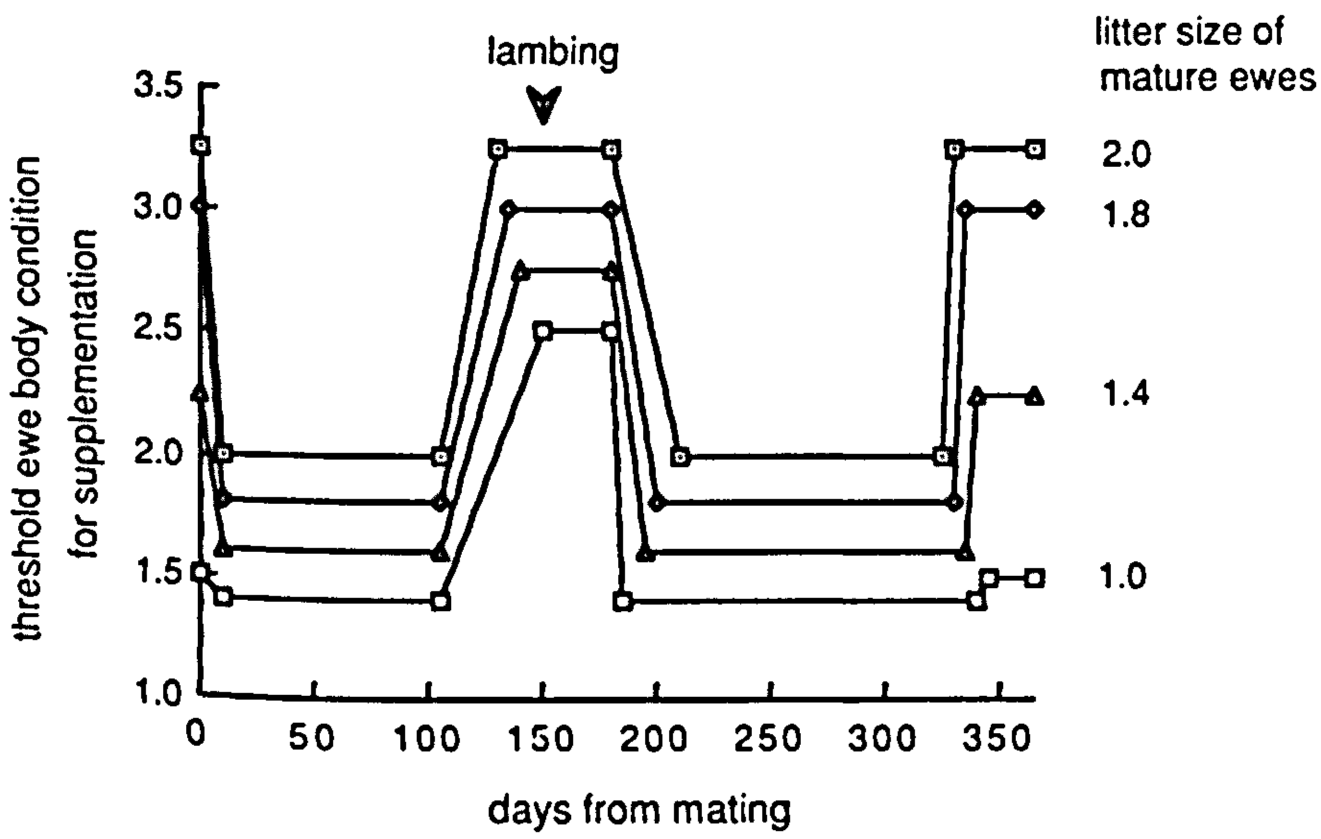


Figure 4. Minimum body condition score below which the ewe is supplemented, as a function of physiological stage and target reproductive performance.

late-season green wheat by the parameter for the time limit of early-season wheat grazing.

Determining which localities are 'grazable' is more involved. Green pasture is 'grazable' from the moment biomass of pasture exceeds the optimum biomass for deferment. The problem of grazing deferment on pasture is dealt with in Section 5.3. Similarly, an optimum time for entry of stock can be defined for early-season green wheat (Section 5.4), which determines when that locality becomes 'grazable'. Late-season green wheat is deemed 'grazable' only if it is economically preferable to graze the wheat rather than leave it for grain (Section 5.5). Dry pasture is 'grazable' if there is some minimum biomass in the field, and if the biomass exceeds that of the wheat aftermath. Similarly, wheat aftermath is 'grazable' if there is some minimum biomass in the field, which also exceeds that of the dry pasture.

The method used to choose between 'grazable' localities is to ascribe a priority ranking to all the localities, and always select the 'grazable' locality with the highest priority ranking. The relative ranking of localities that cannot coexist (e.g. any of the three wheat localities) is irrelevant.

The ranking of the holding paddock is a simple way of blocking certain localities altogether and so evaluating their contribution to the system. If the holding paddock is ranked lowest, the stock will only be moved there if no other locality is 'present' and 'grazable' (e.g. before germination, after the localities dry pasture and wheat aftermath have been grazed out). If the holding paddock is ranked higher than some locality, that locality will never be selected since the holding paddock is always 'present' and 'grazable'. If the holding paddock is ranked higher than all three wheat grazing options, it would be possible to simulate a pastoral system in which straw is bought in. (The option of baling straw or cutting hay is not affected by the priority ranking.)

The ranking of green pasture with respect to early-season green wheat can also be significant. Consider a situation where the optimum time of entry to pasture is before the time limit for early-season wheat grazing. If the pasture is ranked higher than the wheat, the ewes would be transferred to the pasture as soon as the pasture is 'grazable'. If the wheat is ranked higher than the pasture, the ewes would remain on wheat until the time limit for early-season grazing, and only then be moved to the pasture.

The ranking of green pasture with respect to late-season green wheat is relevant. Late-season green wheat will only be deemed 'grazable' if it is economically preferable to graze the wheat than continue supplementing the ewes at their current locality. That current locality could only be green pasture or the holding paddock. Both those localities would still be 'grazable', even if uneconomical, and therefore the ewes would not be moved to the wheat if the current locality is ranked higher than the wheat.

On the basis of those considerations, the priority ranking used in the standard run in this study is (highest to lowest):

- late-season green wheat (as an alternative to grain)
- green pasture
- early-season green wheat (not as an alternative to grain)
- wheat aftermath
- dry pasture
- holding paddock.

Table 2. Parameters and non-local variables used by subroutine EWMOVE of the agropastoral model. The value is for the standard run of the model.

Name	Value	Acronym
area fraction of system to pasture (1)	0.5	AREA (1)
stage of development of pasture locality (1)		DVS(1)
stage of development of wheat locality (1)		DVS(2)
ewe's current nutritional locality (1)		EWELOC
time interval since emergence for wheat locality (d)		GRODY(2)
user-defined priority ranking array for ewe locality. 1 = green pasture, 2 = early-season green wheat, 3 = wheat aftermath, 4 = dry pasture, 5 = late-season green wheat, 6 = holding paddock (1)	5, 1, 2, 3, 4, 6	PRIORT
area fraction of system to wheat available for grazing (1)		WAAG
area fraction of system to green wheat allocated for late-season grazing of the ewe at current decision time (1)		WAGRE
time limit of early-season grazing of green wheat from emergence (d)	42	WGTML

5.2.2 Programming considerations

The grazing schedule of the ewe is handled by subroutine EWMOVE (Chapter 11, Lines 1562-1668). Parameters and non-local variables used by the algorithm are given in Table 2. The non-local variables are of interest because they represent the information required for the decision. The algorithm determines which localities are 'present', calls subroutine CRITEW for each of those to determine whether the locality is 'grazable', and sets the ewe locality to the highest-ranking 'grazable' locality. The priority-ranking array (PRIORT) is set by the user in the parameter file.

5.3 Grazing deferment

5.3.1 Introduction

Grazing deferment has been defined as "discontinuance of grazing by livestock on an area for a specified period of time during the growing season to promote plant production, establishment of new plants, or restoration of vigour by old plants" (Huss, 1964). In the present context, the objectives of promoting plant reproduction and the establishment of new plants are relevant, though other considerations enter in determining the optimum deferment. Grazing deferment is one of the most important management controls over dynamics of grazing systems. At even the most abstract level of description, it is difficult to discuss appropriate or optimum stocking rates without considering grazing deferment. The influence of that management decision stems from the fact that:

- the net rate of growth of a grazed sward is the balance between growth and consumption processes
- under a given set of environmental conditions, both those processes are strongly related to the amount of herbage present
- the balance between those two processes is negative or small over a wide range of availability of herbage and stocking rates.

Grazing deferment is essential if that balance is negative during the initial growth phase. It may also be employed when the balance is positive but small to increase the rate at which availability increases.

5.3.2 Objective function

The optimum time to commence pasture grazing can be estimated with a simple low-resolution algorithm. It seems reasonable to assume that the time of entry to pasture that maximizes gross margin of the system will be similar, if not identical, to that which maximizes cumulative intake of herbage. Intake can be defined in terms of intake of green herbage (GC) and intake of dry herbage (DC), weighted according to their relative nutritive value. In the integrated agropastoral system, the lower requirement for herbage of dry pasture through intake of wheat aftermath (WC) should be taken into account. The objective function to maximize intake can thus be expressed as:

$$\max \{\tilde{C} + \min [t_h + t_q, t_{d,req}]\, i_s HF\} \qquad \text{Equation 2}$$

where

$\tilde{C}$ is cumulative green-season intake of herbage (kg ha^{-1})
t_h is grazing time provided by dry pasture per animal (d)
t_q is grazing time provided by wheat aftermath per animal (d)
$t_{d,req}$ is grazing time required during the dry season per animal (d)
i_s is rate of intake per animal for satiation (kg d^{-1})
H is stocking rate (ha^{-1})
F is relative nutritional value of dry to green herbage (1)

5.3.3 Green-season dynamics

Cumulative green-season intake of herbage is calculated with a simple two-function model. Growth during the green season is described by the logistic function:

$$\mathrm{d}V_p/\mathrm{d}t = \mu\, V_p(1 - V_p/V_x) \qquad \text{Equation 3}$$

where

V_p is biomass of green pasture (kg ha^{-1})
μ is relative rate of growth at low biomass (d^{-1})
V_x is peak undisturbed aerial biomass (kg ha^{-1})

A negative exponential function is used to define rate of intake as a function of biomass of pasture:

$$I_h = H\, i_s\{1 - \exp[-(V_p - V_r)/(V_s' - V_r)]\} \qquad V > V_r$$
$$I_h = 0 \qquad V \leqslant V_r \qquad \text{Equation 4}$$

where

I_h is rate of intake of herbage with respect to area (kg ha^{-1} d^{-1})
V_r is ungrazable residual biomass (kg ha^{-1})
V_s' is biomass at which rate of intake is a factor about 0.63 of satiation (kg ha^{-1})

Since the deferment decision needs to be taken near the start of the green season, the growth function cannot be parametrized according to current seasonal conditions. The approach adopted is to take the long-term undisturbed growth curve. For the Migda site, the undisturbed growth curve was simulated over 20 years with ARID CROP, and the logistic function was fitted to each curve. The following mean values of parameters were obtained: $V_x = 4440$ kg ha^{-1}, $\mu = 0.06$ d^{-1}, for an average growing season of 120 d. Assumed values of parameters for the function of intake are: $i_s = 2.5$ kg d^{-1}, $V_s' = 400$ kg ha^{-1}, $V_r = 50$ kg ha^{-1}.

5.3.4 *Dry-season dynamics*

The grazing-deferment algorithm computes $\tilde{C}$ for all possible deferments from zero to 120 d. The biomass after 120 d is taken as the dry pasture available at the start of the dry season. The grazing time (d) at intake for satiation provided by that biomass is given by

$$t_h = 1/d \ln [(V_l + i_s H/d)/(V_s + i_s H/d)] \qquad \text{Equation 5}$$

where

V_l is biomass of dry pasture available at the start of the dry season (kg ha^{-1})
V_s is biomass at which rate of intake for satiation is reached (kg ha^{-1})
d is relative rate of 'disappearance' of dry herbage during the dry season (d^{-1})
Derivation of that function is given in Section 5.8.2.

The amount of wheat aftermath expected to be available for the dry season can be estimated from the peak undisturbed biomass, V_x, since total primary production for pasture and wheat are similar:

$$V_a = V_x (1-h) L \qquad \text{Equation 6}$$

where

V_a is biomass of wheat aftermath to be available for grazing during the dry season (kg ha^{-1})
h is harvest index or, more precisely, $(1-h)$ is fraction of peak wheat biomass that remains available for grazing after harvest (1)
L is area ratio of wheat to pasture (1)

The grazing time (d), at intake for satiation, provided by that biomass is given by

$$t_q = 1/d \ln [(V_a + i_s H/d)/(V_s + i_s H/d)] \qquad \text{Equation 7}$$

The total grazing time (d) required during the dry season, $t_{d,req}$, is 245 d for an average green season of 120 d. Assumed values of parameters for F, h, V_s (at dry herbage), and d are 0.5, 0.5, 1200 kg ha^{-1}, and 0.003 d^{-1}, respectively.

5.3.5 *Behaviour of the model*

Several biological feedback pathways constrain the cost of poor estimation of parameters in the decision to defer grazing. That can be understood intuitively by first considering maximization of total intake of green herbage only (Figure 5). For the parameter set used in the simple deferment algorithm, the response surface of GC is quite flat around the optimum time of entry (d) up to about H(ewes) = 9 ha^{-1}. Over that range of stocking rates, little loss would be incurred by employing zero deferment management. In fact at low stocking rates, it is preferable to shorten the deferment than to extend it under uncertainty in estimation of parameters. Above a stocking rate of about 9 ha^{-1}, the cost of poor decision making in terms of forfeited GC can be considerable. However at those

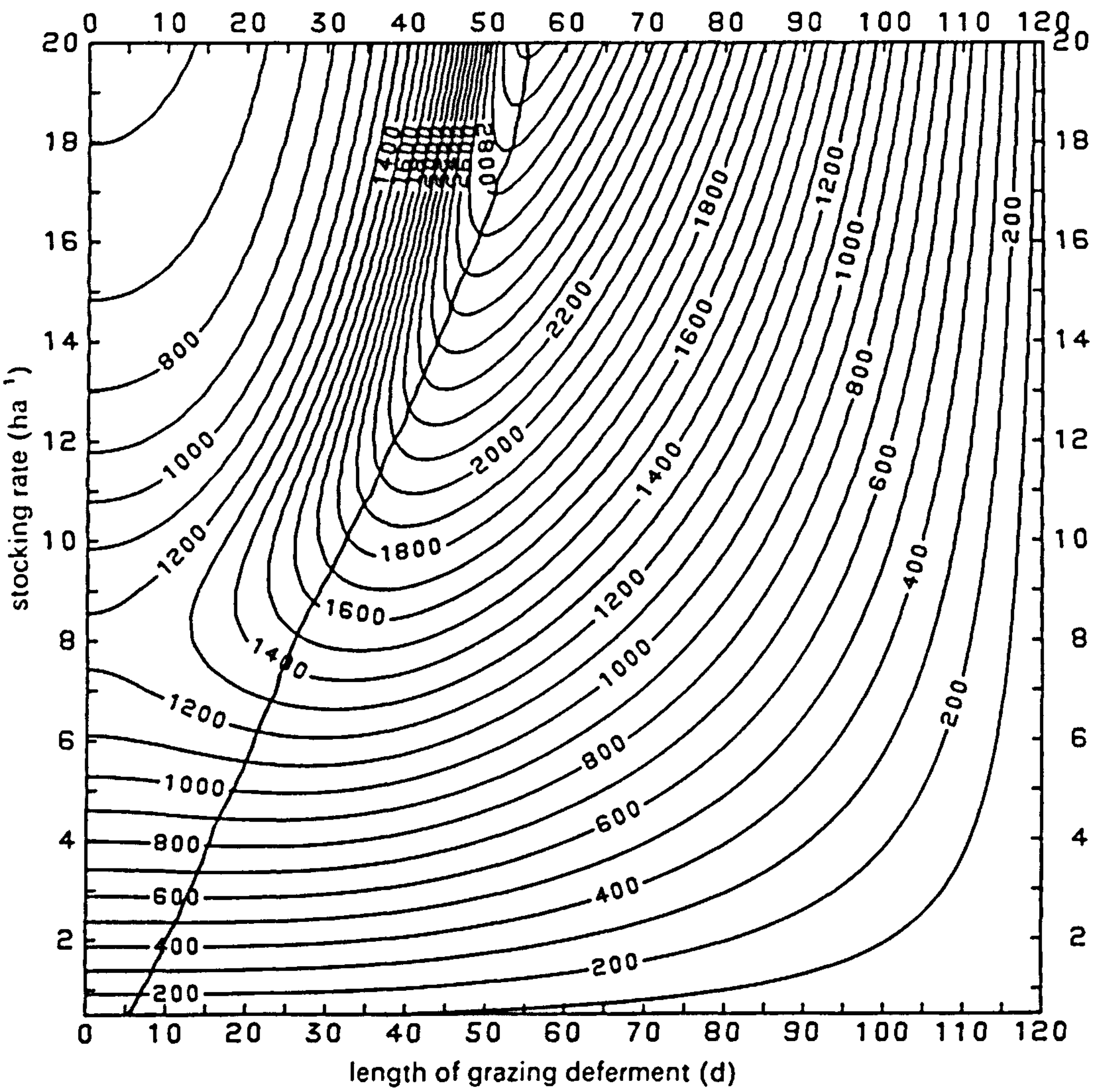


Figure 5. Response surface of pasture utilization to grazing deferment and to stocking rate, where utilization is defined as total consumption of green herbage (kg ha^{-1}). Total consumption of green herbage is computed over 120 days. Growth rate of herbage is defined by a logistic function. Consumption rate of herbage is defined by a negative exponential function. A heavy line is drawn along the peak ridge of the surface and represents the deferment that maximizes total green herbage consumption for each stocking rate. Parameter values are as given in Table 3.

stocking rates, it is preferable to extend the deferment, when faced with uncertainty, and so avoid the risk of a pasture 'crash'.

By adding utilization of dry herbage into the objective function, reductions in GC through deferment beyond the optimum are compensated by the additional dry biomass remaining at the end of the green season (Figure 6).

For comparison, cumulative intake can be normalized by dividing by the maximum (corresponding to the optimum time of entry (d)) and plotted against deferment. That is shown in Figure 7 for four stocking rates, representing different sectors of the response space. As an indication of robustness to decision making, the 'tolerance zone' for deferment that yields a cumulative intake within

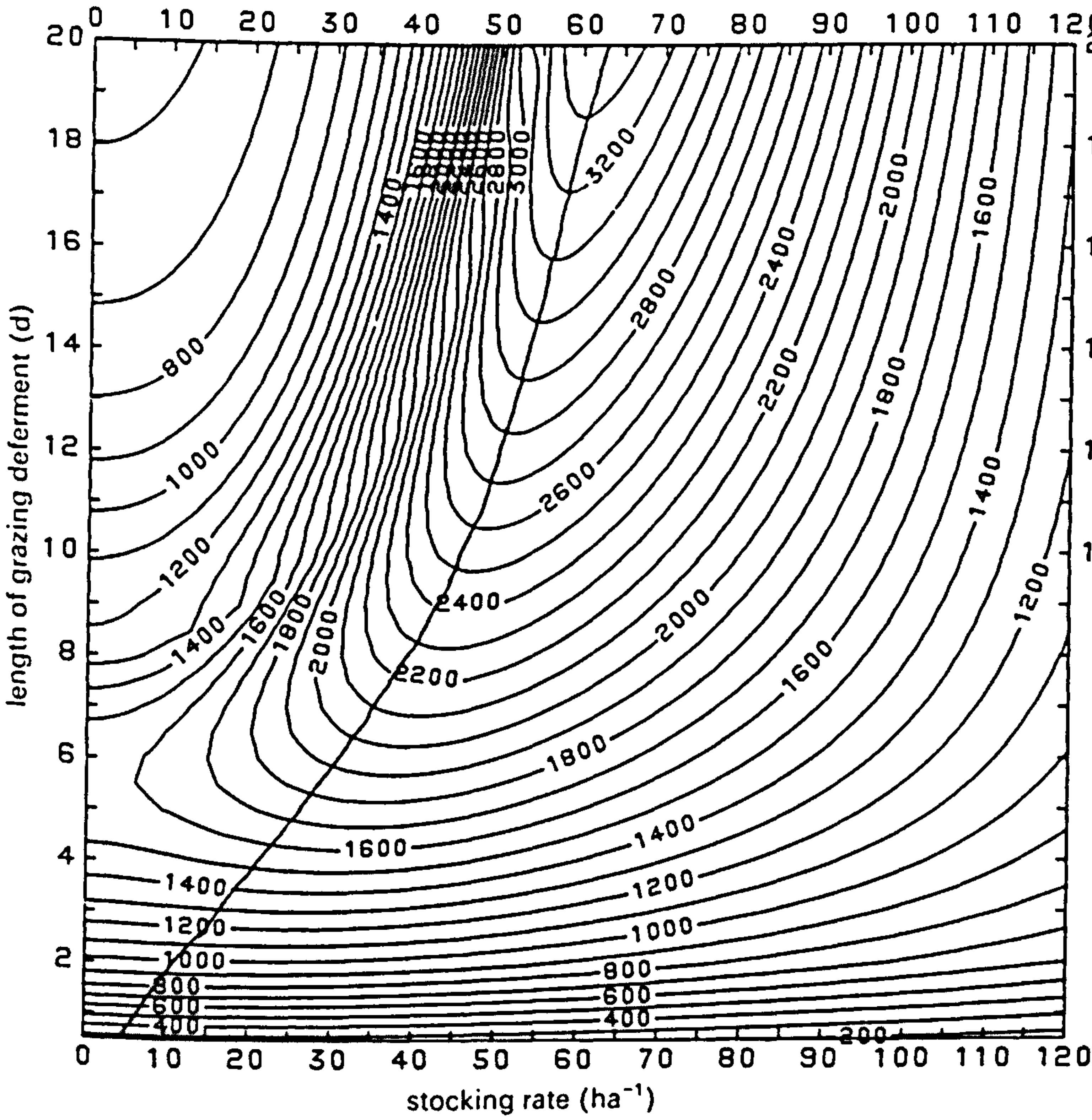


Figure 6. Response surface of pasture utilization to grazing deferment and to stocking rate, where utilization is defined as total consumption of green plus dry herbage (kg ha^{-1}). Total consumption of green herbage is computed as described in Figure 5. To this is added the amount of dry herbage remaining at the end of the green season, or the total herbage requirement in the dry season, whichever is less. Consumption of dry herbage is weighted by a factor of 0.5 to reflect its low relative value. A heavy line is drawn along the peak ridge of the surface and represents the deferment that maximizes total consumption of green plus dry herbage for each stocking rate. Parameter values are as given in Table 3.

10% of the optimum is also shown.

Stock entry before the optimum time of entry (d) results in a steeper decline in relative intake when considering GC + DC than when considering GC only. In that region, there is no compensation since early stock entry reduces both cumulative green intake and V_1. As indicated in Figure 7, adding utilization of dry herbage into the objective function results in a wider tolerance zone for deferment.

Adding availability of wheat aftermath into the objective function is qualitatively different from proceeding from GC to GC + DC. Here, there is no interaction between deferment and the amount of wheat aftermath that becomes available at the end of the green season. At low stocking rates (up to 2 ha^{-1}), V_1 is not limiting for any deferment. Therefore the optimum deferment for maximum GC and maximum GC + DC are identical, and the availability of wheat aftermath has no effect on the optimum solution or the normalized curve for intake (Figure 7A). Over a higher range of stocking rates (2-3 ha^{-1}), V_l is limiting

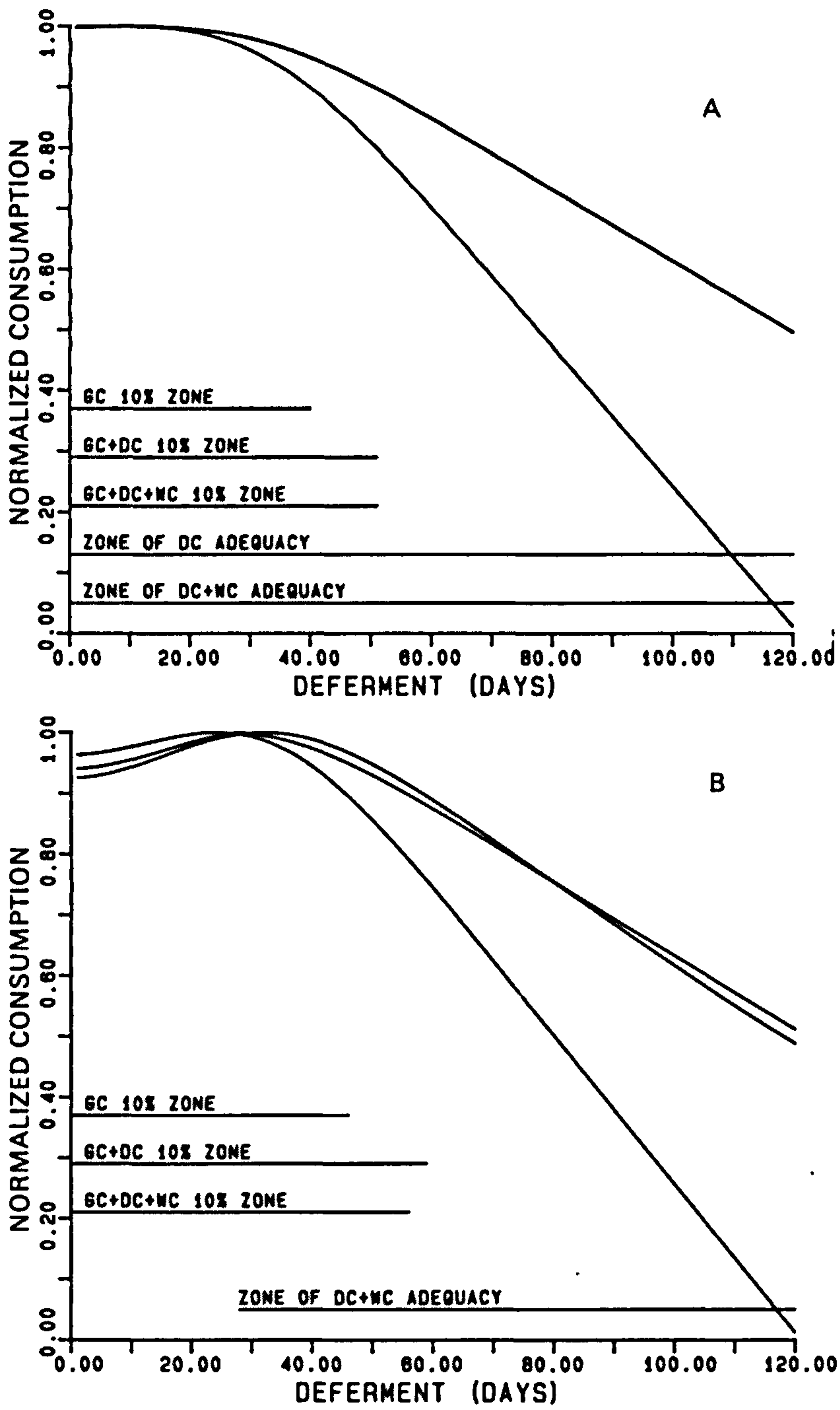


Figure 7. Relationship between normalized herbage consumption and grazing deferment.

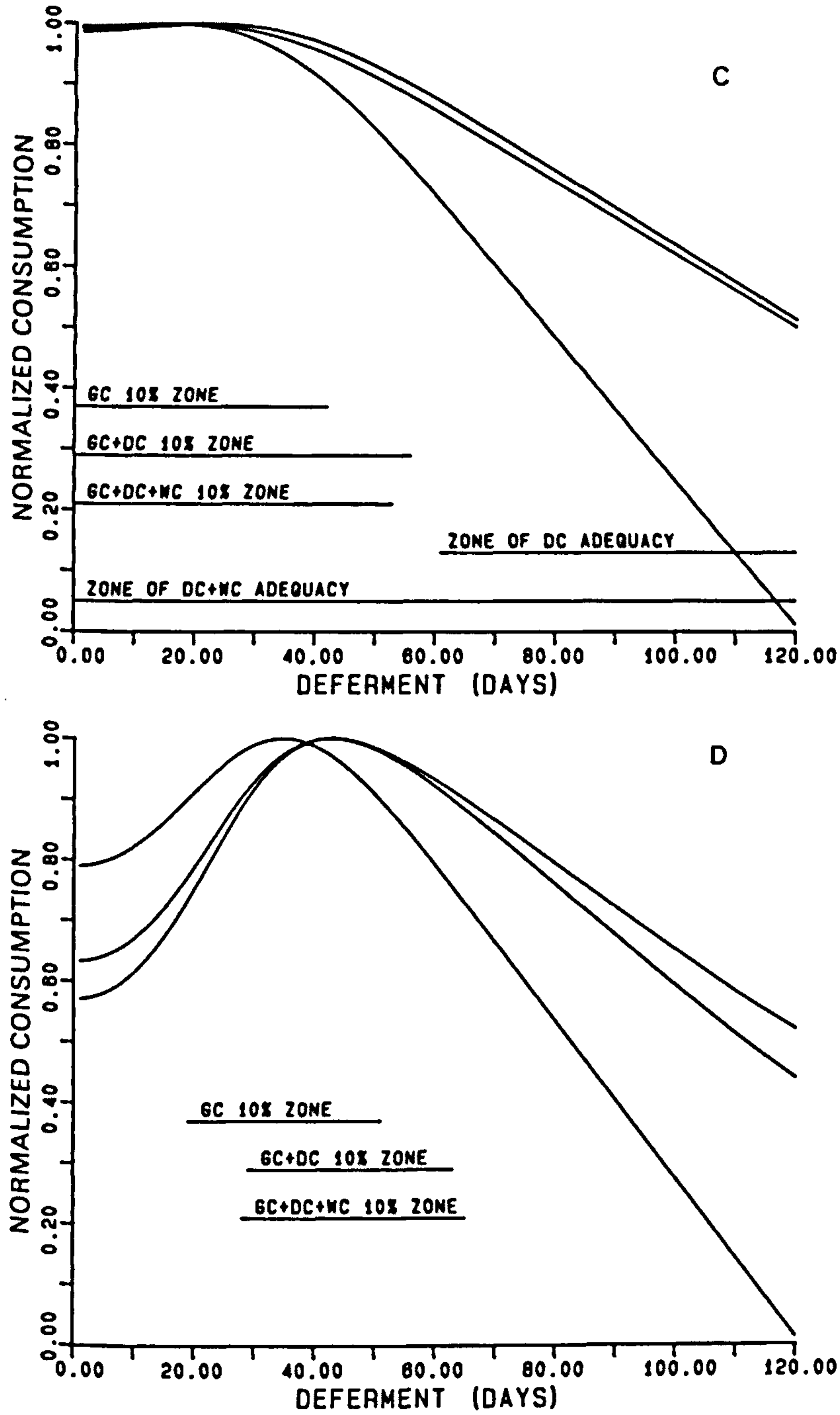


Figure 7. Relationship between normalized herbage consumption and grazing deferment for utilization of green, green plus dry, and green plus dry herbage plus wheat aftermath. The curves are normalized by dividing through by the maximum. Each curve is normalized independently. Horizontal lines indicate the range of deferment over which the remaining biomass of dry pasture, and biomass of dry pasture plus wheat aftermath, meets the total requirement in the dry season. Also indicated by horizontal bars is the range of deferment over which total utilization of herbage, for each definition, is within 10% of the maximum. Parameters are as given in Table 3. GC, consumption of green herbage; DC, consumption of dry herbage, WC, consumption of wheat aftermath. A. Stocking rate with ewes 1.5 ha^{-1}. B. Stocking rate 2.5 ha^{-1}. C. Stocking rate 4.5 ha^{-1}. D. Stocking rate 8.0 ha^{-1}.

(except for long deferments) and therefore the optimum deferment for maximum GC + DC is different from that for maximum GC only. However there is sufficient wheat aftermath to make up the deficit in the dry season over the entire deferment range, and therefore the optimum deferment for maximum GC + DC + WC equals that for maximum GC only. In addition, the 90% tolerance zone for intake is wider than that for GC only (Figure 7B).

Above a stocking rate of about 3 ha^{-1}, not only is V_I always limiting, but there is insufficient wheat aftermath to make up the deficit in the dry season over a wide range of deferments. Thus the optimum deferment for maximum GC + DC + WC differs from that for maximum GC only. However since there is no interaction between deferment and availability of wheat aftermath, the optimum time of entry (d) for maximum GC + DC + WC is the same as that for maximum GC + DC. Provision of wheat aftermath does, of course, alter the total absolute intake, and also broadens the tolerance zone for deferment relative to the other objective functions (Figures 7C and 7D).

This account explains the shape of the relationship between optimum deferment and stocking rate, shown in Figure 8. The lower bounding line represents stocking rates at which the total amount of dry herbage is not limiting (optimum equal to that for maximum GC only), and the upper bounding line represents stocking rates at which that amount is limiting (optimum equal to that for maximum GC + DC only). The position of the narrow transitional zone depends on the allocation of area between wheat and pasture.

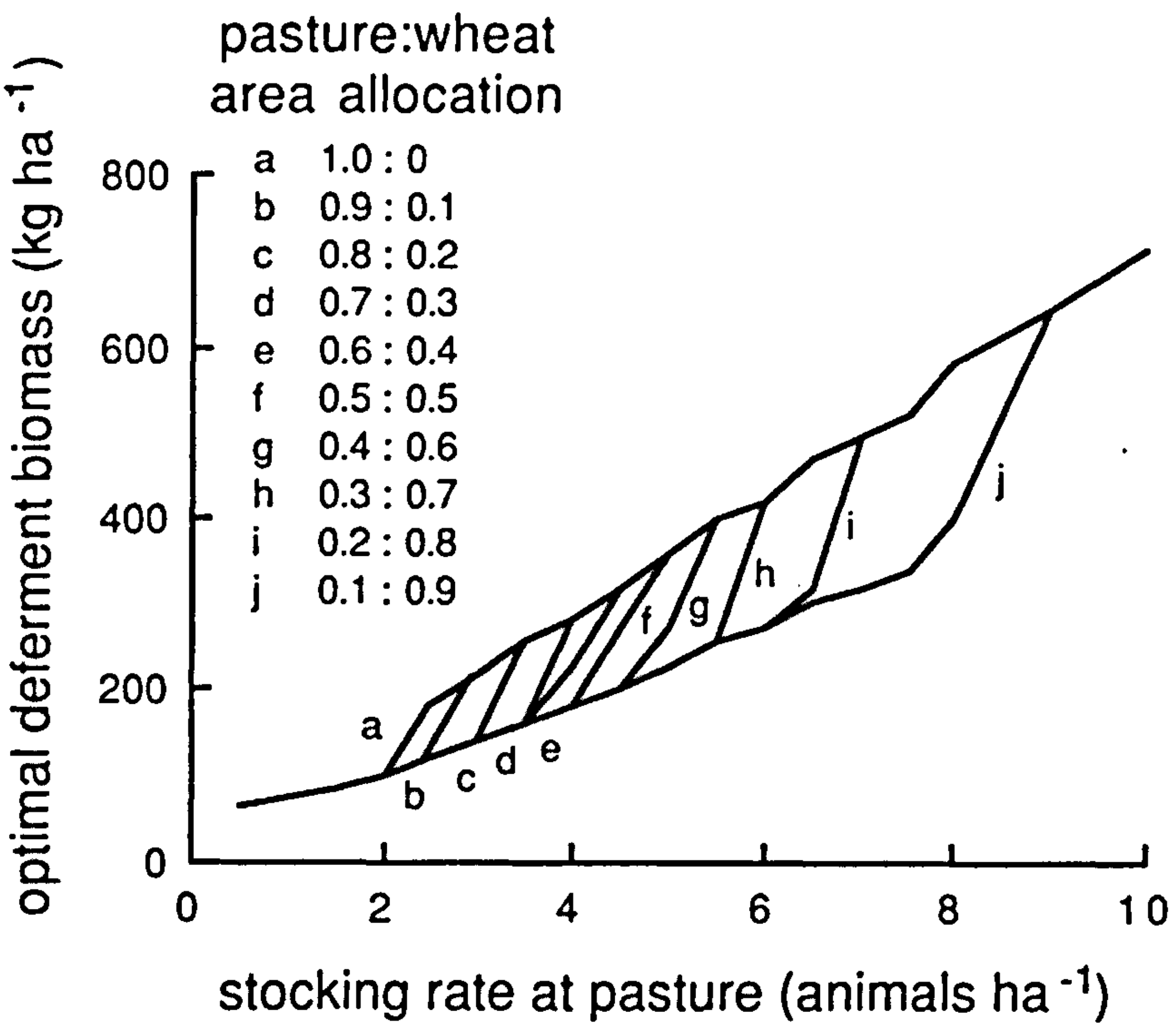


Figure 8. Optimum biomass at stock entry as a function of stocking rate and allocation of land between pasture and wheat. Herbage utilization is defined by Equation 2. Parameter values are as given in Table 3.

Table 3. Parameters and non-local variables in algorithm for deferment of grazing on pasture in agropastoral model. The symbol used in the text is given alongside the name and acronym, where applicable. The value is for the standard run of the model. Parameter VRES(1) is set to VRESG during the green season; where VRESG = 50 kg ha^{-1}.

Name	Value	Acronym	Symbol
area fraction of system to pasture (1)	0.5	AREA(1)	
relative rate of disappearance of dead leaf in dry season (d^{-1})	0.004	DCLV	
relative rate of disappearance of dead non-leaf in dry season (d^{-1})	0.002	DCNLV	
rate of intake per animal for satiation (kg d^{-1})	2.5	GDCS	i_s
switch indicating whether algorithm has been invoked (1)		GDDEC	
relative nutritional value of dry to green herbage (1)	0.5	GDF	F
long-term average relative rate of growth at low biomass (d^{-1})	0.06	GDG	μ
harvest index (1)	0.5	GDI	h
fraction of peak biomass of wheat available for grazing after harvest (1)			$1 - h$
average duration of green-pasture season (d)	121	GDTEND	
long-term average peak undisturbed aerial biomass (kg ha^{-1})	4440	GDVM	V_x
multiplication factor for optimum biomass at entry of stock, used for error analysis (1)	1	GDVMF	
biomass at which rate of intake is a factor about 0.63 of satiation (kg ha^{-1})	400	GDVS	V_s'
time interval since emergence for pasture locality (d)		GRODY(1)	
initial aerial biomass at full emergence for pasture locality (kg ha^{-1})	50	IBIOM(1)	
stocking rate of ewes + hoggets (ha^{-1})	5.0	NEWES	
time limit for deferment of grazing from emergence (d)	80	PGDLIM	
total aerial biomass for pasture locality (kg ha^{-1})		TADRW(1)	
ungrazable residual biomass for pasture locality (kg ha^{-1})	50	VRES(1)	V_r
dry biomass at which rate of intake for satiation is reached (kg ha^{-1})	1200	VSATD	V_s
area fraction of system to wheat available for grazing (1)		WAAG	

5.3.6 Programming considerations

The grazing-deferment algorithm is one section of subroutine CRITEW (Chapter 11, Lines 1729-1784). All parameters and non-local variables used by the algorithm are given in Table 3. Where applicable, corresponding symbols used in Chapter 5 and acronyms used in the model are given. The stocking rate on pasture (parameter H above) equals NEWES/AREA(1). The relative 'disappearance' rate of dry herbage during the dry season (parameter d above) equals (DCLV + DCNLV)/2. Optimum deferment is expressed as the biomass corresponding to the optimum time of entry (d), found by rearranging the logistic growth equation. Since optimum deferment is computed from long-term average pasture parameters, the algorithm is invoked once only at the start of the green season (when GDDEC = 0). On subsequent calls (when GDDEC = 1), the algorithm compares the computed optimum biomass at entry with current biomass of pasture (TADRW(1)). Grazing is also allowed to commence if the growing time (d) (GRODY(1)) has exceeded an arbitrary deferment limit (PGDLIM). If biomass of pasture has not reached the optimum by that time, it is probably a disastrous year and there is no point in deferring any longer. The algorithm returns a reply code of 1 if TADRW(1) exceeds the optimum biomass at entry or if GRODY(1)>PGDLIM, and 0 otherwise.

5.4 Early-season grazing of green wheat

5.4.1 Introduction

With deferred grazing, the flock is generally maintained in a holding paddock on supplementary feeds during grazing deferment. The cost of feeding can be considerable, since that period usually coincides with high pregnancy or early lactation in the ewe. Those feed costs can be reduced by grazing on green wheat during part of the pasture deferment. Trials at Migda indicate that there is a period of at least six weeks from emergence during which defoliation does not reduce yield of grain (Benjamin et al., 1976; Yanuka et al., 1981). Beyond that period, defoliation reduces yield of grain, the effect on yield increasing with lateness and severity of defoliation (Dann, 1968). Insufficient data are available to estimate the effect of extended grazing on yield of grain. In view of that uncertainty, it is assumed here that wheat grazed beyond six weeks after emergence is not harvested for grain. Such an option is discussed in Section 5.5.

The management decision about early-season grazing of green wheat is whether to graze the wheat and at what time to commence grazing. Trials at Migda have shown that early-season defoliation reduces peak vegetative biomass by up to five times the biomass consumed. If the resultant reduction in availability of wheat aftermath needs to be replaced by purchased feeds, the benefit from early-season grazing may be cancelled. That question will be addressed with the system model.

5.4.2 *Objective function*

If the effect on availability of wheat aftermath is ignored, the optimum time to commence wheat grazing can be estimated with a simple low-resolution algorithm. It seems reasonable to assume that the time of entry to wheat (d) that maximizes gross margin of the system will be similar, if not identical, to that which maximizes cumulative intake of herbage during wheat grazing. Cumulative intake of herbage can be calculated with a simple two-function model.

Growth during the first six weeks after emergence can be assumed to be exponential:

$$dV_w/dt = \mu V_w \qquad \text{Equation 8}$$

where
V_w is biomass of green wheat (kg ha^{-1})
μ is relative rate of growth at low biomass (d^{-1})

Rate of intake can be expressed as a ramp function of biomass of herbage:

$$I_h = H \max \{0, \min [s(V_w - V_r), i_s]\} \qquad \text{Equation 9}$$

where
I_h is rate of intake of herbage with respect to area (kg ha^{-1} d^{-1})
H is stocking rate (ha^{-1})
V_r is ungrazable residual biomass (kg ha^{-1})
i_s is rate of intake per animal for satiation (kg d^{-1})
s is 'grazing efficiency' or slope of the rising section of the ramp function of rate of intake per animal (ha d^{-1})

The optimum time of entry (d) is found by calculating the cumulative intake of herbage until 42 d after emergence for all possible times of entry (d) from the moment of decision. The biomass of wheat at the start of the grazing period is given by

$$V_w = V_i \exp (\mu t) \qquad \text{Equation 10}$$

where
V_i is biomass at the time of decision (kg ha^{-1})
t is time interval from the moment of decision till the time of entry being considered (d)

5.4.3 *Behaviour of the model*

Figure 9 shows the response surface of optimum time of entry (d) and mean daily intake during the grazing period to stocking rate and relative rate of growth of wheat. The long-term management decision about sowing density of wheat is relevant here, since it has a strong effect on the mean daily intake during the grazing period.

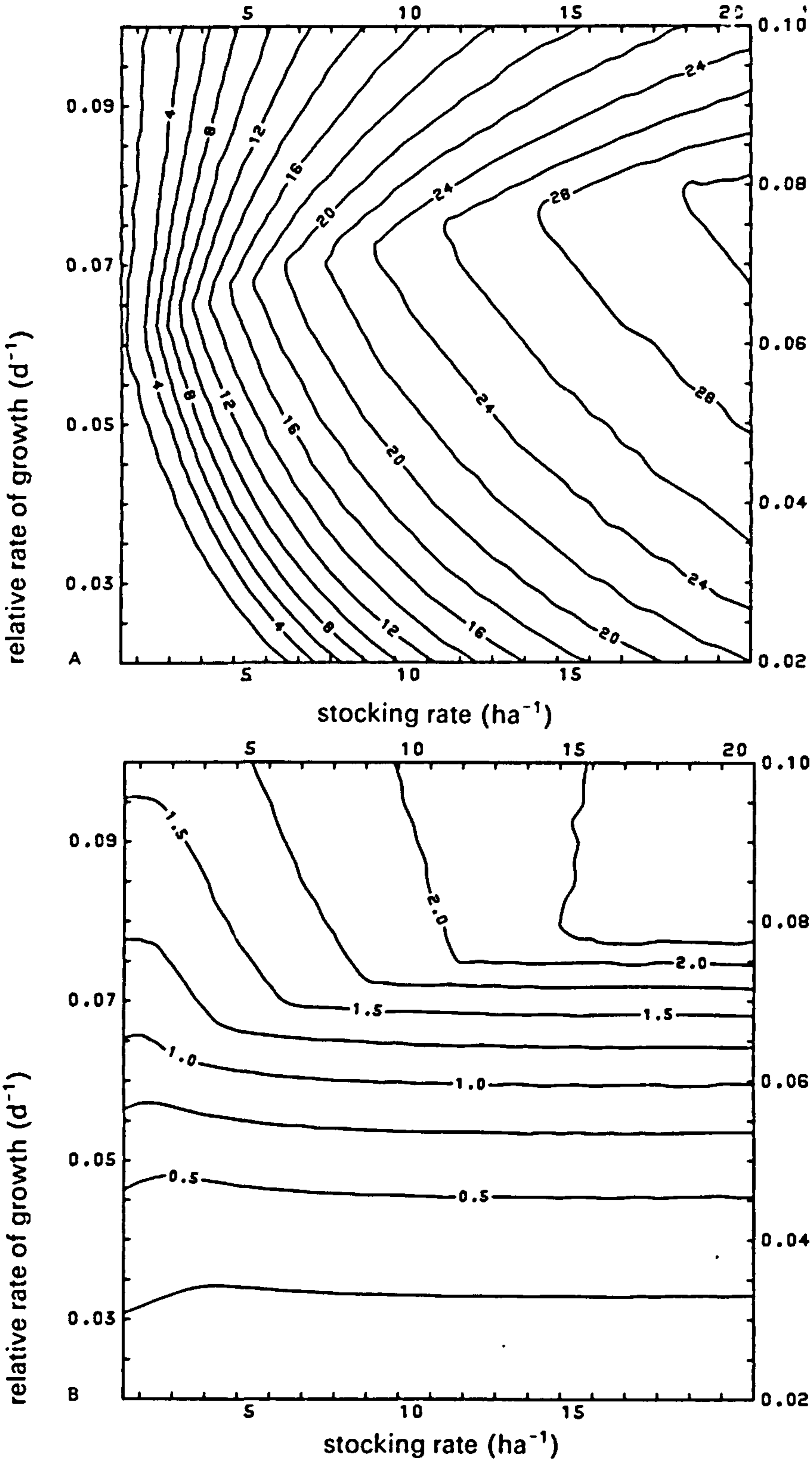


Figure 9. Results of the early-season green wheat grazing algorithm. A. Contour map of the optimum time of entry as a function of the relative growth rate of the wheat and stocking rate (contours, ha^{-1}). B. Contour map of the mean rate of herbage intake per animal ($kg\ d^{-1}$) as a function of the relative growth rate of the wheat and stocking rate (contours ha^{-1}). Computed for the period from the stock entry day until 6 weeks after emergence. Growth rate of herbage is defined by an exponential function. Rate of consumption of herbage is defined by a ramp function. Parameter values are as given in Table 4.

5.4.4 *Programming considerations*

The early-season wheat-grazing algorithm is one section of subroutine CRITEW (Chapter 11, Lines 1786-1825). All parameters and non-local variables used by the algorithm are given in Table 4. The stocking rate on wheat (parameter *H*) equals NEWES/WAAG. Unlike the growth function in the grazing-deferment algorithm, parameters of the wheat-growth function are based on conditions at the time the algorithm is invoked. Parameter μ in Equation 8 is computed from TADRW(2), GRODY(2) and IBIOM(2) by rearranging. A small computational saving is made by comparing only cumulative intake for grazing the wheat from the current decision time-step and from the next decision time-step.

Early-season wheat grazing is blocked if the expected average daily intake during the grazing period falls below some threshold (MNIEW). The algorithm returns a reply code of 1 if the cumulative intake from the current decision

Table 4. Parameters and non-local variables used by the algorithm for early-season grazing of wheat in the agropastoral model. The symbol used in the text is given alongside the name and acronym where applicable. The value is for the standard run of the model. Parameter VRES(2) is set to parameter VRESG during the green season; where VRESG = 50 kg ha^{-1}.

Name	Value	Acronym	Symbol
ewe's current nutritional locality (1)		EWELOC	
rate of intake per animal for satiation (kg d^{-1})	2.5	GDCS	i_s
time interval since emergence for wheat locality (d)		GRODY(2)	
initial aerial biomass at full emergence for wheat locality (kg ha^{-1})	50	IBIOM(2)	
time-step between management decisions (d)	5	MNGDEL	
minimum acceptable mean rate of intake (kg d^{-1})	0	MNIEW	
stocking rate of ewes + hoggets (ha^{-1})	5.0	NEWES	
'grazing efficiency' or slope of the rising section of the ramp function of rate of intake per animal (ha d^{-1})	0.005	S	s
total aerial biomass for wheat locality (kg ha^{-1})		TADRW(2)	V_i
ungrazable residual biomass for wheat locality (kg ha^{-1})	50	VRES(2)	V_r
area fraction of system to wheat available for grazing (1)		WAAG	
time limit of grazing from emergence (d)	42	WGTML	

time-step till WGTML is greater than that from the next decision time-step till WGTML, and if the mean expected average daily intake during the grazing period exceeds MNIEW. The reply code is otherwise 0. The algorithm is not invoked if the ewes have already started grazing the pasture area, and the decision is not re-evaluated once wheat grazing has commenced.

5.5 Late-season grazing of green wheat

5.5.1 Introduction

Sheep–wheat integration provides the option of using green wheat for grazing as an alternative to grain. The period for that decision commences at the end of the early-season wheat-grazing period (about six weeks after emergence), and terminates when the wheat crop is ready for harvest. However in the early phase of the decision period green biomass is probably low, i.e. the benefits of grazing are limited, and uncertainty about expected yield of grain is high. In mid-season, biomass of herbage and quality are both high and the expected yield of grain can be estimated with less uncertainty. During that period, the decision becomes most relevant.

To choose between grazing and grain, it is necessary to estimate the expected yield of grain. In a first analysis, elements of risk are ignored and so it is only the mean expected yield of grain that needs to be estimated. As in other short-term management decisions, the problem of maximizing gross margin is reformulated in terms that allow the subsystem to be identified and treated with a simple algorithm for the decision.

5.5.2 Calculating the expected yield of grain

The expected yield of grain is calculated by possible-outcome analysis. The possible outcomes are the yields of grain resulting from possible future rainfall patterns. Thus the calculation involves generating possible rainfall patterns from the moment of decision to the end of the season, the estimation of yield of grain from each rainfall pattern generated and the computation of the mean expected yield of grain. The simplest way of generating possible rainfall patterns is to merge the actual rainfall pattern since the start of the season with historical data for the remainder of the season. For the Migda site, over 20 possible rainfall patterns can be constructed in that way. That series of rainfall patterns can be converted to a set of possible yield outcomes by the use of regression equations or dynamic models.

A regression equation of yield of grain on 30-day rainfall was used. The equation was based on rainfall data and wheat yields for the Migda site (Table 5):

Table 5. Total rainfall over 30-day periods, total seasonal rainfall, actual yield of grain and predicted yield of grain from Equation 11 for Migda, 1962/63 to 1982/83.

season	rainfall (mm)								grain yield ($kg\ ha^{-1}$)	
	30-day period (from month-day/till month-day)							whole season	actual	predicted
	10-01/ 10-30	10-31/ 11-29	11-30/ 12-29	12-30/ 01-28	01-29 /02-27	02-28/ 03-29	03-30/ 04-28			
62/63	22	0	0	0	35	14	2	72	0	-332
63/64	3	8	151	96	37	54	7	354	2030	2778
64/65	0	73	39	198	15	55	35	414	3000	3141
65/66	55	13	4	22	64	61	0	219	950	1321
66/67	7	0	104	32	89	50	0	282	2200	1800
67/68	4	53	32	79	35	2	56	260	1600	1349
68/69	7	26	62	62	11	19	25	212	900	1103
69/70	14	60	0	45	7	39	5	170	550	604
70/71	4	7	80	66	17	7	82	263	1300	1359
71/72	0	41	154	26	73	56	0	349	2500	2505
72/73	0	71	55	95	5	19	0	245	1160	1564
73/74	0	66	11	119	109	25	41	371	2170	2388
74/75	0	40	47	28	105	32	0	251	1000	1300
75/76	8	22	64	21	74	15	0	204	670	1016
76/77	13	0	0	102	12	36	49	212	1120	927
77/78	13	3	75	22	16	30	0	159	920	679
78/79	0	19	38	56	15	72	0	200	960	848
79/80	7	27	97	110	76	47	4	368	3620	2824
80/81	0	10	174	41	33	54	0	312	2500	2299
81/82	0	45	0	42	101	72	0	260	1000	1197
82/83	11	120	28	107	55	45	3	369	3200	2685
mean	8	33	58	65	47	38	15	264	1588	1588

$$G = 18.7R_{1.10-30.10} + 9.6R_{31.10-29.11} + 12.5R_{30.11-29.12} + 12.3R_{30.12-28.1} + 8.7R_{29.1-27.2} + 7.3R_{28.2-29.3} + 4.4R_{30.3-28.4} - 1152 \qquad \text{Equation 11}$$

where

G is expected yield of grain ($kg\ ha^{-1}$)

R_{period} is total rainfall over the period (mm)

Any method of calculating yield of grain from rainfall data, including a complex simulation model, could be substituted here. That is not essential to the line of approach.

5.5.3 *Choosing between grazing and grain*

The choice between grazing and grain only arises if the combination of current pasture availability and current nutritional requirement of the ewe necessitates the provision of supplementary feed. (For lambs, the decision is based on different criteria to those outlined here. See Section 5.7.2.). To retain the option of harvesting some grain if conditions improve later in the season, the grazing option is taken for an area of green wheat that would provide the ewe's requirement for one decision time-step. Thus the wheat is strip-grazed. The decision is re-evaluated at each decision time-step. The model assumes that the option with the lowest net cost is consistent with overall gross margin maximization.

The net cost of choosing grain over grazing equals the supplementation cost on pasture:

$$C_h = i_c H p_c n \qquad \text{Equation 12}$$

where
C_h is cost of supplementary feeding on pasture (\$ ha^{-1})
i_c is rate of intake of supplementary feed on pasture (kg d^{-1})
H is stocking rate (ha^{-1})
p_c is price of supplementary feed (\$ kg^{-1})
n is time-step between management decisions (d)

The net cost of choosing grazing over grain is the forfeited grain income from an area of wheat that would provide the ewe's requirement over time n (d):

$$p_{f,w} = A(\bar{G} p_w - C_w) \qquad \text{Equation 13}$$

$$A = [i_s H n(1 + T)]/V_w \qquad \text{Equation 14}$$

where
$p_{f,w}$ is forfeited grain income (\$ ha^{-1})
A is fraction of system area grazed as wheat (1)
$\bar{G}$ is mean expected yield of grain (kg ha^{-1})
p_w is price of wheat grain (\$ kg^{-1})
C_w is costs of harvesting wheat grain (\$ ha^{-1})
i_s is rate of intake per animal for satiation (kg d^{-1})
T is strip-grazing wastage factor (1)
V_w is biomass of vegetative wheat that would be grazed (kg ha^{-1})

A fraction, A, of the system area is grazed as wheat if $C_h > p_{f,w}$:

$$i_c p_c H n > \{[i_s H n (1 + T)]/V_w\} (\bar{G} p_w - C_w) \qquad \text{Equation 15}$$

$$(i_c p_c)/[i_s(1 + T)] > (\bar{G} p_w - C_w)/V_w \qquad \text{Equation 16}$$

Equation 16 shows that the decision to graze or harvest wheat depends upon the ratio of expected yield of grain to vegetative biomass and not on the expected yield of grain alone.

In general, a lower expected yield of grain is associated with reduced vegetative production, and so the area under wheat that is equivalent to a given nutritional requirement increases as the expected yield of grain declines. Hence, a low expected yield of grain is not a sufficient condition for grazing. Stocking rate does not appear in Equation 16. It can nevertheless influence the decision through its effect on availability of herbage, and so on i_c (Equation 16).

The essential element in that decision is the way the harvest index (or some related index) changes with aridity. Grazing is more likely when there has been good early-season vegetative growth followed by severe moisture stress at a phenological stage that is critical to the determination of yield of grain.

5.5.4 *Programming considerations*

Calculating the expected yield of grain

Subroutine GRYPRO (Chapter 11, Lines 1897-1964) computes the expected yield of wheat grain. The current time (d) in the season and a vector of rainfall totals over 15-day periods from the start of the current season are passed to the algorithm. Historical rainfall data for one season is read from file. Those data are also given as totals over 15-day periods (Table 5). Actual rainfalls are substituted for historical values up to the end of the previous 15-day period in the season. Historical and current rainfall data for the current 15-day period are summed. The expected yield of grain is computed with Equation 11. That process is repeated for each record of historical data available on file. The mean expected yield of grain is computed and returned to the calling programme unit.

Choosing between grazing and grain

The late-season wheat-grazing algorithm is one section of subroutine CRITEW (Chapter 11, Lines 1843-1895). All parameters and non-local variables used by the algorithm are given in Table 6. There is some uncertainty about which plant fractions to include in V_w in Equation 14. To permit different definitions of V_w, an array WGCMPE is defined in the parameter file. Each element of that array corresponds to one plant fraction in the order live leaf, live non-leaf, grains, dead leaf, and dead non-leaf. An element is set to 1 if the corresponding plant fraction is assumed to be grazed. The algorithm sums the biomass of the selected plant fractions, and subtracts the ungrazable residual biomass, VRES(2), to obtain V_w. The algorithm returns a reply code of 0 without any further computations if

- the ewes are not currently being supplemented (ERSI = 0)
- the ewes are on pasture and herbage rate of intake (ERPI) is more than 90% (FRCS) of rate of intake for satiation (EWCS)
- the ewes grazed the wheat during the last decision time-step (EWELOC = 5).

If none of the conditions are met, the net cost of grazing and of not grazing the wheat are computed. If the net cost of grazing the wheat is less than the net cost of not grazing the wheat, the area under wheat to be allocated to the ewes is set (WAGRE), and the algorithm returns a reply code of 1.

As an indication of how sensitive the decision is to parametrization, the

Table 6. Parameters and non-local variables used in the algorithm for late-season grazing of wheat in the agropastoral model. The symbol used in the text is given alongside the name and acronym where applicable. The value is for the standard run of the model. Parameter PGYL6 is strictly a local variable but is passed on by subroutine GRYPRO. Parameter VRES(2) is set to parameter VRESG during the green season; where VRESG = 50 kg ha^{-1}.

Name	Value	Acronym	Symbol
vector of 15-day totals of daily rainfall for current season (mm)		ARF	
costs of harvesting wheat grain (\$ ha^{-1})	60.0	COSTH	C_w
approximate rate of intake per animal for satiation (kg d^{-1})	2.5	DACS	i_s
biomass of dead leaf for wheat locality (kg ha^{-1})		DLBIO(2)	
biomass of dead non-leaf for wheat locality (kg ha^{-1})		DNLBIO(2)	
ewe's rate of intake of herbage (kg d^{-1})		ERPI	
ewe's rate of intake of supplementary feed on pasture (kg d^{-1})		ERSI	i_c
ewe's mass rate of intake to meet energy requirements (kg d^{-1})		EWCS	
ewe's current nutritional locality (1)		EWELOC	
fraction of EWCS above which grazing of wheat is not considered (1)	0.9	FRCS	
time-step between management decisions (d)	5	MNGDEL	n
stocking rate of ewes + hoggets (ha^{-1})	5.0	NEWES	H
price of wheat grain (\$ kg^{-1})	0.22	PGRN	p_w
mean expected yield of wheat grain (kg ha^{-1})		PGYL6	$\bar{G}$
price ratio of supplementary feed for ewe to lamb (1)	0.8	PRELF	
price of supplementary feed for lambs (\$ kg^{-1})	0.25	PSUPPS	
time in season from 30 September (d)		SEADY	
ungrazable residual biomass for wheat locality (kg ha^{-1})	50	VRES(2)	V_r
area fraction of system to wheat available for grazing (1)		WAAG	
area fraction of system to green wheat allocated for late-season grazing of the ewe (1)		WAGRE	
array of components of green wheat selected by ewes during strip-grazing. 0 = not selected, 1 = selected. Order: live leaf, live non-leaf, seeds, dead leaf, dead non-leaf (1)	1 1 1 1 1	WGCMPE	
strip-grazing wastage factor (1)	0.1	WGWF	T
biomass of live leaf for wheat locality (kg ha^{-1})		WLVS(2)	
biomass of live non-leaf for wheat locality (kg ha^{-1})		WNLVS(2)	
biomass of seed for wheat locality (kg ha^{-1})		WSDS(2)	

algorithm computes the price of supplementary feed, the price of wheat grain, and the expected yield of grain that would result in an equal net cost of grazing and of not grazing the wheat. The closer the computed and actual values, the greater the sensitivity to parametrization.

5.6 Lamb feeding

5.6.1 Introduction

The management decision on supplementary feeding and feeding of complete rations to the lamb consists of whether to provide feed and at what rate. The choice of feed is not considered here; a concentrate rich in energy and protein is available. Since only functions for maintenance and liveweight change are involved in the growing lamb, lamb feeding can be optimized. The approach to optimization will depend on whether the system is time-based or product-based.

In time-based systems, there is no inherent limitation to availability of resources or total output, as typified by many industrial situations and some agricultural systems such as yarding of cattle and systems for milk production. Annual profit is maximized by maximizing the rate of profit generation. That requires identifying the input at which marginal income equals marginal cost.

In product-based systems, an essential resource or the total output is limited. That limitation imposes a ceiling on income that cannot be exceeded. Systems for fat-lamb production that produce the lamb 'resource' locally from breeding stock within the system fall into that category. Income is defined as the product of the number of lambs sold, the average weight at sale, and the meat price. The number of lambs sold cannot exceed the number born, and the weight at sale also has an upper limit that the market will accept. So annual profit is maximized by maximizing profit with respect to output rather than as a rate, and the optimum rate of feeding is that which minimizes the cost of gain in liveweight ($p\Delta$). The fact that time itself may represent a cost in terms of interest and risk does not alter the underlying approach. Such factors can be incorporated into the computation of $p\Delta$. (In systems employing accelerated breeding, limitations such as the capacity of the fattening installation may necessitate some deviation from operating in strict accordance with minimization of $p\Delta$. Nevertheless, that economic criterion remains the underlying target objective of all systems for fat-lamb production where lambs are produced locally.)

5.6.2 Model formulation

The functional form adopted is that given by GB-ARC (1980) relating scaled retention of energy to scaled intake of energy (scaling is in multiples of maintenance requirements):

$$E_{r,ret} = B[1 - \exp(-kE_{r,in})] - 1 \qquad \text{Equation 17}$$

where

$E_{r,ret}$ is scaled retention of energy (1)

$E_{r,in}$ is scaled intake of energy (1)

B, k are parameters, defined as functions of diet metabolizability.

Scaled retention of energy is converted to gain in liveweight as follows:

$$\mathrm{d}m(\mathrm{lamb})/\mathrm{d}t = E_{r,ret}\, \dot{E}_{net,m}/e_{\Delta} \qquad \text{Equation 18}$$

where

m(lamb) is lamb liveweight (kg)

$\dot{E}_{net,m}$ is rate of net energy required for maintenance (MJ d^{-1})

e_{Δ} is energy content of gain (MJ kg^{-1})

In the first analysis, only feed costs on a diet with a single feed are considered. In the agropastoral system, that would correspond to concentrate-based fattening in a fattening unit. Then $p\Delta$ is given by the ratio of the feed cost per unit time and the rate of gain in liveweight:

$$\begin{aligned} p\Delta &= p_{M,c}\, E_{r,in}\, \dot{E}_{net,m} /(E_{r,ret}\, \dot{E}_{net,m}/e_{\Delta}) \\ &= p_{M,c}\, E_{r,in}\, e_{\Delta}/\{B[1 - \exp(-kE_{r,in})] - 1\} \end{aligned} \qquad \text{Equation 19}$$

where

$p\Delta$ is cost of gain in liveweight (\$ kg^{-1})

$p_{M,c}$ is price of metabolizable energy in supplementary feed (\$ MJ^{-1})

To find $E_{r,in}{}^{*}$ that minimizes $p\Delta$, we differentiate for $E_{r,in}$ and set to zero. That rearranges to

$$1 - 1/B = \exp(-kE_{r,in})\,(1 + k\, E_{r,in}) \qquad \text{Equation 20}$$

$E_{r,in}{}^{*}$ must be found numerically. That solution can be shown to be identical to maximum biological gross efficiency (Blaxter & Boyne, 1978).

When not in a concentrate-based fattening unit, the lamb grazes some form of pasture and may be sucking milk as well. Minimum $p\Delta$ is no longer synonymous with maximum biological efficiency, since different feeds with different prices are involved. The computation of $p\Delta$ is more involved, since parameters B and k, and the price of metabolizable energy, change with dietary composition (i.e. rate of supplementary feeding). A substitution effect, where intake of supplementary feed displaces intake of pasture to some extent, should also be considered. A maximum of 15 variables are required in the calculation of $p\Delta$: the rate of intake, price, content of metabolizable energy and metabolizability of each of milk, supplementary feeds and pasture (in the absence of supplementary feed), the pasture substitution ratio, maintenance requirements of lambs ($\dot{E}_{net,m}$), and the energy content of gain (e_{Δ}). Here too, $E_{r,in}{}^{*}$ is found numerically with a simple algorithm.

Several time-based non-feed costs are incurred in the process of lamb production and those should be included in the analysis. Those costs might include labour, interest, overheads and a risk factor. Those costs can be lumped together as the time-dependent rate of expenditure, which is converted to a cost of gain by dividing by the rate of gain:

$$\dot{P}_t e_\Delta/(\dot{E}_{net,m} E_{r,ret}) = \dot{P}_t e_\Delta/(\dot{E}_{net,m}\{B[1-\exp(-kE_{r,in})]-1\}) \qquad \text{Equation 21}$$

where

$\dot{P}_t$ is rate of expenditure per lamb on time-dependent costs (\$ d^{-1})

The cost of gain in liveweight is then

$$p\Delta = (p_{M,c} E_{r,in} e_\Delta + \dot{P}_t e_\Delta/\dot{E}_{net,m})/\{B[1-\exp(-kE_{r,in})]-1\} \qquad \text{Equation 22}$$

Differentiating $p\Delta$ for $E_{r,in}$ and setting to zero yields:

$$1 - 1/B = \exp(-kE_{r,in})\{1 + k[E_{r,in} + \dot{P}_t/(\dot{E}_{net,m} p_{M,c})]\} \qquad \text{Equation 23}$$

If the term $\dot{P}_t/(\dot{E}_{net,m} p_{M,c})$ is much smaller than $E_{r,in}$, the inclusion of time-dependent rate of expenditure will have little effect on $E_{r,in}$*. The product $\dot{E}_{net,m} p_{M,c}$ represents feed costs per day for maintenance, and so $\dot{P}_t/\dot{E}_{net,m} p_{M,c}$ represents the ratio of non-feed rate of expenditure for 'maintenance' to rate of expenditure on feed for maintenance.

Note that the optimum rate of supplementary feeding is independent of the price of meat. If it is economical to continue lamb rearing at all (price of meat > $p\Delta$), supplementation should be at the rate as defined by Equation 23.

5.6.3 Behaviour of the model

A set of relationships between $p\Delta$ and rate of supplementary feeding is shown in Figure 10. Each graph shows the relationship for three rates of intake of pasture in the absence of supplementation ($i_{h,-c}$ = 0, 0.6, 1.0 kg d^{-1}). For intake of pasture>0, the relationship is shown for three substitution ratios of concentrates for herbage intake (S = 0, 0.5, 1.0).

The curve for $i_{h,-c}$= 0.6 kg d^{-1}, S = 1 is identical to the curve for $i_{h,-c}$= 0 beyond a rate of supplementary feeding of 0.6 kg d^{-1}, because substitution is complete above that rate of supplementary feeding, and actual intake of pasture is zero. Similarly, the curve for $i_{h,-c}$= 0.6 kg d^{-1}, S = 0.5 is identical to the curve for $i_{h,-c}$= 0 beyond a rate of supplementary feeding of 1.2 kg d^{-1}, and the curve for $i_{h,-c}$= 1.0 kg d^{-1}, S = 1 is identical to the curve for $i_{h,-c}$= 0 beyond a rate of supplementary feeding of 1.0 kg d^{-1}. That implicitly assumes that the grazing animal will consume all available supplementary feeds in preference to green pasture. Experience at Migda has not always confirmed that but, on the whole, it is a common situation.

Consider first the curves relating to a diet with only concentrates. As the rate of supplementary feeding increases beyond the rate for maintenance (at which $p\Delta$ tends to infinity), $p\Delta$ rapidly declines, levelling off as it approaches the minimum, and increases only slowly for supplementary feeding above the optimum. The implication for management is that in situations where ad libitum feeding exceeds the optimum rate of supplementary feeding, it is safer to overfeed than underfeed when uncertain. Suboptimum supplementary feeding can result in $p\Delta$ exceeding the price of meat.

The inclusion of time-dependent rate of expenditure shifts the cost curve upward and raises the optimum rate of supplementary feeding. For the value taken in those numerical examples, feeding would be ad libitum. The value $\dot{P}_t$ = 0.25 \$ d^{-1} is extreme. Interest on a lamb of value \$150, for example, would reach about 0.08 \$ d^{-1} at an interest rate of 20% per year. Any other non-feed costs, per lamb, are likely to be low.

Curves with feeding for the two maintenance requirements (Figure 10) demarcate the response envelope to that variable from a low estimate for a housed lamb to a high estimate for the grazing animal (of about 22 kg liveweight). The effect of $\dot{E}_{net,m}$ is greatest at low rates of supplementary feeding (and rates of growth) where the maintenance component is large. In the absence of time-based costs, $E_{r,in}$* is independent of $\dot{E}_{net,m}$ (Equation 20) and $p\Delta$ at $E_{r,in}$* remains constant with $\dot{E}_{net,m}$. Where $\dot{P}_t > 0$, the effect of $\dot{E}_{net,m}$ on $p\Delta$ is more complex and is contrary to intuition. $E_{r,in}$* decreases with increasing $\dot{E}_{net,m}$, though the optimum rate of supplementary feeding in absolute terms increases. $p\Delta$ at the optimum decreases slightly with increasing $\dot{E}_{net,m}$.

On pasture, if some minimum rate of growth can be supported in the absence of supplementary feeding and if the time-dependent rate of expenditure is low, no supplementary feeds should be provided. If intake of pasture in the absence of supplementation is insufficient to support growth or if the time-dependent rate of expenditure is high, the optimum rate of supplementary feeding tends to be ad libitum. Few of the cost curves shown in Figure 10 show an intermediate optimum rate of supplementary feeding.The response space of optimum rate of supplementary feeding to some parameters relevant to the calculation of $p\Delta$ shows large regions without supplementary feeding and with supplementary feeding ad libitum mediated by a fairly narrow zone of intermediate rates of supplementary feeding. It is reasonable to assume that, under field conditions, the system will traverse that boundary region fairly rapidly (e.g. increasing pasture availability, increasing time-dependent rate of expenditure, declining milk yield) and the problem of supplementary feeding of lambs reduces to a choice between two extreme, easily implemented actions.

As demonstrated earlier in other management decisions, there is a 'neutral' zone of low sensitivity in the parameter response space. The cost curves for $\dot{E}_{net,m}$ = 3.5 MJ d^{-1}, $\dot{P}_t$ = 0.25 \$ d^{-1}, $i_{h,-c}$ = 1.0 kg d^{-1}, at low pasture substitution ratios, show low sensitivity of $p\Delta$ to a wide range of rates of supplementary feeding. Intuitively, the effect of supplementation on the dietary cost is almost exactly offset by the effect on rate of growth. Since the optimum rate of supplementary feeding switches from zero to ad libitum over a narrow range of parameter space, the effect of a parameter change on the optimum will largely depend on how close one is to the switch-over zone to start with. Thus it is only relevant to estimate certain values of parameters accurately in the sensitive zone of the response space.

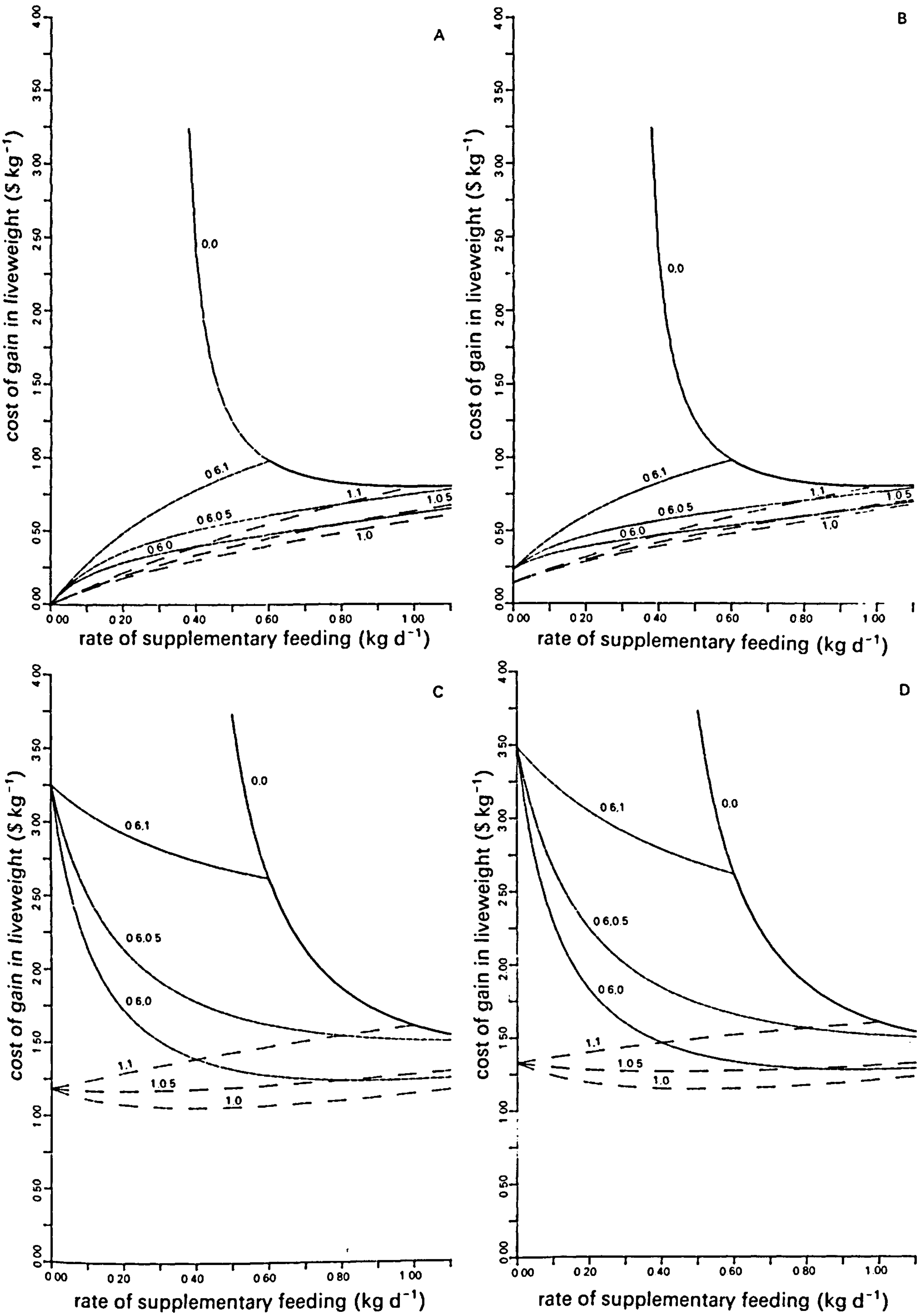


Figure 10. Cost divided by liveweight gain of lamb as a function of rate of supplementary feeding.

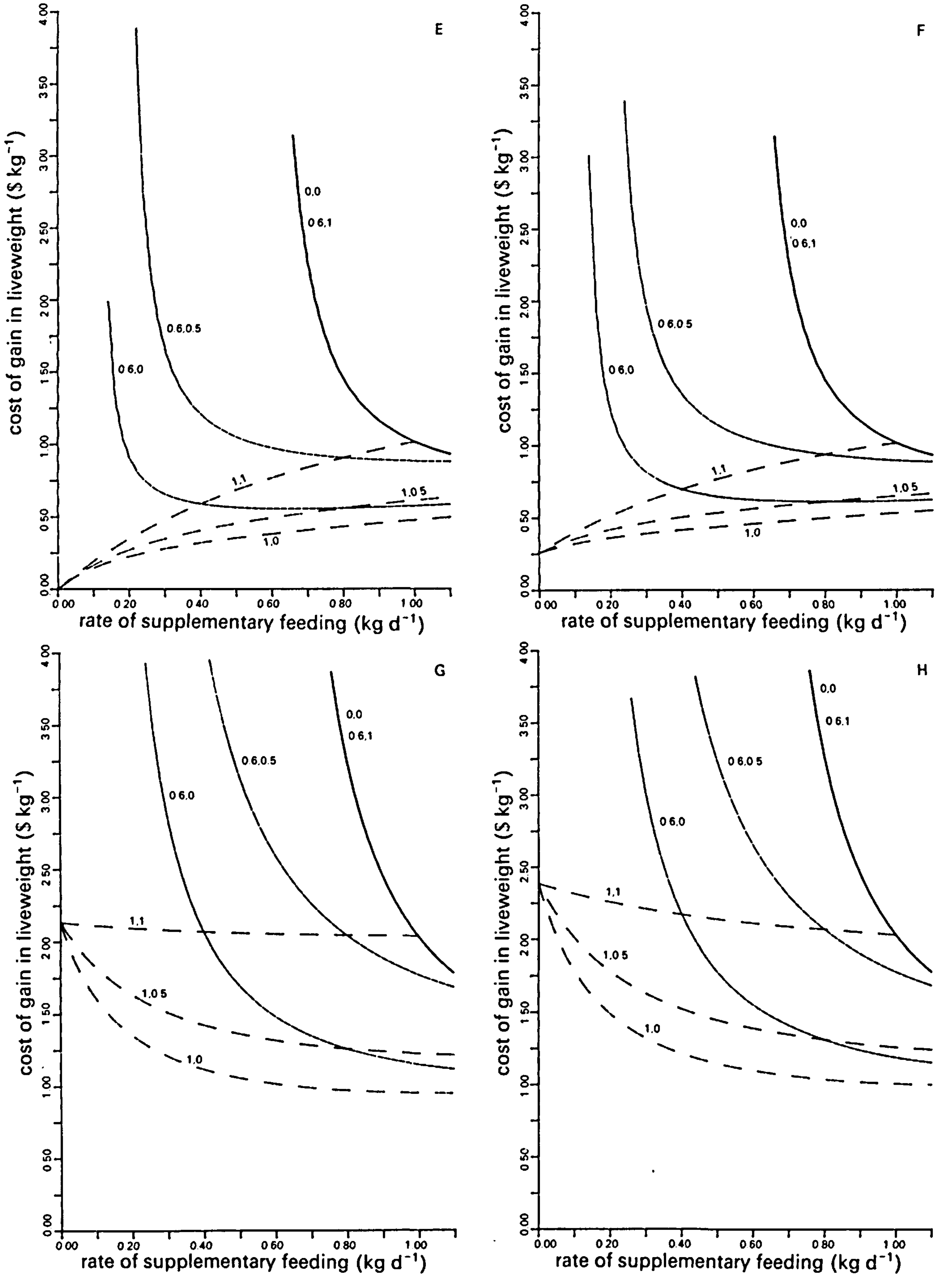


Figure 10 continued

In the agropastoral model, all herbage consumed by the lamb is ascribed a zero price except when green wheat is being grazed as an alternative to grain. Computation of the price of grazed herbage is given in Section 5.7.2. Intake of milk is also priced if the ewe is being supplemented at the time. Computation of the price of milk is given in Section 6.3.

5.6.4 Programming considerations

Supplementary feeding of lambs is optimized in subroutine SUPOPT (Chapter 11, Lines 2169-2301). Parameters and non-local variables used by the algorithm are given in Table 7. Most of the equations in that subroutine concern the feeding system and are explained in Section 6.2.

5.7 Lamb rearing

5.7.1 Approach

The problem of management in lamb rearing is to select a rearing pathway that maximizes profit. The rearing pathway is a nutritional time course, where nutrition is determined by the physical locality of the lamb in the system, whether the lamb is sucking and supplementary feeding. In an agropastoral system, eight nutritional localities can be defined:
- holding paddock whilst sucking
- holding paddock after weaning
- pasture (green or dry) whilst sucking
- pasture (green or dry) after weaning
- wheat (green or dry) whilst sucking
- wheat (green or dry) after weaning
- special-purpose pasture after weaning
- fattening unit after weaning.

Figure 10. Cost of gain in liveweight gain of lamb as a function of rate of supplementary feeding. Number pairs are $i_{\mathrm{h},-\mathrm{c}}$, rate of herbage intake in the absence of supplementation (kg d^{-1}), and S, substitution rato of concentrates for herbage intake (1). A. Rate of net energy required for maintenance, $\dot{E}_{\mathrm{net,m}} = 3.5\ \mathrm{MJ\ d^{-1}}$, cost of grazed herbage, $p_{\mathrm{p}}=0$, rate of expenditive per lamb on time-dependent costs, $P_t =$ O. B. $\dot{E}_{\mathrm{net,m}} = 3.5\ \mathrm{MJ\ d^{-1}}, p_p = 0.03\ \$\ \mathrm{kg^{-1}}$, $\dot{P}_t = 0$. C. $\dot{E}_{\mathrm{net,m}} = 3.5\ \mathrm{MJ\ d^{-1}}, p_p = 0, \dot{P}_t = 0.25\ \$\ \mathrm{d^{-1}}$. D. $\dot{E}_{\mathrm{net,m}} = 3.5\ \mathrm{MJ\ d^{-1}}, p_p = 0.03\ \$\ \mathrm{kg^{-1}}, \dot{P}_t = 0.25\ \$\ \mathrm{d^{-1}}$. E. $\dot{E}_{\mathrm{net,m}} = 6\ \mathrm{MJ\ d^{-1}}, p_p = 0, P_t = 0$. F. $\dot{E}_{\mathrm{net,m}} = 6\ \mathrm{MJ\ d^{-1}}, p_p = 0.03\ \$\ \mathrm{kg^{-1}}, P_t = 0$. G. $\dot{E}_{\mathrm{net,m}} = \mathrm{MJ\ d^{-1}}, p_p = 0, P_t = 0.25\ \$\ \mathrm{d^{-1}}$. H. $\dot{E}_{\mathrm{net,m}} = \mathrm{MJ\ d^{-1}}, p_p = 0.03\ \$\ \mathrm{kg^{-1}}, P_t = 0.25\ \$\ \mathrm{d^{-1}}$.

Table 7. Parameters and non-local variables used by subroutine SUPOPT of the agropastoral model. The value is for the standard run of the model. Parameters related to the nutritional system are explained in Section 6.2.

Name	Value	Acronym
allowance for activity in maintenance requirement. Equations 44, 45 (MJ kg^{-1} d^{-1})	0.010 6	AAP
cost of gain in liveweight of lamb ($ kg^{-1})		CPUG
intercept in equation defining fraction of maximum allowance for grazing activity to add to requirements for maintenance. Equations 43, 44, 45 (1)	0.15	FGF1
slope in equation defining fraction of maximum allowance for grazing activity to add to requirements for maintenance. Equations 43, 44, 45 (1)	0.85	FGF2
maximum energy requirement for grazing activity relative to requirements for maintenance. Equations 43, 44, 45 (1)	0.73	GF
indicator of grazing by lamb. 0 = not grazing, 1 = grazing (1)		GRAZL
age of lamb (d)		LAGE
e_Δ function: lamb, solid diet, intercept. Equations 49, 53 (MJ kg^{-1})	2.3	LEP1
e_Δ function: lamb, solid diet, slope. Equations 49, 53 (MJ kg^{-2})	0.4	LEP2
e_Δ function: lamb, milk diet, intercept. Equations 52, 53 (MJ kg^{-1})	3.73	LEP3
e_Δ function: lamb, milk diet, slope. Equations 52, 53 (MJ kg^{-2})	0.419	LEP4
content of metabolizable energy of herbage grazed by lambs (MJ kg^{-1})		LMEPA
function table giving rate of intake of concentrate ad libitum (kg d^{-1}) in relation to liveweight of lamb (kg)	Figure 17	LPDMIT
substitution ratio of concentrates for herbage intake by lambs (1)		LPSUBF
metabolizability of herbage grazed by lambs (1)		LQMP
lamb's expected rate of intake of whole milk if moved to a sucking locality (kg d^{-1})		LRMIX
lamb's expected rate of intake of herbage in absence of supplementary feeding (kg d^{-1})		LRPIX
optimum rate of supplementary feeding of lamb (kg d^{-1})		LRSIX
mass fraction of solids in ewe's milk (kg kg^{-1} = 1)	0.2	MDMC
content of metabolizable energy in supplementary feed (MJ kg^{-1})	12.55	MESU
content of metabolizable energy in ewe's whole milk (MJ kg^{-1})	4.6	MEWM
k_f function: ewes and weaners, slope. Equations 33, 35 (1)	0.78	PKF1
k_f function: ewes and weaners, intercept. Equations 33, 35 (1)	0.006	PKF2
k_f function: lamb, milk diet. Equation 35 (1)	0.7	PKF3

Table 7 continued

Name	Value	Acronym
k_m function: ewes and weaners, slope. Equations 30, 32 (1)	0.35	PKM1
k_m function: ewes and weaners, intercept. Equations 30, 32 (1)	0.503	PKM2
k_m function: lamb, milk diet. Equations 31, 32 (1)	0.85	PKM3
cost ascribed to ewe's whole milk in lamb's diet ($ kg^{-1})		PMILK
cost ascribed to lamb's intake of herbage ($ kg^{-1})		PPAST
price of supplementary feed for lambs ($ kg^{-1})	0.25	PSUPPS
time-dependent rate of expenditure for lamb rearing ($ d^{-1})		PTIME
metabolizability of ewe's milk (1)	0.7	QMM
metabolizability of supplementary feed (1)	0.622	QMS
tolerance limit of $p\Delta$ in optimization ($ kg^{-1})	0.000 1	TOL
weight exponent in equation for requirements for maintenance. Equations 40, 44, 45 (1)	0.75	WE
liveweight of lamb (kg)		WLAM

The fattening unit and holding paddock for weaners are nutritionally equivalent.

In the development of the agropastoral model, we intended to avoid, as far as possible, the definition a priori of rearing criteria. Instead, all possible options are defined, and the algorithm selects between them on the basis of a single economic criterion. The rearing options are contained in the lamb-movement matrix, which defines the possible flow links between each of the rearing localities. The standard configuration is shown in Figure 11.

	to	holding paddock		pasture		wheat		medic	fattening unit
from		sucking	weaned	sucking	weaned	sucking	weaned	weaned	weaned
holding paddock	sucking	1	1	1	1	1	1	1	1
	weaned	0	1	0	1	0	1	1	1
pasture	sucking	1	0	1	1	1	1	1	1
	weaned	0	0	0	1	0	1	1	1
wheat	sucking	1	0	1	1	1	1	1	1
	weaned	0	0	0	1	0	1	1	1
medic	weaned	0	0	0	0	0	1	1	1
fattening unit	weaned	0	0	0	1	0	0	1	1

Figure 11. The matrix of lamb movement, which defines all possible transfers between nutritional localities of lambs in an agropastoral system. 0, transfer is not permitted; 1, transfer is, in principle, permitted. Lambs can be born into and sold from any locality.

Selection of the rearing pathway is based on a comparison of all possible management alternatives, as defined by the matrix. Thus the first step in the analysis is to predict lamb performance for each possible alternative, which should be calculated at the optimum rate of supplementary feeding for the locality with the algorithm described in Section 5.6. The second step in the analysis is to compare lamb performance at the various localities by a single economic criterion. Just as the optimum rate of supplementary feeding at a given nutritional locality is that which minimizes the cost of gain in liveweight ($p\Delta$), here also the optimum locality is that which provides the lowest $p\Delta$ (for which rate of income accretion is positive). With that approach, it is not necessary to set criteria for weaning, supplementary feeding or sale of lambs.

That crude short-term optimization approach is inadequate if the response surface has local optima that represent a significantly lower total income than the global optimum. That would mean that there are circumstances where it might be more profitable to suffer poor economic performance in the short term in order to follow a pathway providing high income later. Such a possibility is not taken into account in the present approach. However the optimality of a rearing pathway can be checked by using the lamb-movement matrix to force alternative rearing pathways.

5.7.2 Programming considerations

The pathway of lamb rearing is determined in subroutine LAMOVE (Chapter 11, Lines 1965-2168). Parameters and non-local variables used by the algorithm are given in Table 8. In view of its central role in the model, the algorithm is described here in some detail. There are three stages to the algorithm.

1. The lamb-movement matrix (LMM) defines all transfers between localities that the user permits. The row of LMM that corresponds to the current locality for lambs (LAMLOC) is copied into an option vector. At that point, the vector contains the maximum set of options. Some of those may have to be excluded at the outset. If the lambs are not weaned and the ewe's body condition (EBC) is below some threshold (EBCLIM), all sucking localities in the option vector are set at zero. That will force weaning. If EBC>EBCLIM, the ewe's current locality (EWELOC) is the only option of a sucking locality retained for the lambs. The model is formulated such that the ewe's locality is determined independently of considerations of lamb rearing. Thus the lamb has to follow the ewe to continue sucking. The model does not accommodate separate localities for grazing ewes and lambs during the day with night-time access of the lambs to their dams. The lowest weaning age is 21 d. That limit should avoid the need to introduce the effect of early weaning on lamb survival. Estimating such an effect would be fairly arbitrary, yet even a small change in lamb survival rates could have a large impact on system profitability. These criteria of age limit and the ewe's body condition are the only explicit non-economic criteria of lamb rearing used in the algorithm.

Table 8. Parameters and non-local variables used by subroutine LAMOVE of the agropastoral model. The symbol used in the text is given alongside the name and acronym, where applicable. The value is for the standard run of the model. Parameter PGYL5 is strictly a local variable but is passed on by subroutine GRYPRO. Parameter VRES(2) is set to parameter VRESG during the green season and to VRESD during the dry season; where VRESG = 50, VRESD = 300 kg ha^{-1}.

Name	Value	Acronym	Symbol
area fraction of system to pasture (1)	0.5	AREA(1)	
area fraction of system to special-purpose pasture (1)	0	AREA(3)	
vector of 15-day totals of daily rainfall for current season (mm)		ARF	
cost of gain in liveweight of lamb at the selected locality (\$ kg^{-1})		CLLWG	
costs of harvesting wheat grain (\$ ha^{-1})	60	COSTH	C_w
cost of gain in liveweight of lamb (\$ kg^{-1})		CPUG	$p\Delta$
switch for culling ewes. 0 = no, 1 = yes (1)		CULL	
biomass of dead leaf for wheat locality (kg ha^{-1})		DLBIO(2)	
biomass of dead non-leaf for wheat locality (kg ha^{-1})		DNLBIO(2)	
stage of development of wheat locality (1)		DVS(2)	
ewe's body condition score (1)		EBC	
threshold of ewe's body condition score below which weaning is forced (1)	1	EBCLIM	
ewe's current nutritional locality (1)		EWELOC	
indicator of grazing by lamb. 0 = not grazing, 1 = grazing (1)		GRAZL	
time interval since emergence for wheat locality (d)		GRODY(2)	
age of lamb (d)		LAGE	
code for present locality of lambs (1)		LAMLOC	
matrix for lamb movement (1)	Figure 11	LMM	
substitution ratio of concentrates for herbage intake by lambs (1)		LPSUBF	S
lamb's actual rate of intake of whole milk (kg d^{-1})		LRMI	
lamb's expected rate of intake of whole milk if moved to a sucking locality (kg d^{-1})		LRMIX	
lamb's expected rate of intake of herbage in absence of supplementary feeding (kg d^{-1})		LRPIX	$i_{h,-c}$
lamb's actual rate of intake of supplementary feed (kg d^{-1})		LRSI	

Table 8 continued

Name	Value	Acronym	Symbol
optimum rate of supplementary feeding of lamb (kg d^{-1})		LRSIX	
time-step between management decisions (d)	5	MNGDEL	
stocking rate of lambs, including replacements (ha^{-1})		NLAMS	
price of wheat grain (\$ kg^{-1})	0.22	PGRN	p_w
mean expected yield of wheat grain (kg ha^{-1})		PGYL5	$\bar{G}$
cost ascribed to lamb's intake of herbage (\$ kg^{-1})		PPAST	p_p
price of lamb's meat (\$ kg^{-1})	2.5	PRLAM	
time in season from 30 September (d)		SEADY	
switch for selling lambs. 0 = no, 1 = yes (1)		SELL	
maximum liveweight of lambs at sale (kg)	45	SLVWT	
ungrazable residual biomass for green and dry herbage for wheat locality (kg ha^{-1})	50, 300	VRES(2)	V_r
area fraction of system to wheat available for grazing (1)		WAAG	
area fraction of system to green wheat allocated for late-season grazing of lambs (1)		WAGRL	
switch for weaning lamb. 0 = no, 1 = yes (1)		WEAN	
indicator of weaning status. 0 = not weaned, 1 = weaned (1)		WEANED	
array of components of green wheat selected by lambs during strip-grazing. 0 = not selected, 1 = selected. Order: live leaf, live non-leaf, seeds, dead leaf, dead non-leaf (1)	1 1 1 1 1	WGCMPL	
time limit of early-season grazing of green wheat from emergence (d)	42	WGTML	
strip-grazing wastage factor (1)	0.1	WGWF	T
liveweight of lamb (kg)		WLAM	
biomass of live leaf for wheat locality (kg ha^{-1})		WLVS(2)	
biomass of live non-leaf for wheat locality (kg ha^{-1})		WNLVS(2)	
biomass of seed for wheat locality (kg ha^{-1})		WSDS(2)	

(As yet, EBC has never reached EBCLIM, since feedbacks built into the simulation of intake, supplementary feeding and performance are sufficiently strong to prevent EBC falling so low. Furthermore, performance of lambs weaned less than 21 d old is poor, and such an option would generally not be selected even if allowed in principle.)

2. For each option remaining in the option vector, the algorithm calls subroutine INTAK to compute intake-related variables, and subroutine SUPOPT to optimize supplementary feeding and compute $p\Delta$. Subroutine INTAK computes six variables required by either subroutine LAMOVE or subroutine SUPOPT:

- metabolizability of herbage grazed by the lambs (LQMP)
- content of metabolizable energy in herbage grazed by the lambs (LMEPA)
- expected rate of herbage intake in the absence of supplementary feeding (LRPIX)
- current rate of intake of milk (LRMI), computed if the lamb has not been weaned
- cost ascribed to ewe's whole milk in lamb diet (PMILK), computed if the ewe is receiving supplementation
- substitution ratio of concentrates for herbage intake by lambs (LPSUBF).

If the locality for lambs being tested is the current locality of the ewe, the expected rate of intake of milk (LRMIX) is set to LRMI. Otherwise, LRMIX = 0.

A complication arises when the locality for lambs being tested is late-season grazing of green wheat (i.e. as an alternative to grain). One approach might be to compare the value of wheat for grain with the value of wheat biomass converted to meat. However such an approach would only be valid if grain and meat production were mutually exclusive. That is not so in the agropastoral system. The correct approach is to incorporate the forfeited grain revenue from the grazed area into the feed cost of the animal and thereby into $p\Delta$. The algorithm calls subroutine GRYPRO, which returns the mean expected yield of grain. The price of grazed wheat herbage is defined as

$$p_p = (1 + T)(\bar{G}\, p_w - C_w)/V_w \qquad \text{Equation 24}$$

where

p_p is price of grazed wheat herbage (\$ kg^{-1})
T is strip-grazing wastage factor (1)
$\bar{G}$ is mean expected yield of grain (kg ha^{-1})
p_w is price of wheat grain (\$ kg^{-1})
C_w is costs of harvesting wheat grain (\$ ha^{-1})
V_w is biomass of vegetative wheat that would be grazed (kg ha^{-1})

There is some uncertainty about which plant fractions to include in V_w in Equation 24. To permit different definitions of V_w, an array WGCMPL is defined in the parameter file. Each element of that array corresponds to one plant fraction. An element is set to 1 if the corresponding plant fraction is assumed to be grazed. The algorithm sums the biomass of the selected plant fractions and subtracts the ungrazable residual biomass, VRES(2), to obtain V_w.

Subroutine SUPOPT is called. That computes the optimum rate of supplementary feeding (LRSIX) and the corresponding cost of gain in liveweight (CPUG). If CPUG is less than the price of lamb's meat (PRLAM), the values LRSIX and CPUG are stored.

3. If none of the localities in the options vector yielded CPUG$<$PRLAM or if the maximum weight at sale of the lamb has been reached, the lambs are sold. Localities for which CPUG$<$0 (through liveweight loss being predicted) are ruled out, as long as at least one locality yielded CPUG$>$0. (Liveweight loss can occur when predicting performance of young lambs at localities without milk. The maximum intake of dry matter from solid feed may be inadequate to meet maintenance requirements.) The locality with the lowest CPUG is found (or the locality with the maximum CPUG if all CPUG$<$0), and the rate of supplementary feeding of lambs and the new locality for lambs are set accordingly.

If the new locality for lambs is late-season green wheat, the area under wheat to be allocated to grazing is computed. An equation similar to Equation 14 for the ewes is used, except that i_s is replaced by the expected rate of herbage intake by the lamb. That equals the herbage intake in the absence of supplementary feeding for the wheat locality (computed by subroutine INTAK) minus the product of the optimum rate of supplementary feeding (LRSI) and the substitution ratio of concentrates for herbage intake by lambs (LPSUBF).

Finally, if a change in locality for lambs happens to involve a move from a sucking to a weaned nutritional locality, the weaning and culling switches are set.

5.8 Baling of straw

5.8.1 Introduction

The decision on baling of straw determines the amount of wheat straw to bale rather than leave in the field. The amount baled should be the biomass that is surplus to grazing requirements during the dry season. Since straw is baled soon after harvesting grain, the decision needs to be based on expected daily requirements during the dry season. The decision should consider the amount of wheat aftermath and dry pasture available and the rate of 'disappearance' of biomass by processes other than grazing.

5.8.2 Algorithm for the decision

A simple algorithm for the decision calculates the amount of straw to bale. It assumes that the rate of disappearance of dry biomass is negligible in the absence of the grazing animal, but cannot be ignored when the dry biomass is grazed. The difference is largely due to the effect of trampling. Thus when grazed, the rate of change in availability of biomass (when availability does not limit intake, i.e. $V \geqslant V_s$, where V_s is the biomass at which rate of intake for satiation is reached) is given by

$$dV/dt = -d\,V - i_s\,H \qquad \text{Equation 25}$$

where
V is biomass (kg ha^{-1})

d is relative rate of 'disappearance' of dry herbage during the dry season (d^{-1})
i_s is rate of intake per animal for satiation (kg d^{-1})
H is stocking rate (ha^{-1})

The biomass remaining after grazing for time t (assuming $V \geqslant V_s$ throughout the grazing period) equals

$$V_t = V_i \exp(-dt) - i_s H/d [1 - \exp(-dt)] \qquad \text{Equation 26}$$

where
V_t is biomass remaining after grazing time t (kg ha^{-1})
V_i is biomass at start of grazing (kg ha^{-1})

To find the grazing time (at satiation) provided by dry pasture, V_i in Equation 26 is set to the availability of dry pasture at the time of decision about baling of straw, V_t in Equation 26 is set to V_s, and the equation rearranged:

$$t_h = 1/d \ln [(V_i + i_s H/d) / (V_s + i_s H/d)] \qquad \text{Equation 27}$$

where
t_h is grazing time (at satiation) provided by dry pasture (d)

The grazing time required on wheat aftermath, $t_{q,req}$, is then:

$$t_{q,req} = \max [0, t_{d,req} - t_h] \qquad \text{Equation 28}$$

where
$t_{d,req}$ is grazing time from the decision until ploughing (d)

To find the biomass of wheat aftermath required to provide intake for satiation for a period $t_{q,req}$, t in Equation 26 is set to $t_{q,req}$, V_t is set to V_s, and the equation rearranged:

$$V_q = (V_s + i_s H/d)/\exp(-d\, t_{q,req}) - i_s H/d \qquad \text{Equation 29}$$

where
V_q is biomass of wheat aftermath required (kg ha^{-1})
The amount of straw baled is then the difference between the biomass of wheat aftermath and V_q. If the biomass that cannot be picked up by the baler exceeds V_q, that value is substituted for V_q in calculating the amount of straw baled. Straw is never baled if the cost of baling (\$ kg^{-1}) exceeds the estimated value of straw (\$ kg^{-1}).

5.8.3 *Programming considerations*

The decision is handled by subroutine STRABAL (Chapter 11, Lines 2703-2790). All parameters and non-local variables used by the algorithm are given in Table 9. The algorithm is invoked once immediately after harvest of grain. The baling option is not considered if there is too little biomass in the wheat field (TADRW (2)⩽STLEFT), or if the baling cost exceeds the value of straw (BALEC⩾PSTRW), or if the option switch prevents baling (STROP<0). If STROP>0 (and the biomass and price criteria are met), the maximum amount

Table 9. Parameters and non-local variables used by subroutine STRABAL of the agropastoral model. The symbol used in the text is given alongside the name and acronym where applicable. The value is for the standard run of the model.

Name	Value	Acronym	Symbol
approximate rate of intake of dry biomass per animal for satiation (kg d^{-1})	1.5	APCS	i_s
area fraction of system to pasture (1)	0.5	AREA (1)	
cost of baling wheat straw ($ kg^{-1})	0.018	BALEC	
time in year from 31 December (d)		DAY	
relative rate of disappearance of dead leaf (d^{-1})	0.004	DCLV	
relative rate of disappearance of dead non-leaf (d^{-1})	0.002	DCNLV	
stocking rate of ewes + hoggets (ha^{-1})	5.0	NEWES	
time of ploughing from 31 December (d)	290	PLOWD	
price of straw ($ kg^{-1})	0.06	PSTRW	
array for priority ranking of all localities		RATING	
biomass of wheat straw baled with respect to system area (kg ha^{-1})		STBL	
biomass of straw left in field by baler (kg ha^{-1})	1200	STLEFT	
switch for baling of straw: ⟨0 = do not bale straw; 0 = bale according to normal criteria; ⟩0 = bale maximum if value greater than costs of baling (1)	0	STROP	
total aerial biomass for pasture locality (kg ha^{-1})		TADRW(1)	
total aerial biomass for wheat locality (kg ha^{-1})		TADRW(2)	
dry biomass at which rate of intake for satiation is reached (kg ha^{-1})	1200	VSATD	V_s
area fraction of system to wheat available for grazing (1)		WAAG	

(TADRW(2) - STLEFT) is baled, irrespective of expected animal requirements. When the option switch is inoperative (STROP = 0), the amount baled is the biomass that is surplus to the requirements for grazing in the dry season.

The algorithm needs to consider any user-determined restrictions that may have been imposed on the ewe's grazing schedule. If the ewe has access to both the localities dry pasture and wheat aftermath (as in the standard run), t_h, $t_{q,req}$, and V_q are computed as before. If access by the ewe to the locality dry pasture is blocked (for whatever reason), $t_{q,req}$ is set to $t_{d,req}$, and V_q is computed. If access by the ewe to the locality wheat aftermath is blocked, the maximum amount is baled.

5.9 Cutting of wheat for hay

5.9.1 Introduction

The option of grazing as late-season utilization of green wheat was discussed earlier. A second alternative to grain is to cut the wheat for hay. Here too, the period for that decision commences at the end of the early-season wheat-grazing period and terminates when the wheat crop is ready for harvest. The decision is based on a comparison of the current value of the standing biomass as hay and the value of the expected yield of grain.

Since the options of buying and selling hay have not been included in the model, one could argue that the value of the crop of hay should be defined in terms of supplementary feed saved, rather than some arbitrary monetary value. However the amount of purchased feed that will be replaced by a crop of hay depends on numerous future events and decisions, and is extremely difficult to estimate beforehand. So the market value has been taken as the value of the crop of hay. The value of the expected harvest of grain is computed by the algorithm as in Sections 5.5.2 and 5.5.4.

5.9.2 Algorithm for the decision

The simplest way of treating the decision is to assume that the expected yield of grain is a reliable estimate. If so, the entire area under wheat should be cut for hay if the profit from cutting hay exceeds the expected profit from grain. (That will, of course, be optimum in the long term and not necessarily in any particular year.) A more sophisticated approach would be to consider the likelihood of the expected yield of grain changing as the season progresses. The optimum strategy might then be only to harvest some portion of the area under wheat for hay at any single decision. Since it is not clear beforehand whether cutting for hay is ever a feasible alternative to grain, it was decided to adopt the simpler approach. The rule is to cut the entire area under wheat for hay if the following conditions are met:

- the value of the current crop of hay exceeds the costs of harvesting hay
- hay is more profitable than grain, assuming the expected yield of grain
- conditions do not indicate that hay would be more profitable if cut at the time of the next decision.

The value of hay ($\$\ kg^{-1}$) is defined as a function of crop development stage (DVS), since that is closely correlated to quality. It remains at a maximum up to DVS = 0.4, declines linearly to 43% of the maximum at DVS = 0.74, and remains at that value afterwards. It always exceeds the costs of harvesting hay under the standard parameter set. The amount of hay cut is estimated to be the current biomass of wheat minus a constant amount that cannot be collected. The algorithm assumes that the value of the crop of hay with respect to area ($\$\ ha^{-1}$) increases up to DVS = 0.65, unless the crop is suffering severe water stress.

Table 10. Parameters and non-local variables used by subroutine HAYCUT of the agro-pastoral model. The symbol used in the text is given alongside the name and acronym where applicable. The value is for the standard run of the model.

Name	Value	Acronym	Symbol
vector of 15-day totals of daily rainfall for current season (mm)		ARF	
costs of harvesting wheat grain ($\$ \, ha^{-1}$)	60.0	COSTH	C_w
cumulative transpiration deficit for wheat locality (1)		CTRDEF(2)	
stage of development of wheat locality (1)		DVS(2)	
forced price of hay (overrides calculated value if ≥0) ($\$ \, kg^{-1}$)	-1	FORCPH	
expected yield of wheat hay ($kg \, ha^{-1}$)		HAYLD	
costs of cutting wheat for hay ($\$ \, ha^{-1}$)		HVCH	
cumulative transpiration deficit above which cutting for hay, if feasible, is not delayed (1)	1.0	HYCTR	
stage of development above which cutting for hay, if feasible, is not delayed (1)	0.65	HYDVS	
costs of harvesting hay: intercept of cost function ($\$ \, ha^{-1}$)	0	HYHC1	
costs of harvesting hay: slope of cost function ($\$ \, kg^{-1}$)	0.017	HYHC2	
biomass of wheat left in field by baler ($kg \, ha^{-1}$)	1200	HYLEFT	
option of cutting hay: <0 = do not cut hay; 0 = cut according to normal criteria; >0 = cut if value greater than costs of harvesting (1)	0	HYOP	
ratio of top to bottom price of hay (1)	2.3	HYPF1	
parameter in function for price of hay: effect of stage of development (1)	1.7	HYPF2	
price of best-quality hay ($\$ \, kg^{-1}$)	0.1	HYTOPP	
price of wheat grain ($\$ \, kg^{-1}$)	0.22	PGRN	p_w
mean expected yield of wheat grain ($kg \, ha^{-1}$)		PGYHY	$\bar{G}$
time in season from 30 September (d)		SEADY	
total aerial biomass for wheat locality ($kg \, ha^{-1}$)		TADRW(2)	
area fraction of system to green wheat available for grazing (1)		WAAG	
area fraction of system to green wheat to be cut for hay (1)		WACH	

5.9.3 Programming considerations

The decision is handled by subroutine HAYCUT (Chapter 11, Lines 2639-2702). All parameters and non-local variables used by the algorithm are given in Table 10. The price of hay ($ kg^{-1}) is defined as HYPF2 * HYTOPP * (1 – DVS (2)), constrained between a lower limit of HYTOPP/HYPF1 and an upper limit of HYTOPP. The parameter FORCPH can be used to override that price function. Subroutine GRYPRO provides the expected yield of grain, which is required to calculate the expected profit from grain. Parameter HYOP can be used to override the decision criteria. If HYOP$<$0, hay is never cut. If HYOP$>$0, hay is cut if the value of the crop of hay covers harvesting costs, irrespective of the expected profit from grain.

6 Biological and financial framework of simulation

6.1 Primary production

6.1.1 Use of ARID CROP

Simulation of primary production is based on the model ARID CROP (van Keulen, 1975; van Keulen et al., 1981). ARID CROP simulates primary production under semiarid conditions where water is limiting but not nutrients (Figure 12). The model was based on data from fertilized natural pastures at Migda. No

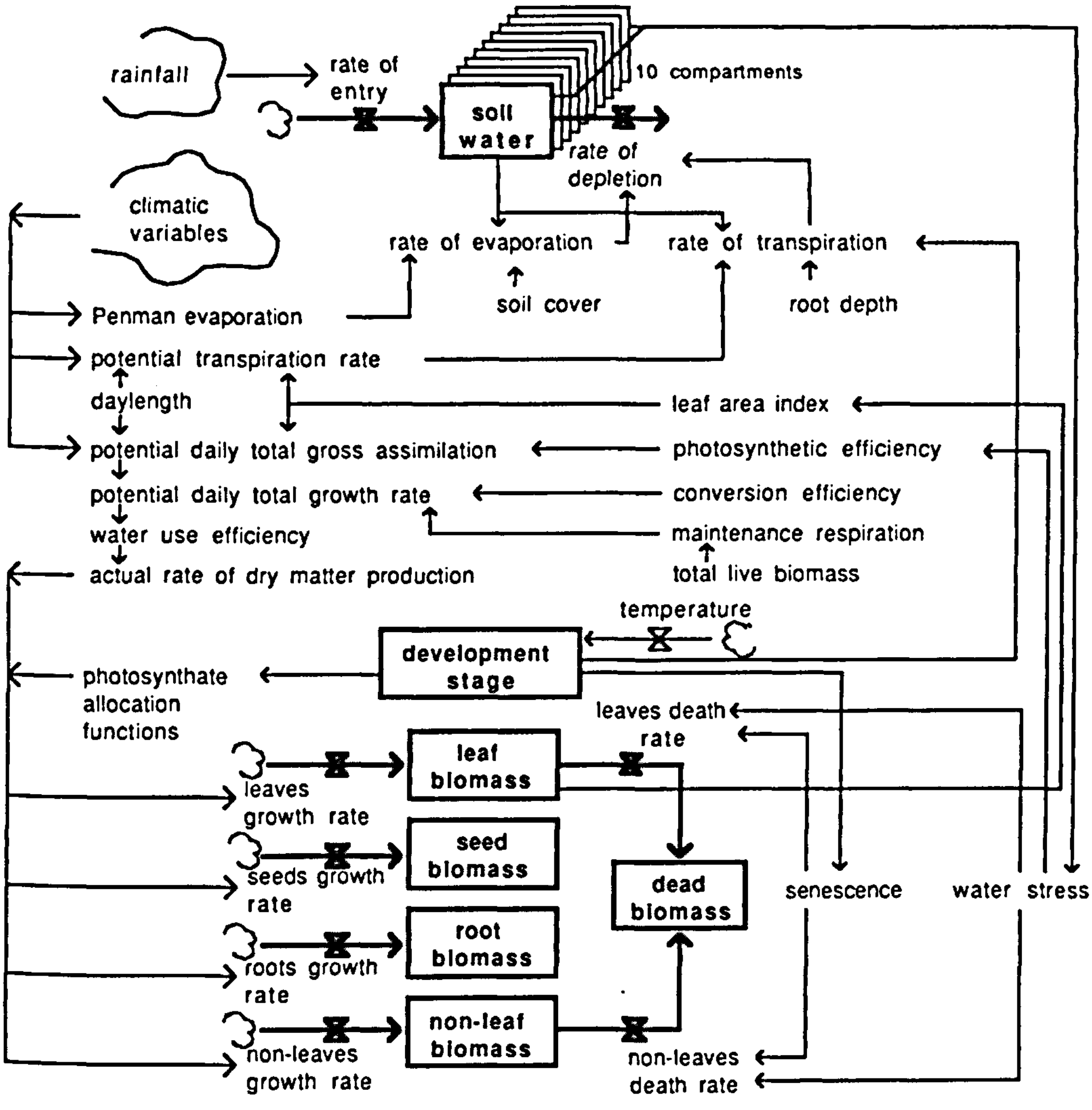


Figure 12. Simplified diagrammatic description of the simulation model ARID CROP. Boxes, state variables (integrals); bold flows, material flows; valves, rates of change; clouds, material source outside system boundary; narrow lines major causal pathways.

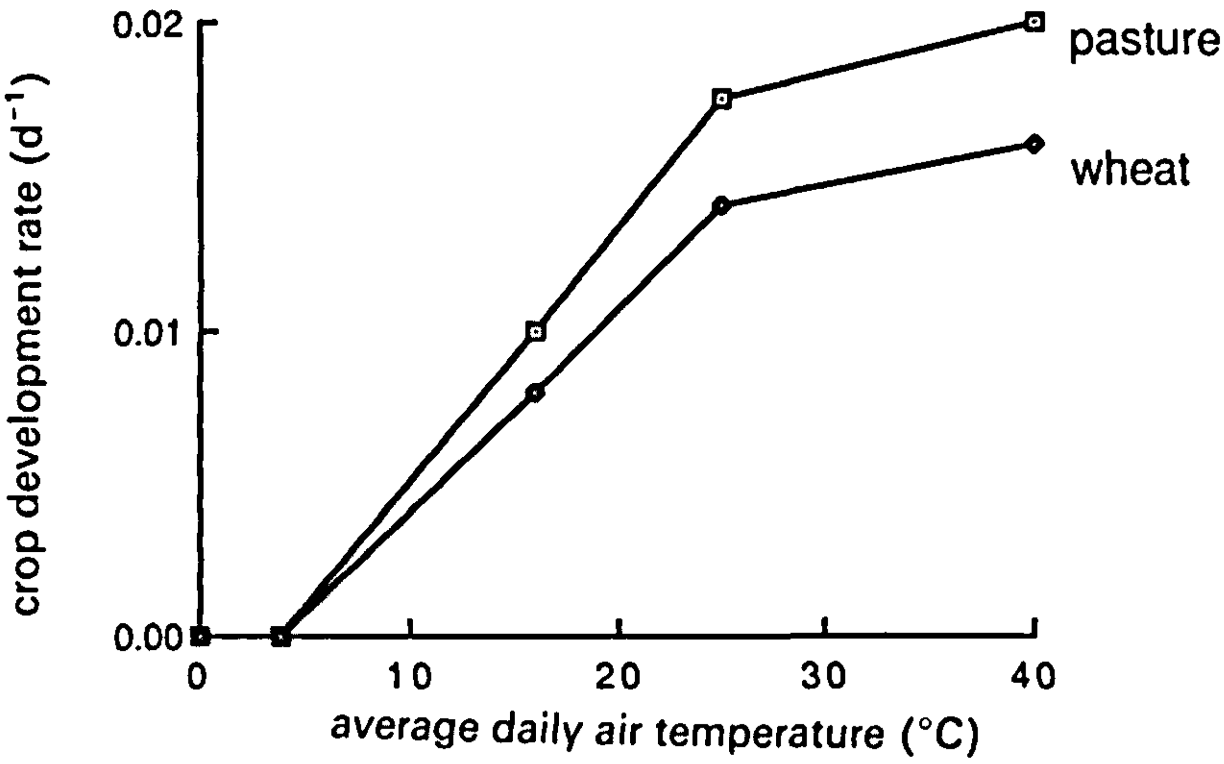


Figure 13. Rate of development of crop (DVR) as a function of average daily air temperature (TMPA). Stage of development of crop (DVS) is the integral of rate development of the crop over time, and serves as the phenological clock of the plant in simulating primary production.

major adjustments were made in incorporating ARID CROP into the agropastoral model, except to distinguish between primary production of natural pasture, wheat and medic swards. The following functions and parameters change according to species.

The stage of development of the crop (DVS) is defined as the integral of the rate of development, which is a function of mean daily temperature. Many functional relations in ARID CROP and in the intake subroutine (the digestibility of plant fractions) are defined by DVS. For any temperature, the wheat and medic develop at 80% of the rate for natural pasture (Figure 13). Thus wheat and medic reach full maturity after natural pasture.

A feature distinguishing between pasture, wheat and medic is the allocation of photosynthetic products between plant sinks. Separate state variables are defined for roots, leaves, stems ('non-leaf') and seeds. DVS is used as the main determinant of allocation of photosynthetic products. Figure 14 shows the functions taken for allocation in the three species.

An efficiency of 0.75 for the conversion of primary photosynthetic products to structural plant material is assumed for both pasture and wheat. An efficiency of 0.66 is taken for medic to reflect the higher requirements for protein synthesis.

An initial aerial biomass at full emergence of 50 kg ha^{-1} is taken for pasture and wheat, and 40 kg ha^{-1} for medic.

The model also assumes an effect of species on digestibility of herbage and hence on rate of intake of herbage. Those aspects are explained in Section 6.3.

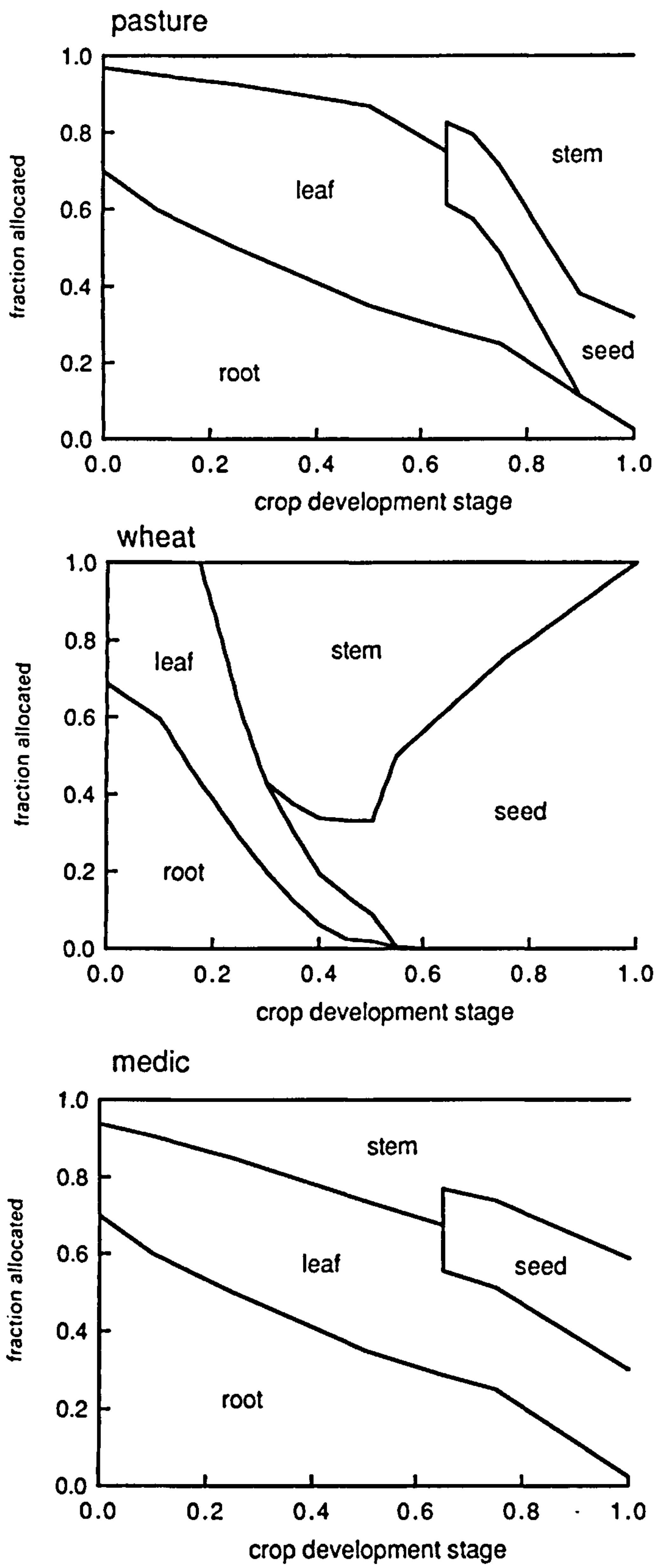


Figure 14. Allocation of photosynthetic products between plant sinks as a function of crop development stage for pasture, wheat, and medic. The graphs were derived from the allocation function tables for photosynthetic products in ARID CROP. These are: CSRRT, CSRRTW, DISTFT, DISTFTM, DISTFTW, and GRAINT; all shown in Figure 15. The graphs are for unstressed growth.

6.1.2 *Programming considerations*

ARID CROP was originally coded in CSMP and translated to FORTRAN in the early stages of this study. Ungar & van Keulen (1982) give a description, listing and directory of the FORTRAN version. It is contained in subroutine SRATES of the agropastoral model (Chapter 11, Lines 1183-1561). Besides the adjustments listed in Section 6.1.1, dry-season processes were added to the model. When full maturity is reached (DVS = 1), values for green leaf and non-leaf material are transferred to the corresponding integral for dead biomass. Seed biomass is set at zero at the end of the green season because

- no attempt is made to relate seed biomass at the end of the green season to the initial biomass at emergence in the following season
- research at Migda indicates that the availability to the grazing animal of seed from natural pasture over the summer months is low, through efficient foraging for seeds by harvester ants and burial of seeds in the soil surface (Luria, 1984)
- yield of wheat grain is computed by a regression equation from rainfall (Section 5.5.2) and not by subroutine SRATES, since that was found to yield better predictions.

All parameters and non-local variables used by the subroutine are given in Table 11. Figure 15 shows the function tables used in ARID CROP. Initial values taken for dead leaf and dead non-leaf biomass at the start of any simulation are 400 and 600 kg ha^{-1}, respectively. Those values are taken irrespective of the year in which simulation starts.

6.2 Animal nutrition and production

The agropastoral model calculates the performance of the ewe and lamb for any diet. Even though feeding of the ewe is target-oriented (Section 5.1), some deviation from the 'norm' in body weight and lactation curve is permitted in response to nutrition. The model also calculates the ewe's energy requirements for any current physiological state or performance. That is required because the rate of intake of the ewe is related to physiological state and energy requirements. Hence a fairly detailed set of equations is needed to describe nutrition.

The calculation of requirements and performance is based upon energy balance. Almost all the equations are from GB-ARC (1980).

Table 11. Parameters used by subroutine SRATES of the agropastoral model. The value is for the standard run of the model. Parameters ADWW, IRTD, LBIB, TIMN and TIMX appear in the main program, not in subroutine SRATES.

Name	Value	Acronym
content of water in air-dry soil relative to content at wilting point (1)	0.333	ADWW
potential maximum rate of gross assimilation of CO_2 (single leaf) (kg ha^{-1} h^{-1})	40	AMAXB
conversion efficiency of primary photosynthetic product (CH_2O) to structural plant material (dry matter) for pasture and wheat (kg kg^{-1} = 1)	0.75	CONFS
conversion efficiency of primary photosynthetic product (CH_2O) to structural plant material (dry matter) for medic (kg kg^{-1} = 1)	0.66	CONFSM
integration time-step (d)	1	DELT
extension rate of the roots under optimum conditions (mm d^{-1})	12	DGRRT
dryness factors of consecutive soil compartments at start of season relative to content of moisture at wilting point for all localities (1)	0.5, 0.75, 0.8, 0.9, 1.0, 1.0, 1.0, 1.2, 1.2, 1.2	DRF
rate of development of crop as a function of average daily air temperature	(Figure 13)	DVRT
stage of development at which seed fill starts for pasture and medic (1)	0.65	DVSSF
basic potential effectiveness of utilization of light at compensation point (kg ha^{-1} h^{-1} W^{-1} m^2)	0.5	EFFEB
field capacity (m^3 m^{-3} = 1)	0.23	FLDCP
mass fraction of water in dead plant material (1)	0.1	FWDB
psychrometer constant (mmHg °C^{-1})	0.49	GAMMA
initial aerial biomass at full emergence for pasture (kg ha^{-1})	50	IBIOM(1)
initial aerial biomass at full emergence for wheat (kg ha^{-1})	50	IBIOM(2)
initial aerial biomass at full emergence for medic (kg ha^{-1})	40	IBIOM(3)
rooting depth at emergence for all localities (mm)	101	IRTD
latitude (Migda Farm)	31	LAT
limiting biomass to be considered, as fraction of initial biomass (1)	0.5	LBIB
quotient of area to mass of leaf (m^2 kg^{-1})	20	LFARR
enthalpy of vaporization of water (10 kcal kg^{-1})	59	LHVAP

Table 11 continued

Name	Value	Acronym
respiration factor for maintenance (kg kg^{-1} d^{-1} = d^{-1})	0.02	MRESF
maximum depth of rooting (mm)	1800	MXRTD
π constant (1)	3.141 6	PI
proportionality factor for division of evaporation of water from soil over various soil compartments (1)	15	PROP
psychrometric constant (mbar $°C^{-1}$ = 100 Pa K^{-1})	0.67	PSCH
cuticular resistance (d cm^{-1})	0.000 37	RC
reflectance of water (1)	0.05	REFCF
reference temperature for maintenance respiration (°C)	25	REFT
volumic heat capacity of air (cal cm^{-3} $°C^{-1}$ = 4.2 MJ m^{-3} K^{-1})	0.000 286	RHOCP
minimum stomatal resistance (d cm^{-1})	0.000 018 5	RS
time constant for build-up of cumulative transpiration deficit (d)	10	TCDPH
time constant for dying of leaf from water shortage (d)	5	TCDRL
time constant for dying of non-leaf from water shortage (d)	5	TCDRNL
thickness of consecutive soil compartments from surface (cm)	2, 3, 5, 10, 10, 30, 30, 30, 30, 30	TCK
time constant for decline in cumulative transpiration deficit (d)	10	TCRPH
initial minimum temperature of soil (°C)	17.2	TIMN
initial maximum temperature of soil (°C)	30.0	TIMX
temperature sum required for emergence (°C d)	150	TSUMG
volume fraction of water in soil at wilting point (m^3 m^{-3} = 1)	0.075	WLTPT

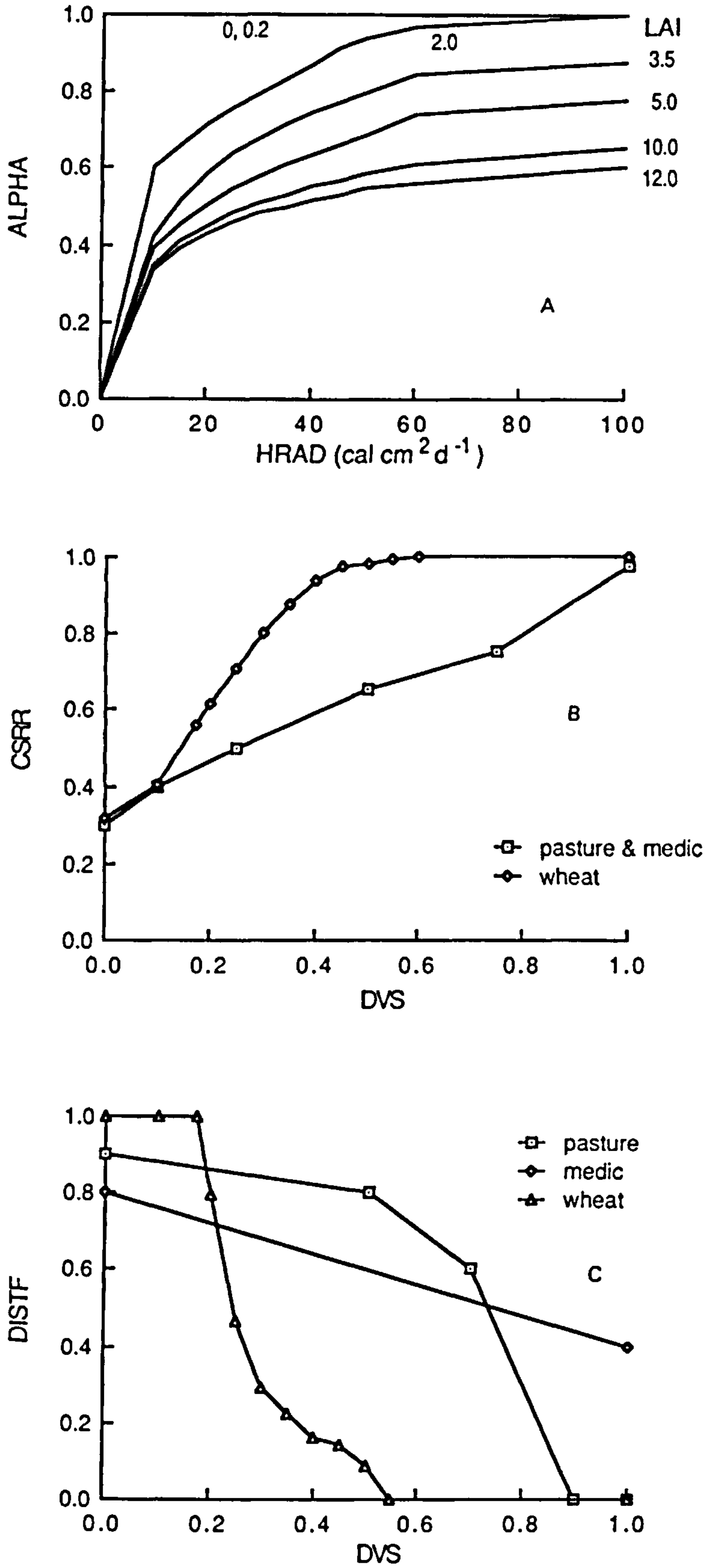
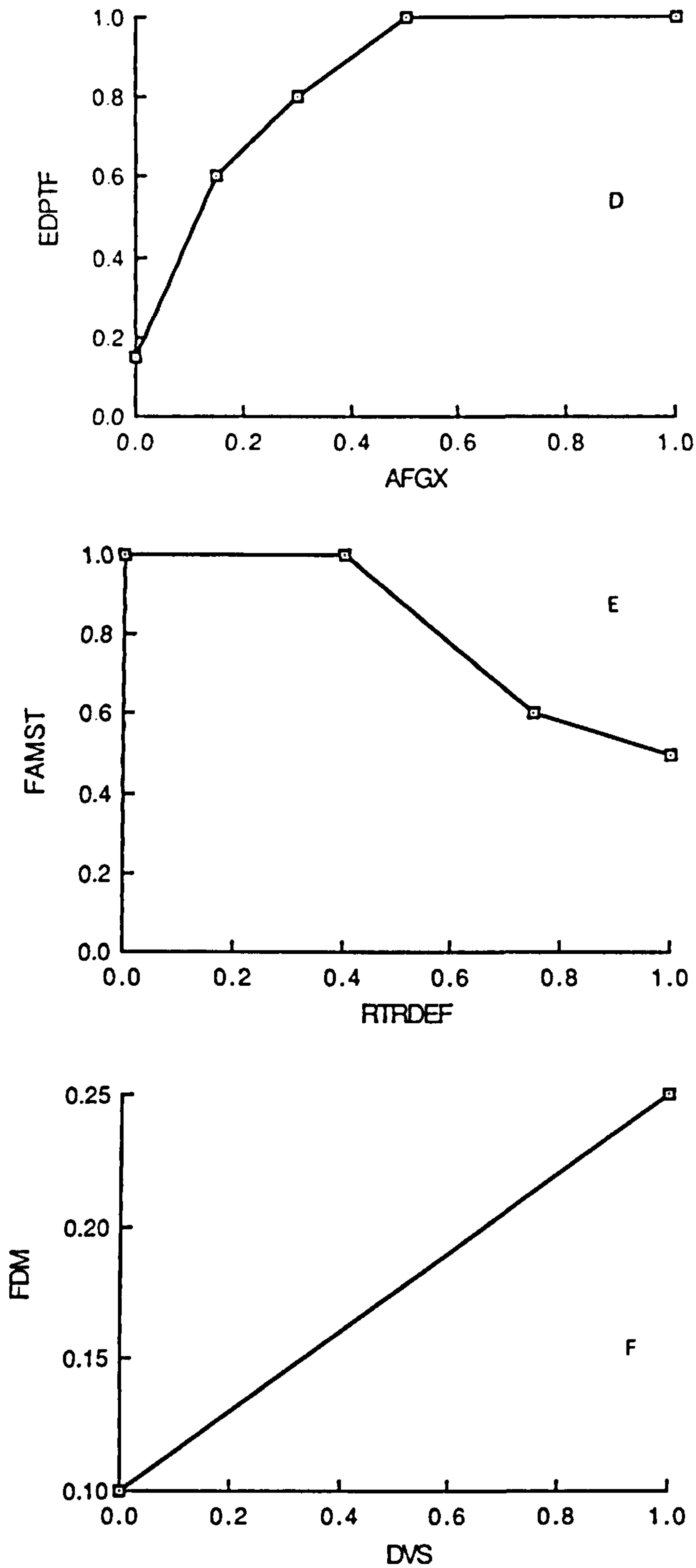


Figure 15. Function tables in the simulation model ARID CROP.



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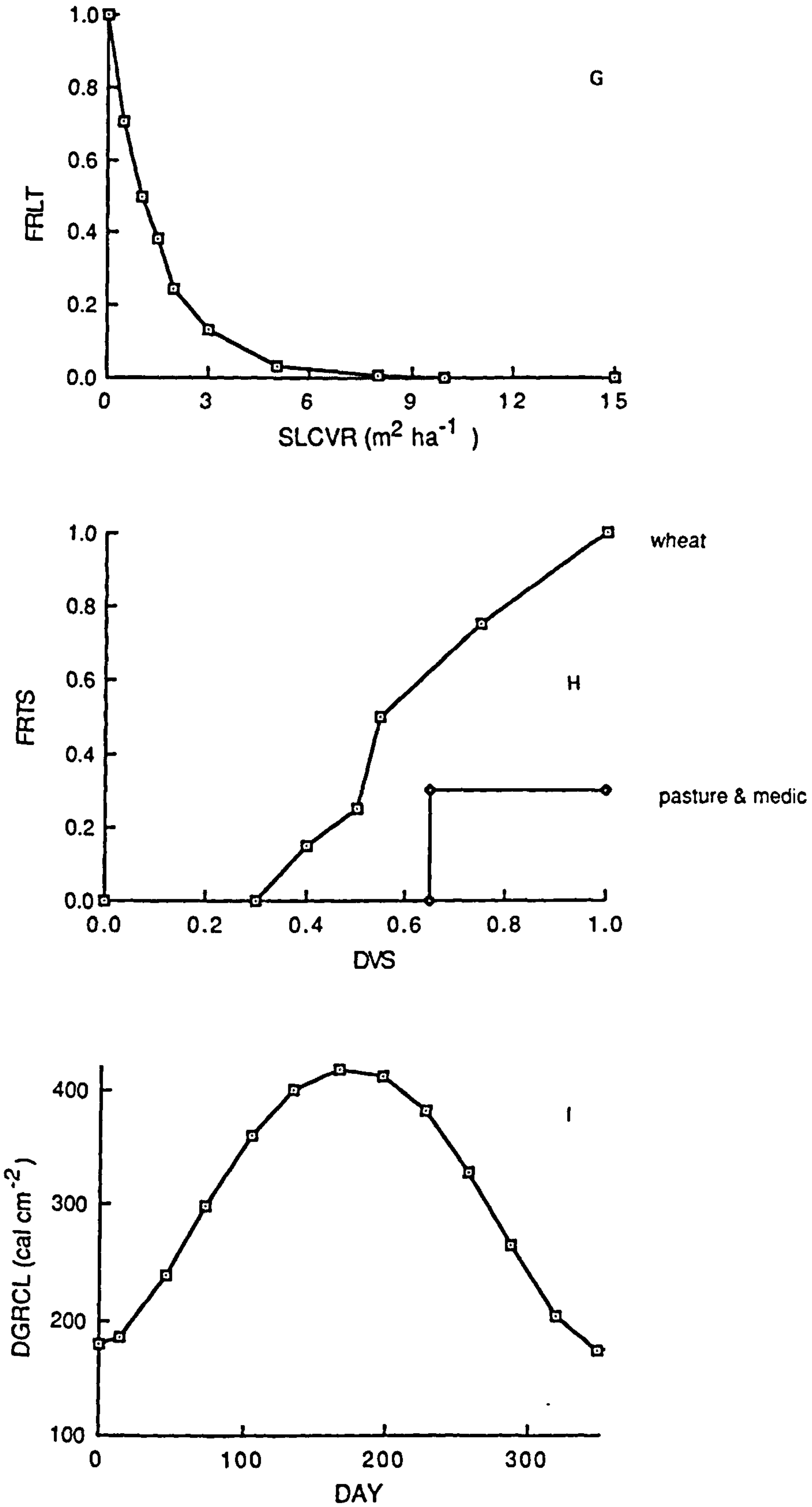

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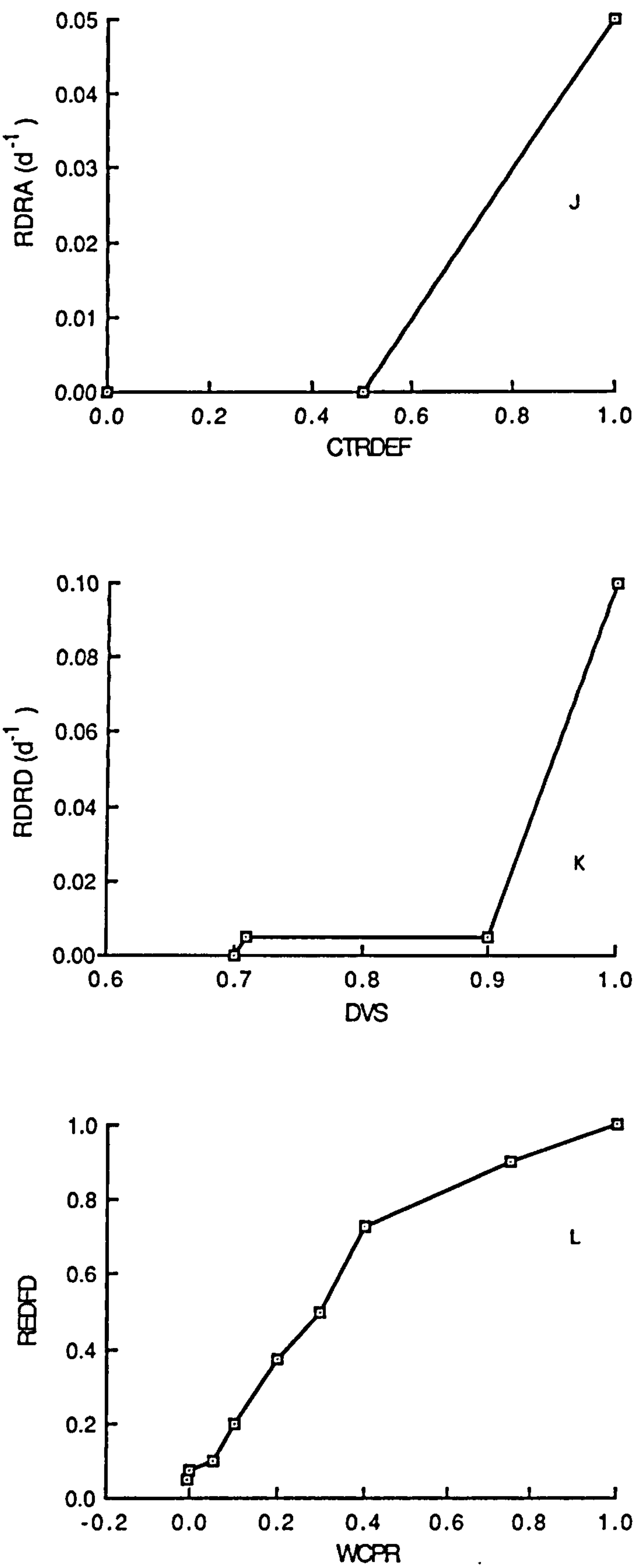

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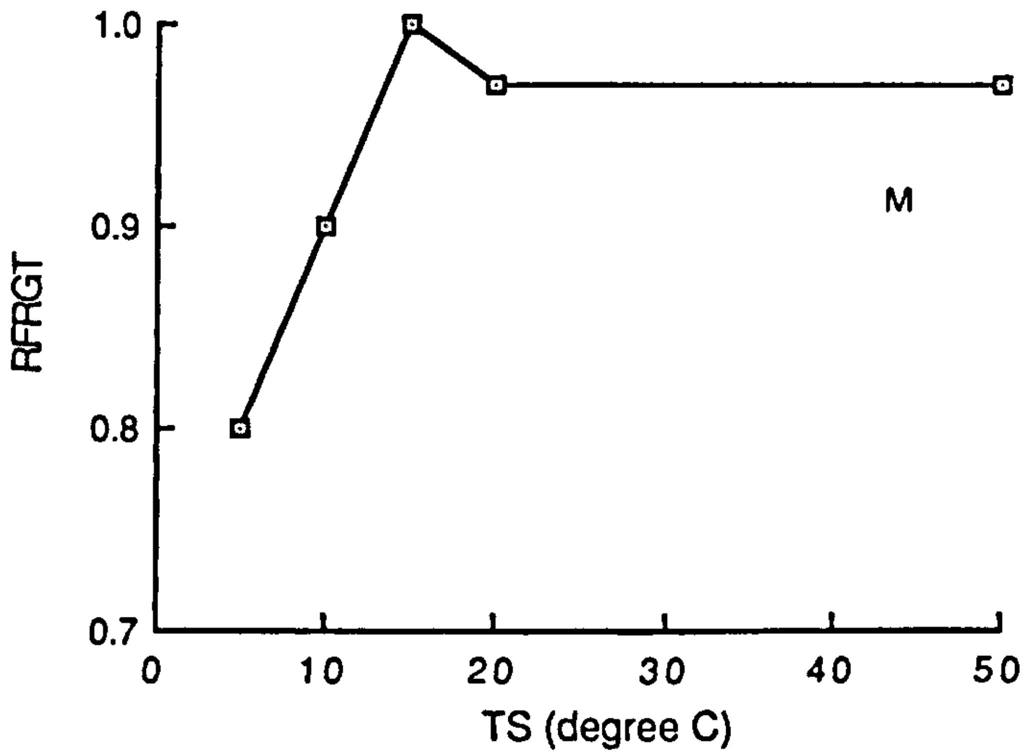

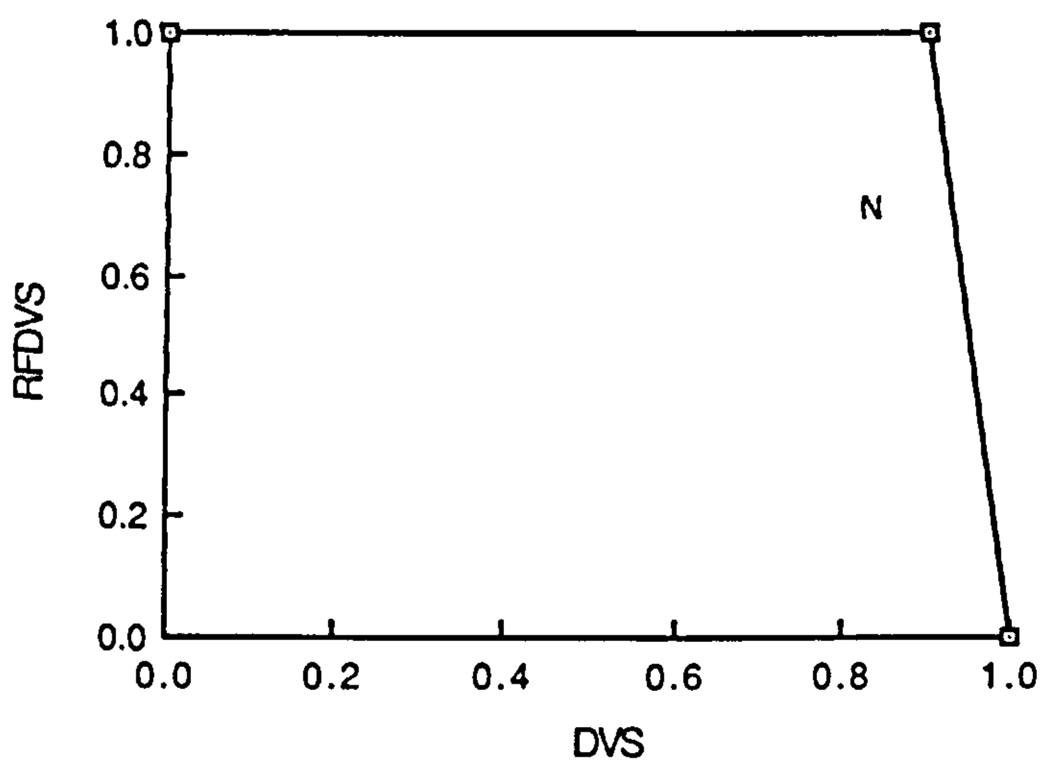

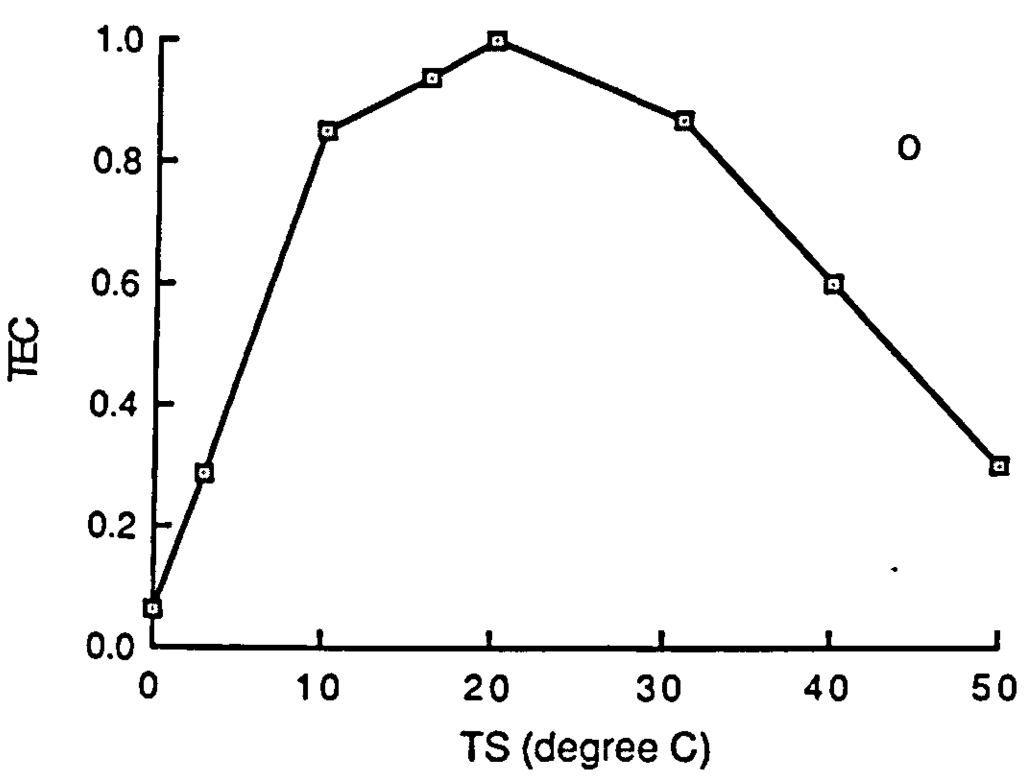

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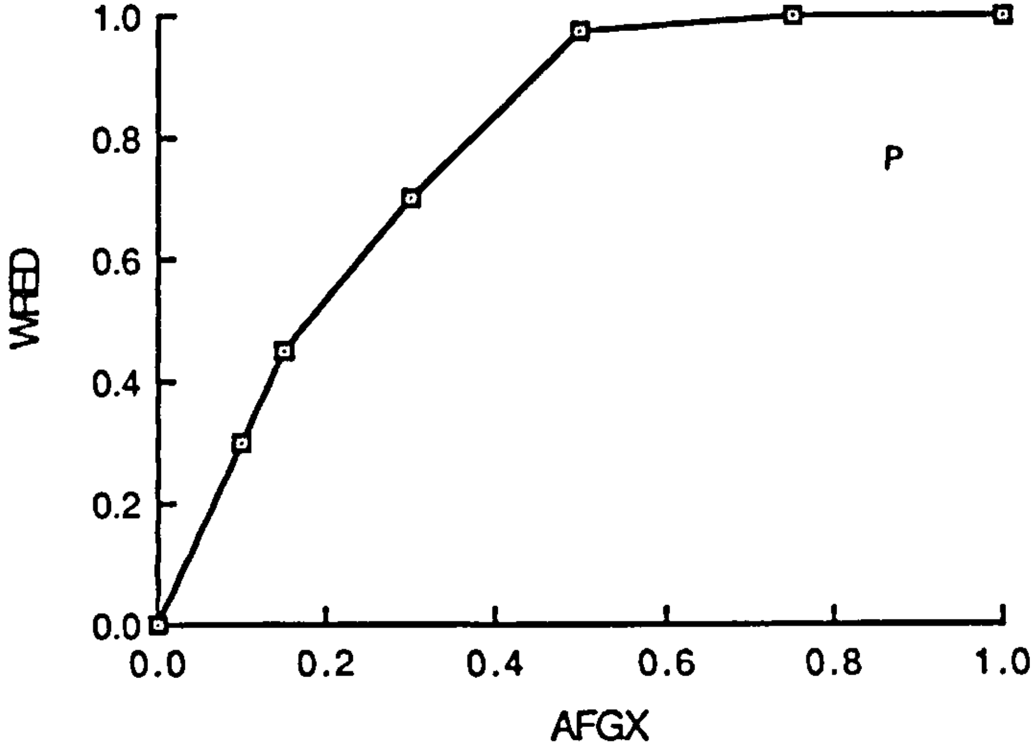

Figure 15. Function tables in the simulation model ARID CROP.

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B. CSRRT & CSRRTW. Fraction of total photosynthetic products allocated to shoot (CSRR) as a function of development stage of crop (DVS) for pasture, medic, and wheat.
C. DISTFT & DISTFTM & DISTFTW. Fraction of leaves in aerial vegetative growth (DISTF) as a function of development stage (DVS) for pasture, medic, and wheat.
D. EDPTFT. Activity coefficient of root (EDPTF) as a function of relative amount of available water in a soil compartment (AFGX).
E. FAMSTT. Reduction factor for photosynthetic products allocated to shoot (FAMST) as a function of relative transpiration deficit (RTRDEF).
F. FDMT. Fraction of dry matter in canopy (FDM) as a function of development stage (DVS).
G. FLTRT. Fraction of light transmitted through vegetation (FRLT) as a function of soil cover (SLCVR).
H. GRAINT. Fraction of total photosynthetic products allocated to seeds (FRTS) as a function of development stage (DVS). Development stage at which allocation to seeds commences in pasture and medic is given by parameter DVSSF.
I. RADTB. Daily total global radiation with clear sky (DGRCL) as a function of time from 1 October (DAY).
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K. RDRT. Relative death rate (RDRD) as a function of development stage (DVS).
L. REDFDT. Reduction factor for evaporation due to drying of soil (REDFD) as a function of dimensionless water content of top soil compartment (WCPR).
M. REDTTB. Multiplication factor for root growth (RFRGT) as a function of soil temperature (TS).
N. RFDVST. Reduction factor for transpiration (RFDVS) as a function of development stage (DVS).
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P. WREDT. Reduction factor for uptake of water by roots (WRED) as a function of relative amount of available water in a soil compartment (AFGX).

6.2.1 *Efficiency of utilization of metabolic energy*

The following equations define the efficiency of utilization of metabolic energy (ME) for maintenance, gain in liveweight, lactation and pregnancy.

$k_m = 0.35\, q_m + 0.503$ ewes and weaners Equation 30
(GB-ARC, 1980, p.80, Table 3.2, equation for 'all diets')

$k_m = 0.85$ milk-fed lambs Equation 31
(GB-ARC, 1980, p.119)

$k_m = (0.35\, q_m + 0.503)(1 - f) + 0.85 f$ lambs on mixed diet Equation 32

$k_f = 0.78\, q_m + 0.006$ ewes and weaners Equation 33
(GB-ARC, 1980, p.84, Table 3.4, equation for 'all diets')

$k_f = 0.95\, k_l$ energy deposition in lactation Equation 34
(GB-ARC, 1980, p.91)

$k_f = (0.78\, q_m + 0.006)(1 - f) + 0.7 f$ lambs on mixed diet Equation 35

$k_p = 0.133$ Equation 36
(GB-ARC, 1980, p.88)

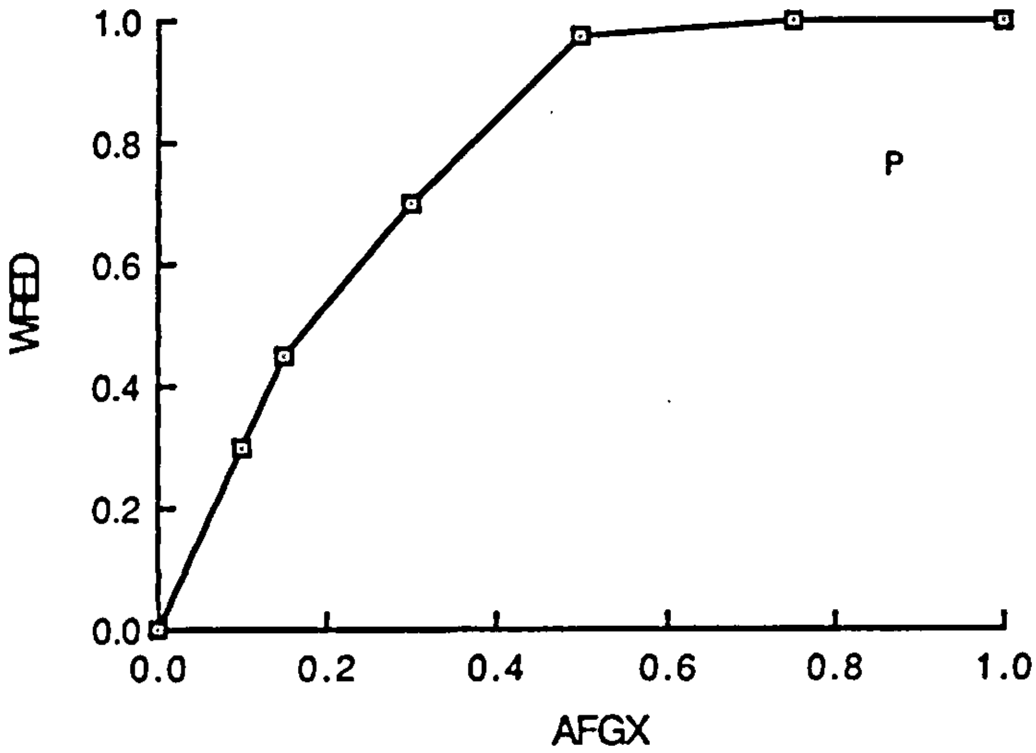
$k_l = 0.35\, q_m + 0.420$ dietary energy source Equation 37
(GB-ARC, 1980, p.81, Table 3.3; p.93)

$k_l' = 0.84$ body energy source Equation 38
(GB-ARC, 1980, p.90)

$q_m = e_{M,d}/e_{G,d}$ Equation 39
(GB-ARC, 1980, p.75)

where

- k_m is efficiency of utilization of metabolic energy for maintenance (1)
- q_m is metabolizability of the gross energy of feed at maintenance (1)
- f is mass fraction of milk in dry matter in diet (1)
- k_f is efficiency of utilization of metabolic energy for gain in liveweight at a rate of feeding of twice maintenance (1)
- k_l is efficiency of utilization of metabolic energy for lactation from dietary energy (1)
- k_l' is efficiency of utilization of metabolic energy for lactation from body energy (1)
- k_p is efficiency of utilization of metabolic energy for pregnancy (1)
- $e_{M,d}$ is content of metabolizable energy in the diet ($MJ\ kg^{-1}$)
- $e_{G,d}$ is content of gross energy in the diet ($MJ\ kg^{-1}$)



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- k_l is efficiency of utilization of metabolic energy for lactation from dietary energy (1)
- k_l' is efficiency of utilization of metabolic energy for lactation from body energy (1)
- k_p is efficiency of utilization of metabolic energy for pregnancy (1)
- $e_{M,d}$ is content of metabolizable energy in the diet (MJ kg^{-1})
- $e_{G,d}$ is content of gross energy in the diet (MJ kg^{-1})

6.2.2 *Energy requirements for maintenance*

Fasting heat production

$\dot{E}_{net,min} = a\, m^{0.75}$ Equation 40

$a = 0.215$ mature ewes Equation 41

$a = 0.245 - 0.02164 \ln t$ growing lambs Equation 42

where

$\dot{E}_{net,min}$ is minimum rate of net energy required (MJ d^{-1})
a is age-dependent coefficient (MJ $kg^{-0.75}$ d^{-1})
m is liveweight (kg)
t is age of lamb (years)

The function for growing lambs yields the coefficients in GB-ARC, 1980, p.100, Table 3.14.

An activity allowance of 0.0106 m (MJ d^{-1}) is added to $\dot{E}_{net,min}$ (GB-ARC 1980, p.114, Table 3.31) and is assumed to be exclusive of any energy requirement for grazing activity.

Energy allowance for grazing activity

Values for sheep of 2.6 J kg^{-1} m^{-1} for horizontal movement and 28 J kg^{-1} m^{-1} for vertical movement are given by GB-ARC (p. 101). Assuming horizontal movement for 6 h d^{-1} at a mean walking speed of 10 cm s^{-1}, the rate of expenditure of energy for grazing is 5.6m KJ d^{-1} or about 7% of fasting metabolism. That estimate is low (Osuji, 1974, review of estimates). Benjamin et al. (1977) estimated maintenance requirements for caged and grazing sheep at Migda. The maintenance requirement of grazing sheep was found to be 73% higher than that of caged sheep. That figure was adopted here, though the reduction in intake of herbage (and presumably expenditure of energy for grazing) due to replacement by supplementary feeds is taken into account. The grazing activity increment is defined as

$\eta = 0.73\,(0.15 + 0.85\, i_h/i_{h,-c})$ Equation 43

where

η is grazing activity increment (1)
i_h is actual rate of intake of herbage (kg d^{-1})
$i_{h,-c}$ is rate of intake of herbage in the absence of supplementary feeding (kg d^{-1})

Derivation of i_h and $i_{h,-c}$ is given in Section 6.3.

Thus the net energy requirement for maintenance is defined as

$\dot{E}_{net,m} = (0.215\, m^{0.75} + 0.010\,6\, m)\,[1 + 0.73\,(0.15 + 0.85\, i_h/i_{h,-c})]$
mature ewes Equation 44

$$\dot{E}_{net,m} = [(0.245 - 0.0216\,4 \ln t)\, m^{0.75} + 0.0106\, m]\,[1 + 0.73(0.15 + 0.85\, i_h/i_{h,-c})]$$
lambs Equation 45

where $\dot{E}_{net,m}$ is rate of net energy required for maintenance (MJ d^{-1})

The rate of metabolic energy required for maintenance is defined as

$$\dot{E}_{M,m} = \dot{E}_{net,m}/k_m$$
Equation 46

(GB-ARC, 1980, p. 118)

where

$\dot{E}_{M,m}$ is rate of metabolic energy required for maintenance (MJ d^{-1}).

6.2.3 *Requirements for production and performance*

Heat of combustion of gain in liveweight

The heat of combustion of gain in liveweight (or 'energy content of gain') is defined as

$$e_\Delta = 2.1 + 0.45\, m$$
females Equation 47

$$e_\Delta = 2.5 + 0.35\, m$$
males Equation 48

(GB-ARC 1980, p.106 and 118)

where

e_Δ is energy content of gain (MJ kg^{-1})

m is liveweight (kg)

for a diet such that at an empty body weight of 15 kg, gut fill with respect to empty body weight would be 300 g kg^{-1}. Average values of parameters are taken for lambs, since the sexes are not differentiated:

$$e_\Delta = 2.3 + 0.4\, m$$
lambs Equation 49

A maximum e_Δ of 28.4 MJ kg^{-1} is set for mature ewes, on the basis of Blaxter et al. (1982, Table 7).

For milk-fed lambs,

$$e_\Delta = 3.67 + 0.472\, m$$
females Equation 50

$$e_\Delta = 3.79 + 0.365\, m$$
males Equation 51

(GB-ARC, 1980, p. 119)

for a diet such that at an empty body weight of 15 kg, gut fill with respect to empty body weight would be 60 g kg^{-1}.

The average values of parameters are taken in the model:

$$e_\Delta = 3.73 + 0.419\, m$$
milk-fed lambs Equation 52

On mixed diets, e_Δ for lambs is computed as

$$e_\Delta = (2.3 + 0.4\, m)\,(1 - f) + (3.73 + 0.419\, m)\, f$$
Equation 53

Liveweight change

Calculations are based on a negative exponential equation for scaled retention of energy:

$$E_{r,ret} = B[1 - \exp(-kE_{r,in})] - 1 \qquad \text{Equation 54}$$

$$E_{r,in} = \dot{E}_{M,in}/\dot{E}_{net,m} \qquad \text{Equation 55}$$

$$B = k_m/(k_m - k_f) \qquad \text{Equation 56}$$

$$k = k_m \ln(k_m/k_f) \qquad \text{Equation 57}$$

(GB-ARC, 1980, p.103-104)

where

$E_{r,ret}$ is scaled retention of energy (1)
$E_{r,in}$ is scaled intake of energy (1)
B, k are parameters, defined as functions of diet metabolizability (1)
$\dot{E}_{M,in}$ is rate of intake of metabolic energy (MJ d^{-1})
$\dot{E}_{net,m}$ is rate of net energy required for maintenance (MJ d^{-1})
k_m is efficiency of utilization of metabolic energy for maintenance (1)
k_f is efficiency of utilization of metabolic energy for gain in liveweight (1)
k_m and k_f are defined in terms of q_m (Equations 30-35).

Where $E_{r,in} > 1/k_m$ (or $\dot{E}_{M,in} > \dot{E}_{M,m}$), the animal is in positive energy balance and change in liveweight is calculated as

$$dm/dt = E_{r,ret}\,\dot{E}_{net,m}/e_\Delta \qquad \text{Equation 58}$$

where

dm/dt is rate of change in liveweight (kg d^{-1})

If $E_{r,in} < 1/k_m$, the animal is in negative energy balance. The energy deficit must be mobilized from body reserves. The model assumes that the energy content of mobilized reserves and the efficiency of mobilization are the same as those for tissue deposition. Thus

$$\dot{E}_{M,d} = \dot{E}_{M,m} - \dot{E}_{M,in} \qquad \text{Equation 59}$$

$$dm/dt = -\dot{E}_{M,d}\,k_m/e_\Delta \qquad \text{Equation 60}$$

(Kahn, 1982)

where $\dot{E}_{M,d}$ is rate of metabolic energy deficit (MJ.d^{-1}).

Pregnancy

Pregnancy requirements are always to be met. They are calculated from day 63 of pregnancy. The energy of the sheep foetus and gravid uterus for a lamb birth weight of 4 kg is given by

$\log_{10} E_t = 3.322 - 4.979 \exp(-0.006\,43\, t)$ Equation 61
(GB-ARC, 1980, p.8, Table 1.6)

where
E_t is energy in the sheep foetus and gravid uterus (MJ)
t is time from conception (d)
The rate of energy deposition (or net energy requirement) is given by

$\dot{E}_{net,p} = E_t\, 0.073\,72 \exp(-0.00643\, t)$ Equation 62
(GB-ARC, 1980, p.119)

where
$\dot{E}_{net,p}$ is rate of net energy required for pregnancy (MJ d^{-1}).
For other birth weights, retentions of energy are in proportion. A similar adjustment is made for litter size.

The rate of metabolic energy required for pregnancy is defined as

$\dot{E}_{M,p} = \dot{E}_{net,p}/k_p$ Equation 63

where
$\dot{E}_{M,p}$ is rate of metabolic energy required for pregnancy (MJ d^{-1})
k_p is efficiency of utilization of metabolic energy for pregnancy (1)

The animal is in positive energy balance if $\dot{E}_{M,in} > (\dot{E}_{M,m} + \dot{E}_{M,p})$.
Scaled intake of energy relative to maintenance is defined net of pregnancy requirements

$E_{r,in} = (\dot{E}_{M,in} - \dot{E}_{M,p})/\dot{E}_{net,m}$ Equation 64

and dm/dt is calculated by Equation 58.

If $\dot{E}_{M,in} < (\dot{E}_{M,m} + \dot{E}_{M,p})$

$\dot{E}_{M,d} = \dot{E}_{M,m} + \dot{E}_{M,p} - \dot{E}_{M,in}$ Equation 65

and dm/dt is calculated by Equation 60.

Lactation

The lactation curve is described according to Wood (1967) by the expression

$Y_t = M\, t^b \exp(-ct)$ Equation 66

where
Y_t is rate of production of whole milk (kg d^{-1})
t is time post partum (d)
M, b, c are constants (1)

A potential lactation curve is taken yielding about 100 kg over 120 d, with values of parameters of 400, 0.35 and 0.01 for M, b and c, respectively. Those values are based on an analysis of data on intake of milk by lambs for Finn-

$$Y' = k_l(\dot{E}_{M,in} - \dot{E}_{M,m})/e_{net,l} \quad \text{Equation 72}$$

where
Y' is rate of production of whole milk from surplus energy (kg d^{-1})
Equation 66 is rearranged for M to fit the yield trajectory to Y':

$$M' = Y'/[t^b \exp(-ct)f_l] \quad \text{Equation 73}$$

where
M' is theoretical milk curve parameter (1)
and the milk curve parameter is adjusted by a small fraction

$$M_{t+1} = M_t[1 + f_p(M' - M_t)] \quad \text{Equation 74}$$

where
M_t is current milk curve parameter (1)
M_{t+1} is milk curve parameter at next time-step (1)
f_p is fraction added to milk curve parameter (1)
The fraction f_p decreases linearly from 0.04 to 0.01 over the period 20 to 120 d of lactation.

If $\dot{E}_{M,in} < (\dot{E}_{M,m} + \dot{E}_{M,l})$, the animal is in negative energy balance and body reserves are mobilized to compensate for the energy deficit. The following assumptions are made about mobilization of reserves and rate of production of milk. There is assumed to be a maximum rate at which reserves can be mobilized. A value equal to the net energy requirement for maintenance is taken. That is a minimum estimate based on the fact that a starving animal must be able to draw on mobilizable reserves at such a rate. Over a wide range of conditions, this is equivalent to a rate of liveweight loss of about 250 g d^{-1}. Two multiplication factors are used to calculate the potential rate of mobilization. The first is related to stage of lactation and decreases linearly from 1 to 0 over the period 20 to 120 d of lactation. The second multiplication factor is related to body condition and increases linearly from 0 to 1 over the range 1 to 3 in body condition. The potential net energy rate for lactation made available by tissue mobilization is then defined as

$$\dot{E}_{net,f}' = \dot{E}_{net,m} \min[f_t, f_b] \quad \text{Equation 75}$$

where
$\dot{E}_{net,f}'$ is potential rate of net energy mobilized for milk (MJ d^{-1})
$\dot{E}_{net,m}$ is rate of net energy required for maintenance (MJ d^{-1})
f_t is mobilization multiplication factor for stage of lactation (1)
f_b is mobilization multiplication factor for body condition (1)

If rate of intake of metabolic energy is sufficient to provide maintenance requirements, the actual rate of mobilization of net energy is defined as

$$\dot{E}_{net,f} = \min[k_l(\dot{E}_{M,m} + \dot{E}_{M,l} - \dot{E}_{M,in}), \dot{E}_{net,f}'] \quad \dot{E}_{M,m} + \dot{E}_{M,l} > \dot{E}_{M,in} > \dot{E}_{M,m}$$
Equation 76

Merino ewes at Migda (unpublished data). Milk yield is adjusted for litter size with an increase factor for twins:

$$f_l = N_{l,1} + (N_{l,2} f_{l,2})/N_l \qquad \text{Equation 67}$$

where
f_l is milk yield multiplication factor for litter size (1)
$N_{l,1}$ is number of lactating ewes with single lambs (1)
$N_{l,2}$ is number of lactating ewes with twins (1)
N_l is total number of lactating ewes (1)
$f_{l,2}$ is milk yield increase factor for twins (1)
A value of 1.4 is taken for $f_{l,2}$ (Benjamin, 1983).

The rate of net energy secretion (or net energy requirement) as ewe's milk is given by

$$\dot{E}_{net,l} = Y\, e_{net,l} \qquad \text{Equation 68}$$

$$e_{net,l} = 0.032\,8\,u + 0.002\,5\,t + 2.203 \qquad \text{Equation 69}$$

(GB-ARC, 1980, p.46)

where
$\dot{E}_{net,l}$ is rate of net energy required for lactation (MJ d^{-1})
Y is rate of production of whole milk (kg d^{-1})
$e_{net,l}$ is content of net energy in whole milk (MJ kg^{-1})
u is fat content of whole milk (g kg^{-1})
t is time in lactation (d)
A value of 70 g kg^{-1} is taken for u.

The rate of metabolic energy required for lactation is defined as

$$\dot{E}_{M,l} = \dot{E}_{net,l}/k_l \qquad \text{Equation 70}$$

where
$\dot{E}_{M,l}$ is rate of metabolic energy required for lactation (MJ d^{-1})
k_l is efficiency of utilization of metabolic energy for lactation from dietary energy (1)

If $\dot{E}_{M,in} > (\dot{E}_{M,m} + \dot{E}_{M,l})$, the animal is in positive energy balance. Concomitant energy deposition in lactation is more efficient than energy deposition in the dry animal and $k_f = 0.95\, k_l$ (Equation 34). Scaled intake of energy relative to maintenance is defined net of lactation requirements:

$$E_{r,in} = (\dot{E}_{M,in} - \dot{E}_{M,l})/\dot{E}_{net,m} \qquad \text{Equation 71}$$

and dm/dt is calculated by Equation 58.

Intake of energy surplus to maintenance and lactation requirements is assumed to raise the yield trajectory in proportion to the surplus, with a declining effect as lactation progresses. Actual yield is calculated by Equation 66, using current values of parameters. The algorithm then calculates the yield that would result from all energy that is surplus to maintenance being used for milk production:

Total energy requirements of the ewe

When computing the energy requirement of the ewe, an allowance is made for gain in liveweight for ewes of low body condition when grazing feed of reasonable quality. The maximum allowance is set at 200 g d^{-1} with respect to body condition score below 2.5. That value is reduced linearly to zero over the range in q_m of 0.5 to 0.4. If the animal is lactating, the total rate of metabolic energy required by the animal is computed as

$$\dot{E}_{M,\Delta} = r\, e_\Delta / k_f \qquad \text{Equation 84}$$

$$i_a = 1 + (\dot{E}_{M,l} + \dot{E}_{M,\Delta}) / \dot{E}_{M,m} \qquad \text{Equation 85}$$

$$i_f = 1 + 0.018\,(i_a - 1) \qquad \text{Equation 86}$$

$$\dot{E}_{M,t} = i_f\,(\dot{E}_{M,l} + \dot{E}_{M,\Delta} + \dot{E}_{M,m}) \qquad \text{Equation 87}$$

(GB-ARC, 1980, p.119)

where
$\dot{E}_{M,\Delta}$ is rate of metabolic energy required for gain (MJ d^{-1})
r is actual allowance for gain (kg d^{-1})
e_Δ is energy value of gain (MJ kg^{-1})
k_f is efficiency of utilization of metabolic energy for gain in liveweight (1)
i_a is approximate level of feeding (1)
i_f is correction factor for level of feeding (1)
$\dot{E}_{M,t}$ is total rate of metabolic energy required (MJ d^{-1})

For the dry animal, total rate of metabolic energy required is computed as

$$E_{r,ret} = r\, e_\Delta / \dot{E}_{net,m} \qquad \text{Equation 88}$$

$$E_{r,in} = \ln\,[B/(B - E_{r,ret} - 1)]/k \qquad \text{Equation 89}$$

$$\dot{E}_{M,t} = \dot{E}_{net,m}\, E_{r,in} + \dot{E}_{M,p} \qquad \text{Equation 90}$$

(GB-ARC, 1980, p.104, 118)

where
$E_{r,ret}$ is scaled retention of energy (1)
$E_{r,in}$ is scaled intake of energy (1)
B, k are parameters (Equations 56 and 57) (1)
$\dot{E}_{net,m}$ is rate of net energy required for maintenance (MJ d^{-1})
$\dot{E}_{M,p}$ is rate of metabolic energy required for pregnancy (where relevant) (MJ d^{-1})

Since pregnancy requirements are generally small compared to lactation requirements, an adjustment for level of feeding is not made in allowing for pregnancy requirements. The retention of energy for pregnancy is not added to the retention of energy in gain in liveweight in calculating $E_{r,ret}$ and thus ewe's liveweight in the model does not include the products of gestation.

Table 12. Parameters and non-local variables used by subroutine LMPERF of the agropastoral model. The value is for the standard run of the model.

Name	Value	Acronym
allowance for activity in maintenance ($MJ\ kg^{-1}\ d^{-1}$)	0.010 6	AAP
intercept in equation defining fraction of maximum allowance for grazing activity to add to requirements for maintenance (1)	0.15	FGF1
slope in equation defining fraction of maximum allowance for grazing activity to add to requirements for maintenance (1)	0.85	FGF2
maximum energy requirement for grazing activity relative to requirements for maintenance (1)	0.73	GF
age of lamb (d)		LAGE
e_Δ function: lamb, solid diet, intercept ($MJ\ kg^{-1}$)	2.3	LEP1
e_Δ function: lamb, solid diet, slope ($MJ\ kg^{-2}$)	0.4	LEP2
e_Δ function: lamb, milk diet, intercept ($MJ\ kg^{-1}$)	3.73	LEP3
e_Δ function: lamb, milk diet, slope ($MJ\ kg^{-2}$)	0.419	LEP4
lamb's rate of gain in liveweight ($kg\ d^{-1}$)		LLWG
content of metabolizable energy of herbage grazed by lambs ($MJ\ kg^{-1}$)		LMEPA
metabolizability of herbage grazed by lambs (1)		LRMI
lamb's actual rate of intake of whole milk ($kg\ d^{-1}$)		LQMP
lamb's actual rate of intake of herbage ($kg\ d^{-1}$)		LRPI
lamb's expected rate of intake of herbage in absence of supplementary feeding ($kg\ d^{-1}$)		LRPIX
lamb's actual rate of intake of supplementary feed ($kg\ d^{-1}$)		LRSI
mass fraction of solids in ewe's milk ($kg\ kg^{-1} = 1$)	0.2	MDMC
content of metabolizable energy in supplementary feed ($MJ\ kg^{-1}$)	12.55	MESU
content of metabolizable energy in ewe's whole milk ($MJ\ kg^{-1}$)	4.6	MEWM
k_f function: ewes and weaners, slope (1)	0.78	PKF1
k_f function: ewes and weaners, intercept (1)	0.006	PKF2
k_f function: lamb, milk diet (1)	0.7	PKF3
k_m function: ewes and weaners, slope (1)	0.35	PKM1
k_m function: ewes and weaners, intercept (1)	0.503	PKM2
k_m function: lamb, milk diet (1)	0.85	PKM3
metabolizability of ewe's milk (1)	0.7	QMM
metabolizability of supplementary feed (1)	0.622	QMS
weight exponent in equation for requirements for maintenance (1)	0.75	WE
liveweight of lamb (kg)		WLAM

6.2.4 *Programming considerations*

Sections of the nutritional system outlined above appear in four subroutines of the agropastoral model:

- subroutine SUPOPT (Chapter 11, Lines 2169-2301) computes the optimum rate of supplementary feeding of the lamb for any nutritional locality and so needs to calculate the rate of change in liveweight for any diet. That subroutine is called by the management section of the model. The only non-local variables changed by that subroutine are the optimum rate of supplementary feeding (LRSIX) and cost of gain in liveweight (CPUG). The parameters and non-local variables used by that subroutine were given in Table 7.
- subroutine LMPERF (Chapter 11, Lines 2302-2386) computes the actual change in liveweight of the lamb for any diet and is called by the biological section of the model. The only non-local variable changed by that subroutine is the rate of liveweight change of the lamb (LLWG). The parameters and non-local variables used by that subroutine are given in Table 12.
- subroutine EWREQM (Chapter 11, Lines 2524-2638) computes the total daily rate of metabolic energy required by the ewe for any physiological state and locality in the system. The only non-local variable changed by that subroutine is the rate of metabolic energy required by the ewe (MER). That subroutine is called by the intake subroutine.
- subroutine EWPERF (Chapter 11, Lines 2387-2523) computes the productive performance of the ewe for any diet and locality in the system. The only non-local variables changed by that subroutine are the daily change in liveweight of the ewe (ELWG), the rate of production of milk (EMY) and the change in parameter *M* of the milk curve function in response to level of nutrition (DMF1). That subroutine is called by the biological section of the model. Since the input requirements of subroutines EWREQM and EWPERF are similar, the parameters and non-local variables used by those subroutines are given together in Table 13.

Table 13. Parameters and non-local variables used by subroutines EWPERF and EWREQM of the agropastoral model. The value is for the standard run of the model. Parameter MXMF1 appears in the main program but not in subroutine EWPERF or EWREQM.

Name	Value	Acronym
allowance for activity in maintenance (MJ kg^{-1} d^{-1})	0.010 6	AAP
coefficient for energy requirement of fasting ewes (MJ $kg^{-0.75}$ d^{-1})	0.215	ALFEW
maximum body condition score of ewe (1)	5.0	BCP2
change in parameter MF1 in equation for rate of production of milk with rate of feeding (d^{-1})		DMF1

where

$\dot{E}_{net,f}$ is actual rate of net energy mobilized for milk (MJ d^{-1})

k_l is efficiency of utilization of metabolic energy for lactation from dietary energy (1)

Yield of milk is calculated as

$$Y = [(\dot{E}_{M,in} - \dot{E}_{M,m})k_l + \dot{E}_{net,f}\,k_l']/e_{net,l} \qquad \text{Equation 77}$$

where

k_l' is efficiency of utilization of metabolic energy for lactation from body energy (1)

$e_{net,l}$ is content of net energy in whole milk (MJ kg^{-1})

Change in liveweight is

$$dm(ewe)/dt = -\dot{E}_{net,f}/e_{\Delta} \qquad \text{Equation 78}$$

If rate of intake of metabolic energy is less than maintenance requirements,

$$\dot{E}_{net,f} = \min[\max[0, \dot{E}_{net,f}' - (\dot{E}_{M,m} - \dot{E}_{M,in})k_m], \dot{E}_{net,l}/k_l'] \quad \dot{E}_{M,in} < \dot{E}_{M,m} \qquad \text{Equation 79}$$

rate of production of milk is calculated as

$$Y = \dot{E}_{net,f}\,k_l'/e_{net,l} \qquad \text{Equation 80}$$

and change in liveweight is

$$dm(ewe)/dt = -[\dot{E}_{net,f} + (\dot{E}_{M,m} - \dot{E}_{M,in})\,k_m]/e_{\Delta} \qquad \text{Equation 81}$$

The model assumes that the energy content of mobilized reserves is the same as that for tissue deposition, hence e_{Δ} in Equations 78 and 81.

Undernutrition is assumed to depress the yield trajectory in proportion to the deficit, with an increasing effect as lactation progresses. The yield trajectory is fitted to the actual rate of production of milk

$$M' = Y/[t^b \exp(-ct)f_l] \qquad \text{Equation 82}$$

where

M' is theoretical milk curve parameter (1)

Y is actual rate of production of milk with $\dot{E}_{M,in} < (\dot{E}_{M,m} + \dot{E}_{M,l})$ (kg d^{-1}) and the milk curve parameter is adjusted by a small fraction

$$M_{t+1} = M_t[1 + f_p(M' - M_t)] \qquad \text{Equation 83}$$

where

M_t is current milk curve parameter (1)

M_{t+1} is milk curve parameter at next time-step (1)

f_p is fraction added to milk curve parameter (1)

though here $M' < M_t$ and the fraction f_p increases linearly from 0.01 to 0.04 over the period 20 to 120 d of lactation.

The section of the algorithm dealing with nutritional effects on lactation is speculative.

Table 13 continued

Name	Value	Acronym
minimum proportion of difference between actual and potential parameter in milk function that can be restored or reduced in one day (1)	0.01	MCRMN
maximum proportion of difference between actual and potential parameter in milk function that can be restored or reduced in one day (1)	0.04	MCRMX
content of metabolizable energy in wheat hay (MJ kg^{-1})	9.0	MEHY
content of metabolizable energy in poultry litter (MJ kg^{-1})	7.5	MEPL
rate of metabolic energy required by the ewe (MJ d^{-1})		MER
content of metabolizable energy in wheat straw (MJ kg^{-1})	6.2	MEST
content of metabolizable energy in supplementary feed (MJ kg^{-1})	12.55	MESU
calculated parameter in equation for rate of production of milk (1)		MF1
parameter in equation for rate of production of milk (1)	0.35	MF2
parameter in equation for rate of production of milk (1)	0.01	MF3
mass fraction of fat in ewe's milk (g $kg^{-1} = 10^{-3}$)	70	MFC
parameter for mobilization of body reserves with stage of lactation (1)	0.01	MRP1
parameter for mobilization of body reserves with stage of lactation (1)	20	MRP2
parameter for mobilization of body reserves with body condition: rate of change (d^{-1})	2	MRP3
parameter for mobilization of body reserves with body condition: time of start of decline (d)	0.5	MRP4
maximum permissible value of parameter MF1 in milk function (1)	500	MXMF1
time in ewe's lactation (d)		NDLACT
time in ewe's pregnancy (d)		NDPREG
stocking rate of ewes lambing (ha^{-1})		NEWL
stocking rate of lambs born (ha^{-1})		NLB
k_l function: slope (1)	0.35	PKA1
k_l function: intercept (1)	0.42	PKA2
k_f function: ewes and weaners, slope (1)	0.78	PKF1
k_f function: ewes and weaners, intercept (1)	0.006	PKF2
k_f function: coefficient for energy deposition in lactation (1)	0.95	PKF4
k_m function: ewes and weaners, slope (1)	0.35	PKM1
k_m function: ewes and weaners, intercept (1)	0.503	PKM2
metabolizability of wheat hay (1)	0.47	QMHY
metabolizability of poultry litter (1)	0.3	QMPL

Table 13 continued

Name	Value	Acronym
metabolizability of supplementary feed (1)	0.622	QMS
metabolizability of wheat straw (1)	0.32	QMST
parameter in equation for content of net energy in the sheep foetus and gravid uterus (1)	3.322	RP1
parameter in equation for content of net energy in the sheep foetus and gravid uterus (1)	4.979	RP2
parameter in equation for content of net energy in the sheep foetus and gravid uterus (1)	0.006 43	RP3
parameter in equation for requirement of net energy for pregnancy (1)	0.073 72	RP4
birth weight assumed in equation for content of net energy in the sheep foetus and gravid uterus (kg)	4	RP5
stage of pregnancy from which pregnancy requirements are calculated (d)	63	SPD
weight exponent in equation for requirements for maintenance (1)	0.75	WE
liveweight of ewe (kg)		WEWE

6.3 Intake

6.3.1 Approach

In view of the significance of rate of intake by the animal to both primary and secondary production, the algorithm to compute the rate of intake of herbage by ewe and lamb, and the rate of supplementary feeding of the ewe is described in detail. Rate of intake is defined in terms of three potentially limiting processes: ingestion, digestion and assimilation. The potential rates of those three processes are determined by availability of herbage, digestibility and total requirements of the animal, respectively. A ramp function defines the intake multiplication factor for availability as a function of the total biomass with reference to area of those plant fractions assumed to be selected by the grazing animal:

$$f_a = 0 \qquad V_g \leqslant V_r$$
$$f_a = (V_g - V_r)/(V_s - V_r) \qquad V_r < V_g < V_s$$
$$f_a = 1 \qquad V_g \geqslant V_s \qquad \text{Equation 91}$$

where

f_a is intake multiplication factor for availability (1)

V_g is biomass with reference to area of selected plant fractions (kg ha^{-1})

Table 13 continued

Name	Value	Acronym
parameter in equation for DMFI (1)	100	DMP1
parameter in equation for DMFI (1)	20	DMP2
ewe's body condition score (1)		EBC
e_Δ function: ewes, intercept (MJ kg^{-1})	2.1	EEP1
e_Δ function: ewes, slope (MJ kg^{-2})	0.45	EEP2
e_Δ function: ewes, maximum (MJ kg^{-1})	28.4	EEP3
parameter in equation for net energy content of milk (1)	0.032 8	ELP1
parameter in equation for net energy content of milk (1)	0.002 5	ELP2
parameter in equation for net energy content of milk (1)	2.203	ELP3
ewe's rate of change in liveweight (kg d^{-1})		ELWG
content of metabolizable energy in herbage grazed by ewes (MJ kg^{-1})		EMEPA
ewe's actual rate of production of milk (kg d^{-1})		EMY
factor for increase in yield of ewe's milk for average litter size (1)		EMYMF
metabolizability of herbage grazed by ewes (1)		EQMP
ewe's rate of intake of (wheat) hay (kg d^{-1})		ERHI
ewe's rate of intake of herbage (kg d^{-1})		ERPI
expected rate of intake of herbage by ewe in absence of supplementary feed (kg d^{-1})		ERPIX
ewe's rate of intake of poultry litter (kg d^{-1})		ERPLI
ewe's rate of intake of supplementary feed (kg d^{-1})		ERSI
ewe's rate of intake of (wheat) straw (kg d^{-1})		ERSTI
efficiency of utilization of body energy for lactation (1)	0.84	EUBL
ewe's current nutritional locality (1)		EWELOC
multiplication factor for ewe's energy requirement for maintenance (1)	1	EWMTMF
intercept in equation defining fraction of maximum allowance for grazing activity to add to requirements for maintenance (1)	0.15	FGF1
slope in equation defining fraction of maximum allowance for grazing activity to add to requirements for maintenance (1)	0.85	FGF2
maximum allowance for ewe's gain in liveweight (kg d^{-1})	0.2	GAP
maximum energy requirement for grazing activity relative to requirements for maintenance (1)	0.73	GF
efficiency of utilization of metabolic energy for pregnancy (1)	0.133	KP
mean birth weight of lambs (kg)		LBW
correction parameter for relative rate of feeding (1)	0.018	LFP

$$i_s = \dot{E}_{M,t}/e_{M,d} \qquad \text{ewes} \quad \text{Equation 92}$$

$$e_{M,d} = q_m \, e_{G,d} \qquad \text{Equation 93}$$

$$q_m = D f_c \qquad \text{Equation 94}$$

where

i_s is potential rate of intake per animal for satiation (kg d^{-1})
$\dot{E}_{M,t}$ is total rate of metabolic energy required (MJ d^{-1})
$e_{M,d}$ is content of metabolizable energy in the selected herbage (MJ kg^{-1})
q_m is metabolizability of the selected herbage (1)
$e_{G,d}$ is content of gross energy in the selected herbage (MJ kg^{-1})
D is digestibility of the selected herbage (1)
f_c is conversion factor for digestibility to metabolizability (1)

For ewes, $\dot{E}_{M,t}$ is returned by subroutine EWREQM. Since metabolic energy requirements are a function of diet metabolizability, the value of q_m for the grazed herbage is assumed. That is only an approximation if the ewes are to be supplemented. The function of intake of concentrates ad libitum for lambs is shown in Figure 17. That function is based on some fattening trials with lambs at Migda (unpublished data).

A value of 0.81 is taken for f_c (GB-ARC, 1965; Graham et al., 1976). A value of 18.4 MJ kg^{-1} is taken for the gross energy content of herbage dry matter (McKinney, 1972).

The rate of intake of herbage in the absence of supplementary feeding is then

$$i_{h,-c} = \min\,[f_a, f_d]\; i_s \qquad \text{Equation 95}$$

where

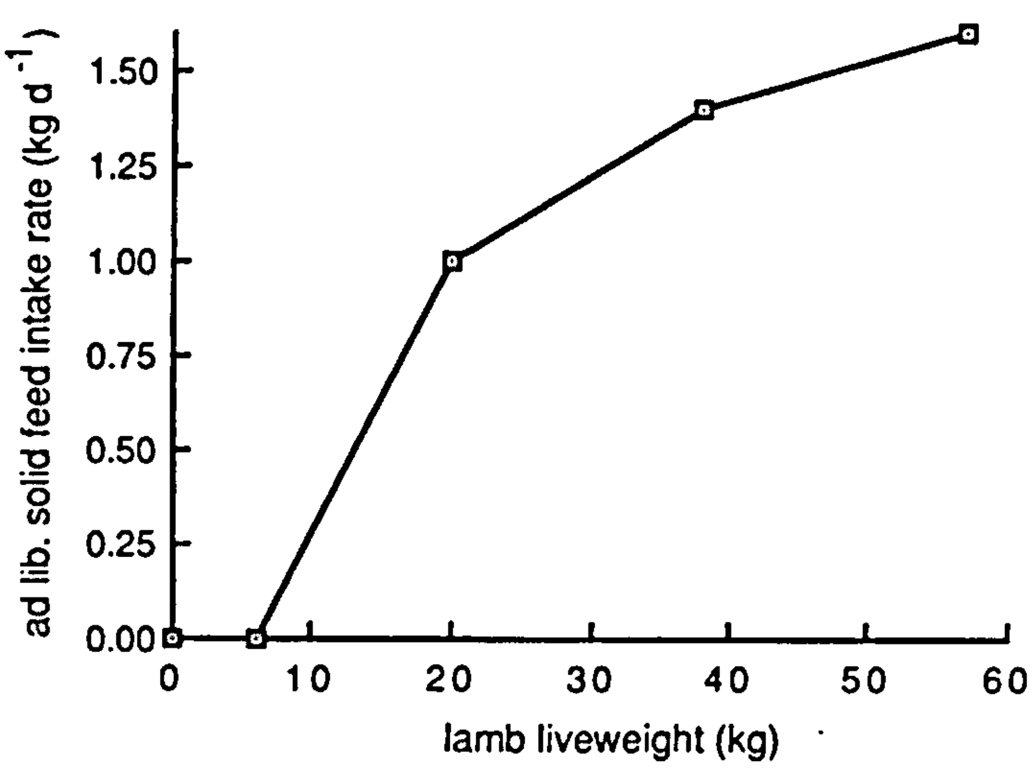

Figure 17. The rate of intake of supplementary feed by lambs ad libitum as a function of liveweight. Based upon four unpublished fattening trials with lambs at the Migda and Gilat experimental stations in the Northern Negev.

$i_{h,-c}$ is rate of intake of herbage in the absence of supplementary feeding ($kg\ d^{-1}$)

f_d is intake multiplication factor for digestibility (1)

f_a is intake multiplication factor for availability (1)

Supplementary feeding of ewes is computed as follows. The ewe's body condition deficit, d_c, is the shortfall below the minimum acceptable body condition for the current physiological state of the ewe (Figure 4). If the ewe is grazing green herbage, the ewe is supplemented with 1 kg of concentrate for every unit of d_c. Otherwise, the ewe is always allocated 0.5 $kg\ d^{-1}$ poultry litter.

If the ewe is in the holding paddock or $d_c>0$ whilst grazing dry herbage, the ewe is supplemented with baled roughage, if available. Hay is given in preference to straw. In the holding paddock, the ration is 1.5 $kg\ d^{-1}$. When grazing on dry herbage, the total intake of dry matter is made up to 1.5 $kg\ d^{-1}$. If $d_c>0$, the rate of metabolic energy required by the ewe is increased by 12.55 $MJ\ d^{-1}$ per unit d_c. Any remaining deficit in intake of metabolic energy is made up with concentrates.

If the ewe is lactating and the total intake of metabolic energy computed as yet provides less than half the total metabolic energy requirements, the metabolic energy deficit is made up with concentrates.

Supplementary feeding of lambs is determined in the management section of the model and is not altered by the intake subroutine.

The actual rate of intake of herbage is computed from $i_{h,-c}$ and the substitution ratio for herbage intake:

$$i_h = i_{h,-c} - S\, i_c \qquad \text{Equation 96}$$

$$S = [i_{h,-c}/(i_s f_a)]^2 \qquad \text{Equation 97}$$

where

i_h is actual rate of intake of herbage ($kg\ d^{-1}$)

$i_{h,-c}$ is rate of intake of herbage in the absence of supplementary feeding ($kg\ d^{-1}$)

S is substitution ratio of concentrates for herbage intake (1)

i_c is rate of intake of supplementary feed on pasture ($kg\ d^{-1}$)

i_s is rate of intake of herbage per animal for satiation ($kg\ d^{-1}$)

f_a is intake multiplication factor for availability (1)

The rate of intake of the selected plant fractions is computed from i_h in proportion to the biomass of each fraction. Those rates are required in the updating of the mass integrals of herbage.

Finally, the rate of intake of milk and price of milk are computed for lambs only. The rate of intake of milk equals the ewe's rate of production of milk divided by the average number of lambs sucking per lactating ewe. If the ewe is currently receiving concentrates, the price of milk is estimated as the price of supplementary feeds for ewes that would provide sufficient metabolic energy to produce 1 kg of milk:

$p_m = p_c\, e_{M,l}/(k_l\, e_{M,c})$ Equation 98

where

p_m	is price of milk ($ kg^{-1})
p_c	is price of supplementary feed for ewes ($ kg^{-1})
$e_{M,l}$	is content of metabolizable energy in whole milk (MJ kg^{-1})
k_l	is efficiency of utilization of metabolic energy for lactation from dietary energy (Equation 37) (1)
$e_{M,c}$	is content of metabolizable energy in supplementary feed for ewes (MJ kg^{-1})

Parameter p_m is required by subroutine SUPOPT in computing the cost of gain in liveweight of the lamb.

6.3.2 Programming considerations

Herbage intake by ewe and lamb, and supplementary feeding of the ewe, is handled by subroutine INTAK (Chapter 11, Lines 856-1182). Parameters and non-local variables used by the subroutine are given in Table 14.

Table 14. Parameters used by subroutine INTAK of the agropastoral model. The value is for the standard run of the model. The parameter VRES is set to parameter VRESG during the green season and to VRESD during the dry season; where VRESG = 50, VRESD = 300 kg ha^{-1}.

Name	Value	Acronym
area fraction of system to pasture (1)	0.5	AREA(1)
area fraction of system to wheat (1)	0.5	AREA(2)
area fraction of system to special-purpose pasture (1)	0	AREA(3)
conversion factor from digestibility to metabolizability (1)	0.81	CFDM
maximum digestibility of dry leaf (pasture or wheat) (1)	0.65	DDLP
maximum digestibility of dry non-leaf (pasture or wheat) (1)	0.55	DDNLP
range in digestibility of dead leaf during dry season (1)	0.1	DDSL1
range in digestibility of dead non-leaf during dry season (1)	0.1	DDSL2
maximum digestibility of green leaf (pasture or wheat) (1)	0.80	DGLP
maximum digestibility of green non-leaf (pasture or wheat) (1)	0.75	DGNLP
decrease in digestibility of green leaf over green season (1)	0.15	DGSL1
decrease in digestibility of green non-leaf over green season (1)	0.20	DGSL2
intercept of multiplication factor for digestibility: pasture and wheat (Figure 16) (1)	– 0.06	DINTG
intercept of multiplication factor for digestibility: legume (Figure 16) (1)	0.441	DINTL
time interval over which DDSL1 declines (d)	120	DND1
time interval over which DDSL2 declines (d)	120	DND2

Table 14 continued

Name	Value	Acronym
slope of multiplication factor for digestibility: pasture and wheat (Figure 16) (1)	1.35	DSLPG
slope of multiplication factor for digestibility: legume (Figure 16) (1)	0.86	DSLPL
ewe's allowance of poultry litter at dry localities or holding paddock (kg d^{-1})	0.5	EPLA
array for matching ewe's nutritional locality to crop locality (1)		EWEMAT
gross energy content of herbage dry matter (MJ kg^{-1})	18.4	GEH
array for matching locality for lambs to crop locality (1)		LAMMAT
rate of intake of concentrate ad libitum by lamb (kg d^{-1}) in relation to lamb liveweight (kg)	Figure 17	LPDMIT
content of metabolizable energy in wheat hay (MJ kg^{-1})	9.0	MEHY
content of metabolizable energy in poultry litter (MJ kg^{-1})	7.5	MEPL
content of metabolizable energy in wheat straw (MJ kg^{-1})	6.2	MEST
content of metabolizable energy in supplementary feed (MJ kg^{-1})	12.55	MESU
content of metabolizable energy in ewe's whole milk (MJ kg^{-1})	4.6	MEWM
minimum store of hay or straw per ewe to permit feeding (kg)	2	MNSTR
stocking rate of ewes + hoggets (ha^{-1})	5	NEWES
k_l function: slope (1)	0.35	PKA1
k_l function: intercept (1)	0.42	PKA2
price ratio of supplementary feed for ewe to lamb (1)	0.8	PRELF
price of supplementary feed for lambs ($ kg^{-1})	0.25	PSUPPS
metabolizability of poultry litter (1)	0.3	QMPL
metabolizability of supplementary feed (1)	0.622	QMS
threshold fraction of metabolic energy required by ewe met by intake of herbage without supplementary feed below which ewe is supplemented on green or dry pasture during lactation (1)	0.5	SPFRC
metabolizable energy rate of supplementary feed given to ewe per unit deficit of body condition score (MJ d^{-1})	12.55	SUPQ
ungrazable residual biomass for green and dry herbage (kg ha^{-1})	50, 300	VRES
dry biomass at which rate of intake per animal reaches satiation (kg ha^{-1})	1200	VSATD
green biomass at which rate of intake per animal reaches satiation (kg ha^{-1})	500	VSATG
array of components of green wheat selected by ewes during strip-grazing. 0 = not selected, 1 = selected. Order: live leaf; live non-leaf; seeds; dead leaf; dead non-leaf (1)	1,1,1,1,1	WGCMPE

Table 14 continued

Name	Value	Acronym
array of components of green wheat selected by lambs during strip-grazing. 0 = not selected, 1 = selected. Order: live leaf; live non-leaf; seeds; dead leaf; dead non-leaf (1)	1,1,1,1,1	WGCMPL
time limit of early-season grazing of green wheat from emergence (d)	42	WGTML

Table 15. Economic parameters of the agropastoral model. The value is for the standard run of the model.

Name	When incurred	Value	Acronym
cost of baling wheat straw ($ kg^{-1})	harvest	0.018	BALEC
cost of land preparation for wheat ($ ha^{-1})	17 October	60	CCULTW
cost of dressing wheat with fertilizer ($ ha^{-1})	22 October	60	CFERTW
cost of harvesting wheat grain ($ ha^{-1})	harvest grain	60	COSTH
cost of sowing wheat ($ ha^{-1})	27 October	50	CSOWW
fixed costs of pasture, including fertilizer ($ ha^{-1} $year^{-1}$)	22 October	50	FXPC
cost function of harvesting hay: intercept ($ ha^{-1})	hay harvest	0	HYHC1
cost function of harvesting hay: slope ($ kg^{-1})	hay harvest	0.017	HYHC2
price of best-quality hay ($ kg^{-1})		0.1	HYTOPP
insurance costs per ewe ($ $year^{-1}$)	29 July	4	INSUR
interest rate on overdraft ($year^{-1}$)	15 September	0.08	LOANR
ewe's miscellaneous rate of expenditure as fraction of total variable costs of ewe (1)	29 July	0.1	MISC
price of wheat grain ($ kg^{-1})		0.22	PGRN
price of dry matter of poultry litter ($ kg^{-1})	as fed	0.034	PPL
price ratio of supplementary feed for ewe to lamb (1)		0.8	PRELF
price ratio of ewe's meat to lamb's meat (1)		0.6	PRELM
price of lamb's meat ($ kg^{-1})		2.5	PRLAM
price of straw ($ kg^{-1})		0.06	PSTRW
price of supplementary feed for lambs ($ kg^{-1})	as fed	0.25	PSUPPS
veterinary costs per ewe ($ $year^{-1}$)	29 July	6	VETC

6.4 Flock dynamics

The number of reproductive stock is comprised of 'mature ewes' and 'hoggets'. In the early breeding system, both those groups produce lambs, whereas in the conventional 18-month breeding system only the mature ewes produce lambs. The number of mature ewes equals the total number of reproductive stock (the stocking rate parameter set by the user) divided by (1 + culling rate). The number of hoggets is simply the difference between the total number of reproductive stock and the number of mature ewes.

Sheep are culled at weaning time and replacement stock are transferred at sale time. Since the flock is static, the number of mature ewes culled and the number of weaners retained for replacement are equal. That number is subtracted from the mature ewe class at weaning time and added to that class at the time lambs are sold. The size of the hogget class is constant, though strictly speaking an equal number of animals is added from the lambs and transferred out to the mature ewe class at the time lambs are sold.

Rams are not considered; nor are mortality of mature ewes and of hoggets.

6.5 Financial balance

The accounting section of the model calculates the gross margin with respect to area for each year. The financial balance is initialized to zero at the start of each season. Direct costs are deducted from the balance as they are incurred. All costs and prices are given in Table 15. The total time-money integral ($ d) for which the financial balance is in deficit is summed separately. The interest payment on that amount is deducted from the financial balance towards the end of the season.

Income derives from sale of lambs, culled ewes and wheat grain. Income from wool is assumed to be little more than the cost of shearing and so is ignored. Wheat hay and wheat straw are neither purchased nor sold.

V_s is biomass at which rate of intake for satiation is reached (kg ha^{-1})
V_r is ungrazable residual biomass (kg ha^{-1})

The biomass at which intake reaches satiation, V_s, is set according to DVS. A value of 500 kg ha^{-1} is taken during the green season (DVS$<$1) and a value of 1200 kg ha^{-1} is taken during the dry season (DVS$\geq$1).

f_a = 1 for late-season strip-grazing of green wheat.

The selected plant fractions are
- green leaf and green non-leaf if DVS$<$1 and total green herbage exceeds V_s
- green leaf, green non-leaf and dead leaf if DVS$\geq$1 and total dead biomass exceeds V_s
- all plant fractions for late-season strip-grazing of green wheat as an alternative to grain
- all leaf and non-leaf plant fractions otherwise.

On the basis of Thornton & Minson (1973), a ramp function defines the intake multiplication factor for digestibility as a function of the weighted mean digestibility of those plant fractions assumed to be selected by the grazing animal (Figure 16). Digestibility (D) is calculated separately for leaf and non-leaf plant fractions:
- of green leaf declines linearly from 0.8 (at DVS = 0) to 0.65 (at DVS = 1)
- of green non-leaf declines linearly from 0.75 (at DVS = 0) to 0.55 (at DVS = 1)
- of dead leaf declines linearly from 0.65 to 0.55 over the first 120 d of the dry season and remains at 0.55 afterwards
- of dead non-leaf declines linearly from 0.55 to 0.45 over the first 120 d of the dry season and remains at 0.45 afterwards.

The potential rate of intake for satiation in the ewe is a function of total rate of metabolic energy required. In the lamb it is set equal to the rate of intake of high-quality feed ad libitum.

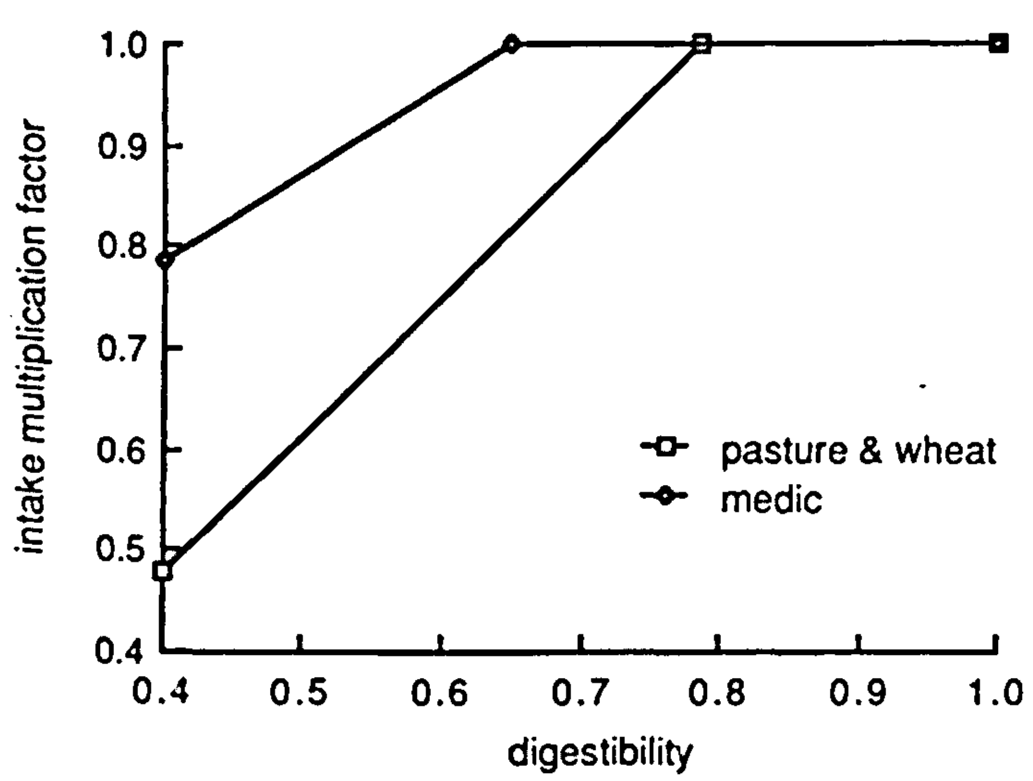

Figure 16. Multiplication factor of intake for digestibility as a function of the weighted mean digestibility of selected fractions of plant.

7 Validation

Extensive checks of the coding of each subroutine were made by hand calculation and a reasonable degree of confidence in the programme coding has been established.

The role of validation, where the measured and simulated performance of a system are compared, depends upon the main purpose of the model. Two modes or paradigms of scientific enquiry can be distinguished: hypothesis-testing and problem-solving. That distinction appears widely though terminology varies (e.g. Duhem, 1953, p.238). In hypothesis-testing, the model is the hypothesis and validation plays a central role. The emphasis is on testing how well a model can mimic reality. In problem-solving, a solution is derived by rigorous argument on the basis of a set of assumptions. The emphasis is on proceeding from a set of assumptions to a solution. So there is concern to choose reasonable assumptions but that is not the focus of attention.

This study is primarily concerned with problem-solving in that it defines major problems of management in an agropastoral system and develops tools to solve them. If a management solution is derived by some deductive process, the correctness of that solution is not established by empirical validation. If the assumptions are correct and the deduction is logically consistent, the solution is by definition correct. Testing the solution in reality is a means of examining whether the assumptions are correct or whether there are additional factors that should be considered. That is valid and desirable but outside the scope of this study.

The task of validation in this study is to establish confidence in the assumptions of the model. These are largely contained in the adopted primary production model ARID CROP (van Keulen, 1975; van Keulen et al., 1981) and GB-ARC's (1980) system of animal nutrition. Both are the product of considerable long-term research and probably represent the state of the art.

Results of the model were found to compare well with the qualitative and semiquantitative behaviour of systems of that kind at Migda. The time course of the ewe's liveweight and body condition, herbage mass, rates of intake of herbage and supplementary feed by ewes and lambs, and the lamb's rate of growth were examined closely and found to be realistic.

A further major source of confidence in the model is the fact that the model was not tuned at all. All parameters remained at their originally estimated values. A single tuning parameter was used in the original version of the model (Ungar, 1984) but that was eliminated after correcting a coding error.

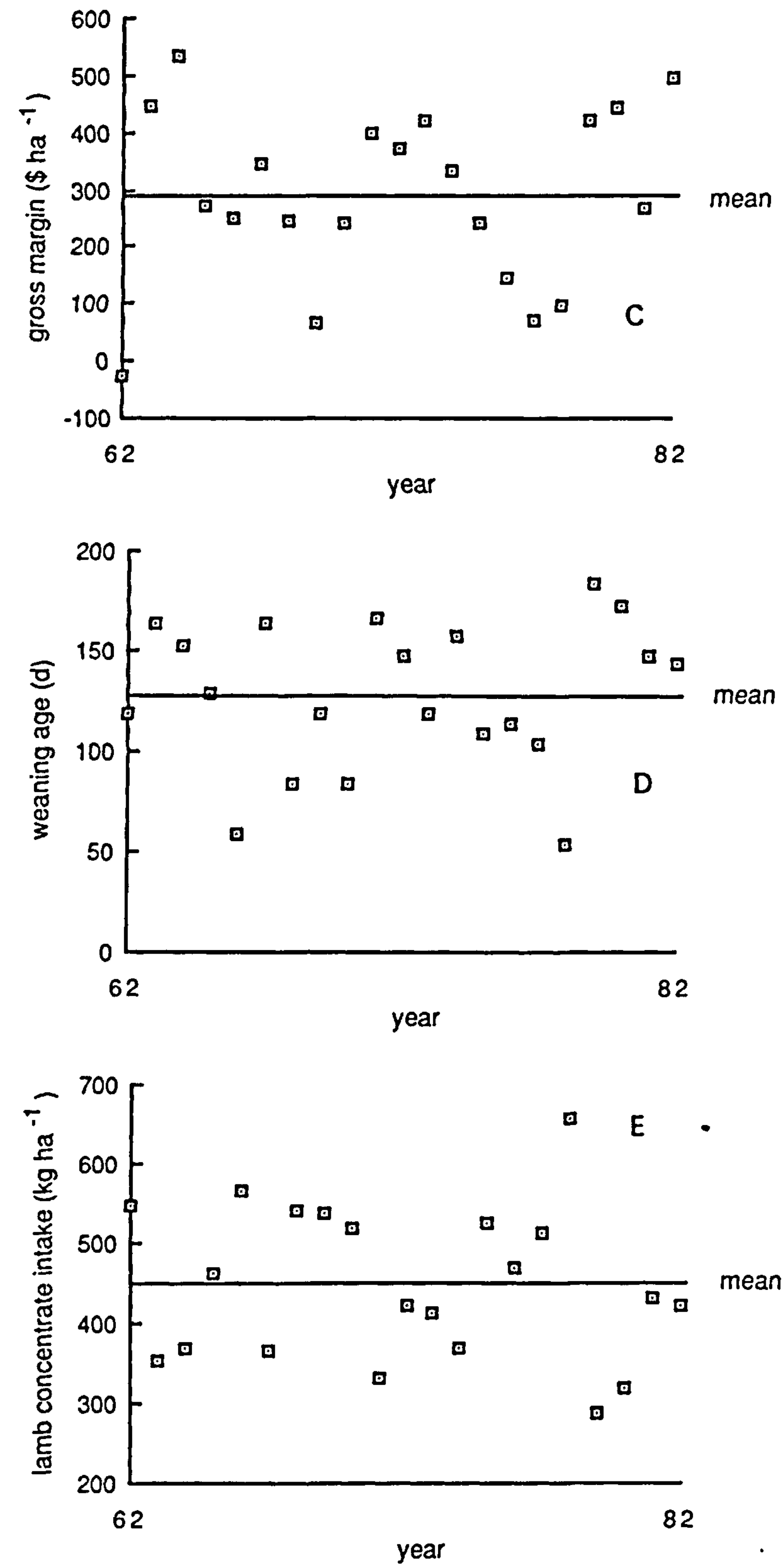

Figure 18 continued

A. Total rainfall (mm).

B. Grain yield (kg ha^{-1} wheat).

C. Gross margin ($ ha^{-1}).

D. Weaning age (d).

E. Total intake of supplementary feed by lambs with respect to system area (kg ha^{-1}).

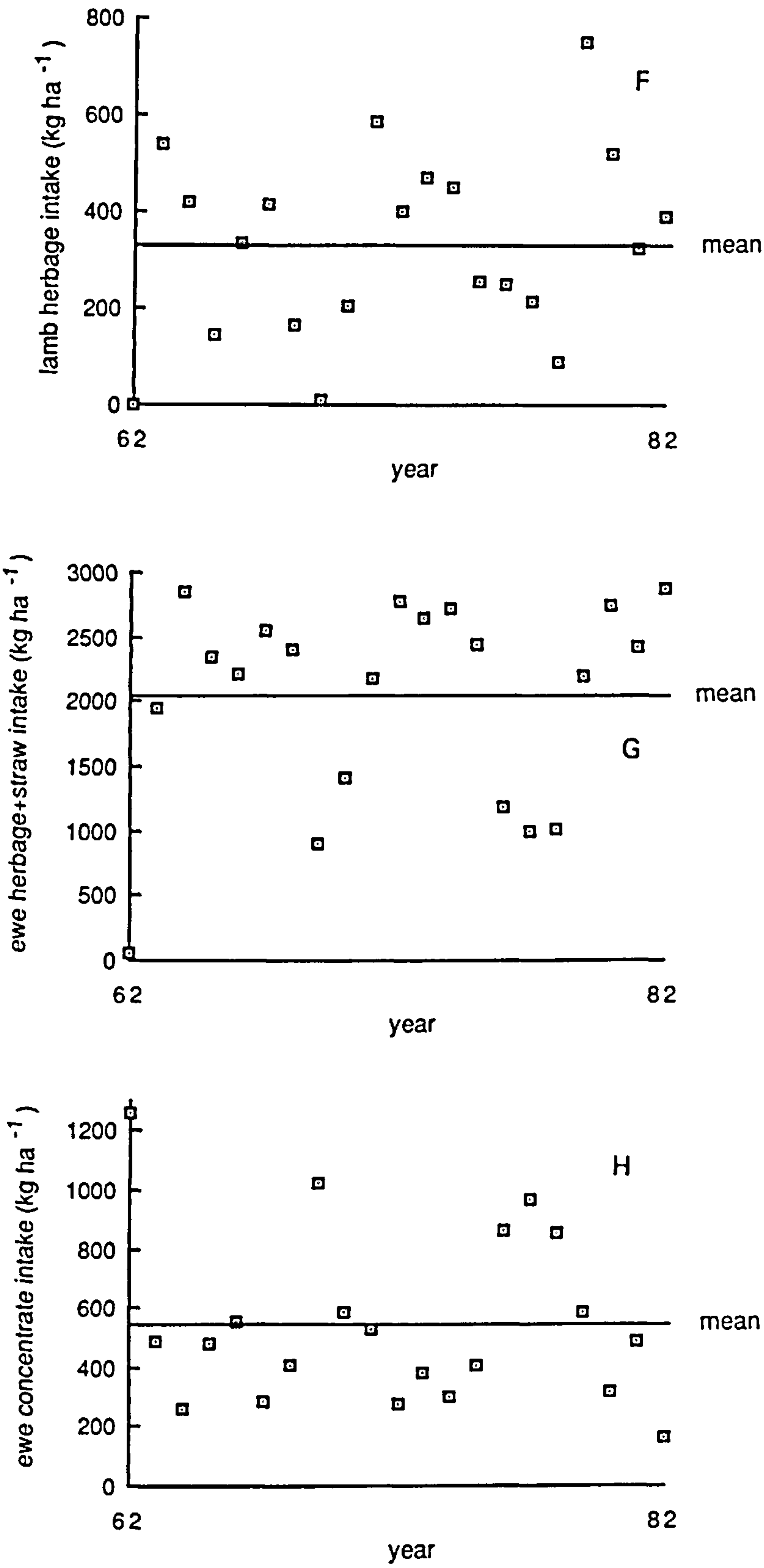

Figure 18 Results of the standard run of the agropastoral model.
F. Total intake of herbage by lambs with respect to system area (kg ha^{-1}).
G. Total intake of herbage and baled straw by ewes with respect to system area (kg ha^{-1}).
H. Total intake of supplementary feed by ewes with respect to system area (kg ha^{-1}).

8 Results of the agropastoral model

8.1 Standard run

Results of the standard run will be presented in some detail, followed by a discussion of each management decision in terms of its effect on performance of the system.

Figure 18 shows the variability between seasons of some major performance indices for the standard run. Mean gross margin was 289.6 \$ ha^{-1}, with a standard deviation of 150.0 \$ ha^{-1}. Wheat hay was never cut. Straw was baled in 8 out of 21 seasons. An average with reference to system area of 1774 kg ha^{-1} (3548 kg ha^{-1} wheat) was baled in those 8 years. Over 70% of the straw baled was used. That

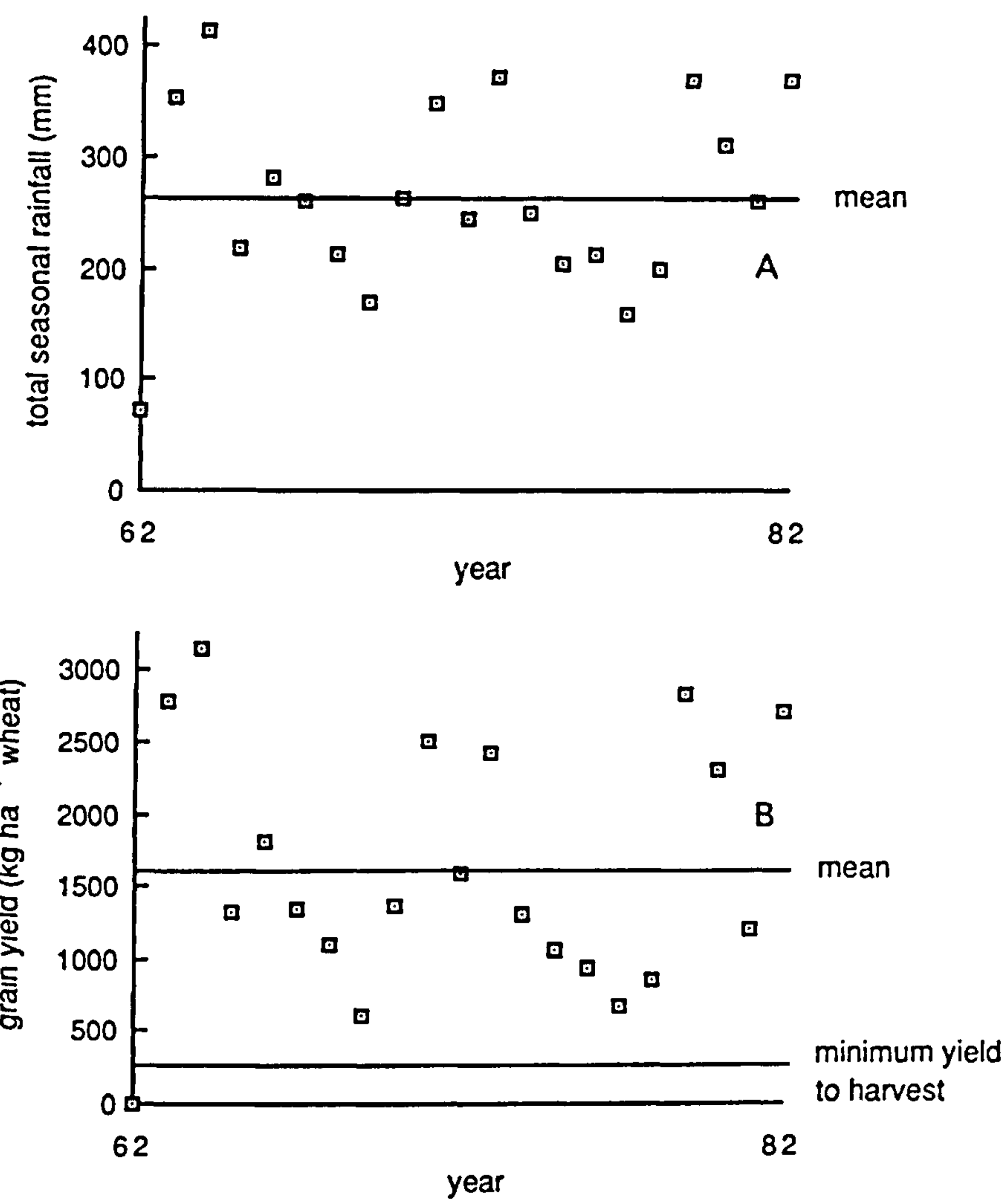

Figure 18. Results of the standard run of the agropastoral model.

Table 16 continued

Variable	Value for Run Number								
	1	9	6	4	5	3	2	10	7
mean intake of herbage and straw by ewes in system (kg ha^{-1})	2041	2042	2051	1998	1838	1884	1634	1501	1330
mean intake of herbage by lambs in system (kg ha^{-1})	330	316	337	338	320	331	332	334	328

does not necessarily mean that the straw supply exceeded requirement, since utilization of straw depends strongly on the sequence of years of high and low rainfall. Average weaning age was 128 d.

Table 16 shows some summary key statistics. Average annual herbage intake by the ewe-lamb combination was 377 kg excluding utilization of baled straw and 474 kg including utilization of straw.

8.2 Early-season grazing of green wheat

In the standard run (R 1), the ewes grazed early-season green wheat for an average of 24 d per season. The average rate of intake of herbage by the ewe during those periods was about 0.5 kg d^{-1}. Blocking the option of early-season grazing of green wheat (R 9) increased mean gross margin by 2% (Table 16). Despite that negligible effect on profitability, there were some significant changes in the management pathway selected by the algorithms for the decisions. The immediate effect was to increase the average period spent by the ewe in the holding paddock by 20 d. That must have increased supplementary feeding to the ewe during that period. In three seasons, the additional time in the holding paddock triggered early weaning and major changes in the total intake of supplementary feed by ewes and lambs in those seasons. Blocking the option of early-season wheat grazing resulted in a small reduction in the late-season grazing of green wheat and so increased the amount of grain harvested. The amount of straw baled was also increased by not grazing the wheat early in the season. The additional available straw, together with a lower average weaning age, resulted in a reduction in total supplementary feeding of ewes. The average time spent by the lamb in either the holding paddock or fattening unit increased from 59 d per season in Run 1 to 79 days per season in Run 9. This resulted in an increase in supplementary feeding of lambs. Overall, the various effects on income and costs balanced out.

In farming practice, it is inconceivable that the complex set of interactions between the early-season grazing of green wheat and other aspects of system behaviour could be taken into account in a quantitatively meaningful way.

However the system exhibits 'compensatory' or 'buffering' properties that reduce sensitivity to that management option. Thus the simple algorithm for the decision about early-season wheat grazing would appear adequate. At Migda and at the stocking rate examined, the early-season grazing of green wheat is probably an unnecessary complication to management.

8.3 Late-season utilization of green wheat by grazing

An area of green wheat was grazed as an alternative to harvesting for grain in 8 out of 21 years in the standard run (R 1). The wheat-grazing period lasted for one, two and three management-decision time-steps (of 5 d) in 5, 2 and 1 season, respectively. The largest fraction of the area under wheat that was grazed in any one season was 17% (in 1977). Wheat grazing did not occur in all years that yielded insufficient grain to cover production plus harvesting costs, nor was wheat grazing confined exclusively to years with low yield of grain. The season with the highest yield of grain in which a fraction of the area under wheat was grazed was 1973. That season had the sixth highest yield of grain in 21 years, and the expected yield of grain during the grazing decision was only 6% below the actual yield. That highlights the dependence of the wheat-grazing decision on other factors besides expected yield of grain.

In some of the seasons in which the wheat was grazed in R 1, the decision to move the ewes to the wheat triggered weaning. In R 6 (Table 16), the weaning option was blocked whenever the ewes were moved to the wheat and so the lambs were forced to follow the ewes to the wheat. That resulted in a delay in weaning of at least one month, and in four seasons increased the number of 5-day periods that the wheat was grazed. Changing the pathway of lamb rearing in that way generally had a negative effect on gross margin. Thus the effect of the wheat-grazing decision on the weaning decision in the standard run appears to have been correct management.

The simplest way to examine the optimality of the wheat-grazing decision for the ewe is to block the wheat-grazing option (R 4). The mean gross margin over 21 years was reduced by 3% (Table 16). This rather small effect on gross margin came about through major changes in management pathway in the 8 seasons that were directly affected. On the whole, blocking the wheat-grazing option resulted in a delay in weaning, with the lamb receiving a greater portion of its requirements from herbage and less from concentrates. However for the ewes, later weaning in those seasons increased intake of supplementary feed and reduced herbage utilization (presumably because of increased utilization of herbage by the lamb).

To examine whether the wheat should have been grazed more often than it was in R 1, the wheat-grazing algorithm was adjusted to return a positive reply whenever the criteria that trigger the asking of the question were met (R 5). That resulted in a total of 42 5-day grazing periods over 21 years. Average gross margin was reduced by 22% to 227.1 \$ ha^{-1} (Table 16). In only one year was gross margin increased. At Migda and at a stocking rate of ewes with reference to system area of

5 ha^{-1}, the late-season utilization of green wheat by grazing is not a relevant option for management.

8.4 Late-season utilization of green wheat for hay

The area under wheat was never cut for hay in the standard run. However there were instances where the value of the crop of hay during decision was only slightly less than the expected grain profit. Thus the hay-cutting decision is probably sensitive to parametrization. The simplest way to trigger the cutting of hay is by adjusting the function for price of hay. Since hay is not sold out of the system, the function is purely an estimate of the internal value of the crop and does not directly contribute to income. A 25% increase in the function resulted in a 3% increase in mean gross margin. Hay was cut in 2 out of 21 years (Table 16, R 3). A 50% increase in the price of hay reduced mean gross margin by 1%, with hay being cut in 5 out of 21 years (Table 16, R 2). Further increases in price resulted in significant reductions in mean gross margin (Table 16, R 10 & R 7). Frequent cutting for hay does result in a large reduction in supplementary feeding of ewes with bought-in feedstuffs but that saving is insufficient to compensate for the loss in income from grain and the reduction in the amount of straw baled.

At Migda and for the price regime assumed in the standard run, the option of cutting green wheat for hay can be ignored. If hay is cut occasionally, the long-term profitability of the system may be affected only slightly. That long-term robustness is achieved by a large reduction in profit in the year hay is cut, followed by a small increase in profit over some seasons.

8.5 Utilization of wheat aftermath by grazing and baling of straw

In the standard run, straw was baled in 8 out of 21 years. A total of 14 190 kg ha^{-1} system was baled, of which 72% was used. On average, the ewes grazed the wheat aftermath for 107 d per season, with a utilization of 433 kg ha^{-1} system. The lambs spent an average of 11 d on wheat aftermath but that was in order to delay weaning and so maintain a low cost of gain, rather than for the nutritional value of the herbage.

The three options of management for early-season grazing of green wheat, grazing of wheat aftermath and baling of straw are closely related for obvious reasons. Those three management options can be combined in a variety of ways. The early-season grazing of green wheat can be blocked or allowed. Similarly, utilization of wheat aftermath by grazing can be allowed or blocked. Baling of straw can be blocked, allowed in accordance with the decision criteria outlined in Section 5.8 or forced whenever the value of straw exceeds the cost of baling. That yields a total of 12 permutations. These are shown in Table 17, ranked by mean gross margin. An additional run (R 12) was included where grazing of dry pasture was blocked as well as grazing of early-season wheat or wheat aftermath.

The results fall into two groups; those that permit baling of straw and those that

Table 16. Summary of results for the standard run, runs related to the early-season and late-season grazing of green wheat, and cutting for hay.

Run Number

1 standard run.

2 increase of 50% in top price of hay (parameter HYTOPP).

3 increase of 25% in top price of hay (parameter HYTOPP).

4 no late-season grazing of green wheat by ewes.

5 force late-season grazing of green wheat by ewes when algorithm invoked.

6 lambs follow ewes to late-season grazing of green wheat.

7 increase of 200% in top price of hay (parameter HYTOPP).

9 no early-season grazing of green wheat.

10 increase of 100% in top price of hay (parameter HYTOPP).

Variable	Value for Run Number								
	1	9	6	4	5	3	2	10	7
mean gross margin in system ($ ha^{-1})	289.6	296.2	287.0	280.4	227.1	297.4	285.5	252.6	216.4
number of seasons hay cut (1)	0	0	0	0	0	2	5	9	16
total amount of hay cut in system (kg ha^{-1})	0	0	0	0	0	6373	16316	28506	33410
total amount of hay utilized in system (kg ha^{-1})	0	0	0	0	0	6368	13699	18033	22386
number of seasons straw baled (1)	8	8	8	8	7	6	4	1	0
total amount of straw baled in system (kg ha^{-1})	14190	16411	14190	14183	10499	11226	5340	810	0
total amount of straw utilized in system (kg ha^{-1})	10224	11454	10220	10268	6850	7261	2667	548	0
mean intake of concentrates by ewes in system (kg ha^{-1})	547	469	565	594	568	443	356	285	295
mean intake of concentrates by lambs in system (kg ha^{-1})	449	474	438	428	480	448	451	450	449
mean yield of grain harvested in system (kg ha^{-1})	787	794	769	754	499	715	556	332	125
mean age at weaning (d)	128	117	140	143	115	129	128	129	130
mean time spent by ewes in holding paddock (d)	96	116	100	107	109	97	106	110	147

Table 17. Summary of results of runs related to integration with wheat. Runs are defined according to whether early-season grazing of green wheat is permitted (YES/NO), whether grazing of wheat aftermath is permitted (YES/NO), and the option for baling of straw. Baling options are: prevented (NO), according to regular criteria (REG), or whenever the value of straw exceeds the cost of baling (MAX). Options MAX and REG are equivalent when grazing of wheat aftermath is not permitted. Run Number 12 has no grazing of dry pasture.

Variable	Value for Run number										
	11	13	19	14	9	12	1	16	15	18	17
early-season wheat	NO	NO	YES	YES	NO	NO	YES	NO	YES	NO	YES
wheat aftermath	NO	YES	NO	YES	YES	NO	YES	YES	YES	NO	NO
baling of straw	MAX/ REG	MAX	MAX/ REG	MAX	REG	REG	REG	NO	NO	NO	NO
mean gross margin in system ($ ha^{-1})	318.8	316.2	308.2	307.6	296.2	294.6	289.6	258.7	255.0	253.5	251.4
mean gross margin relative to R 1 (1)	110	109	106	106	102	102	100	89	88	88	87
mean total requirement of metabolic energy per ewe (MJ year^{-1})	5926	6164	6225	6432	6249	5153	6470	6295	6548	6035	6316
number of seasons straw baled (1)	19	19	19	19	8	19	8	0	0	0	0
total amount of straw baled in system (kg ha^{-1})	28809	28447	25670	25296	16411	28484	14190	0	0	0	0
total amount of straw utilized in system (kg ha^{-1})	22209	21628	19980	19275	11454	26536	10224	0	0	0	0
mean intake of concentrates by ewes in system (kg ha^{-1})	320	323	425	427	469	444	547	701	752	736	782
mean intake of concentrates by lambs in system (kg ha^{-1})	485	476	451	452	474	491	449	473	449	469	449
mean yield of grain harvested in system (kg ha^{-1})	794	795	787	787	794	791	787	794	788	792	788
mean age at weaning (d)	117	115	130	129	117	124	128	116	125	119	128
mean time spent by ewes in holding paddock (d)	181	135	159	112	116	300	96	116	95	181	158
mean intake of herbage and straw by ewes in system (kg ha^{-1})	2258	2364	2225	2327	2042	1948	2041	1446	1498	1186	1255
mean intake of herbage by lambs in system (kg ha^{-1})	312	314	330	333	316	221	330	305	315	314	328

do not. Within each group, it is difficult to estimate how meaningful the differences in mean gross margin are. It is surprising that certain runs yielded such similar results. Once again, the property of robustness under different management configurations emerges clearly. The variable that correlates most obviously with mean gross margin in Table 17 is the average annual amount of supplementary feed to the ewes. Two main determinants of supplementary feeding of ewes are the energy requirements of the ewe and the availability of herbage as grazing or straw. A critical parameter in determining the energy requirement of the ewe is the increment to activity due to grazing. That reaches a maximum of 73% of maintenance requirements when availability and quality of herbage do not limit intake, and grazing activity is at a maximum (Section 6.2.2, Equation 43). Thus the lowest energy requirements are achieved when the ewe spends the greatest time off pasture in the holding paddock. Moreover, the amount of straw baled is increased by not grazing the wheat early in the season or as aftermath. Thus combinations that maximized baling of straw and time spent in the holding paddock proved the most profitable. The considerable stabilizing effect of the increment to grazing activity is most evident in R 12, where only green pasture (plus a small amount of late-season green wheat) was grazed, and the ewes spent an average of 300 d per season in the holding paddock.

At Migda, the options of cutting green wheat for hay, early-season grazing of green wheat, and late-season grazing of green wheat were of marginal importance. The main contribution of the wheat component in integrated systems is the availability of wheat aftermath. Utilization of wheat aftermath by baling and feeding in the holding paddock is preferable to grazing, because of the increase in energy requirements with grazing.

8.6 Lamb rearing

The algorithms for feeding and rearing lambs are based on the single economic principle of minimizing cost of gain in liveweight ($p\Delta$). The model is not constrained by other criteria in selecting a pathway for rearing lambs and any one of numerous permutations allowed by the lamb-movement matrix could, in principle, be selected. A second feature of the algorithm is that it is based upon the $p\Delta$ expected at any locality during decision. The pathway by which the lamb reached its current position and the future expected behaviour of the system are not considered at all in making decisions. Despite the simplicity of the decision criteria, the model generally selected conventional rearing pathways.

8.6.1 Main rearing patterns in the standard run

In the standard run, lambing is on 26 December. That is almost always after the first effective rains and germination. Usually the ewe is in the holding paddock at lambing, though in a few seasons the ewes are on early-season grazing of green wheat. Lambing was never on green pasture but was during the pasture deferment. On the basis of the 21 rearing pathways generated in R 1, some common patterns can be identified.

In one type of lamb-rearing pattern, the lambs suck milk on pasture during the green season, are weaned at 35 to 40 kg liveweight and are finished to 45 kg in the fattening unit. Such a pattern is associated with seasons of average or above-average rainfall, with adequate distribution for sustained primary productivity once the green season has commenced. That type of rearing pathway was followed in 9 out of 21 seasons.

Figure 19 shows $p\Delta$ at alternative rearing localities for one such season. The points along the $p\Delta$ curves are calculated at a 5-day interval between decisions. Thus the closer the points the lower the rate of growth by lambs. Lambs were born during early-season grazing of green wheat. They remained at that locality, receiving milk only, until the end of the early-season wheat-grazing period on 9 January. Biomass of green pasture had not then reached the optimum biomass at entry, as determined by the grazing-deferment algorithm, so the ewes and lambs were moved to the holding paddock for 10 d until that biomass was reached on 19 January. The lambs were supplemented in the holding paddock and briefly on green pasture, but voluntary intake of supplementary feed at such low liveweights is only about 150 g d^{-1}. The lambs remained with the ewes during the green-pasture season (until 30 March) and the early part of the dry-pasture season, until the wheat aftermath became available on 24 April. The lambs received no supplementary feeds over the period 24 January to 23 April. On 24 April, immediately after harvest of wheat grain and baling of surplus straw, the ewes and lambs were moved to the wheat aftermath for one month. At first, the lambs received only partial supplementary feeding but after further decline in herbage quality the lowest $p\Delta$ was attained with supplementary feeding ad libitum and full substitution for intake of herbage. The locality wheat aftermath was selected because of the effect of intake of milk on rate of gain and hence on $p\Delta$. However by 29 May, the rate of production of milk of the ewe was low and insufficient to compensate for the additional energy requirements for maintenance of the lamb relative to those in the fattening unit. Thus the lambs were weaned and transferred to the fattening unit for 20 d to finish to a weight at sale of 45 kg.

During grazing of green pasture, there were three alternative localities for the lamb as a weaner:

- remaining on pasture as a weaner (assuming that is technically feasible). This yields a characteristic U-shaped curve of $p\Delta$ for that type of season. At low liveweight, the voluntary rate of intake of herbage is barely sufficient to support growth and the lowest $p\Delta$ is then reached with supplementary feeding ad libitum. Beyond about 15 kg liveweight, the optimum rate of supplementary feeding of weaners on pasture falls to zero and $p\Delta$ declines rapidly. The minimum is reached at about 20 kg liveweight. Then, the predicted gain in liveweight of the weaner on pasture is highest for that nutritional locality (75 g d^{-1}). That is still considerably less than the rate of growth of 320 g d^{-1} achieved by lambs sucking on pasture at the same time and therefore $p\Delta$ of weaners on

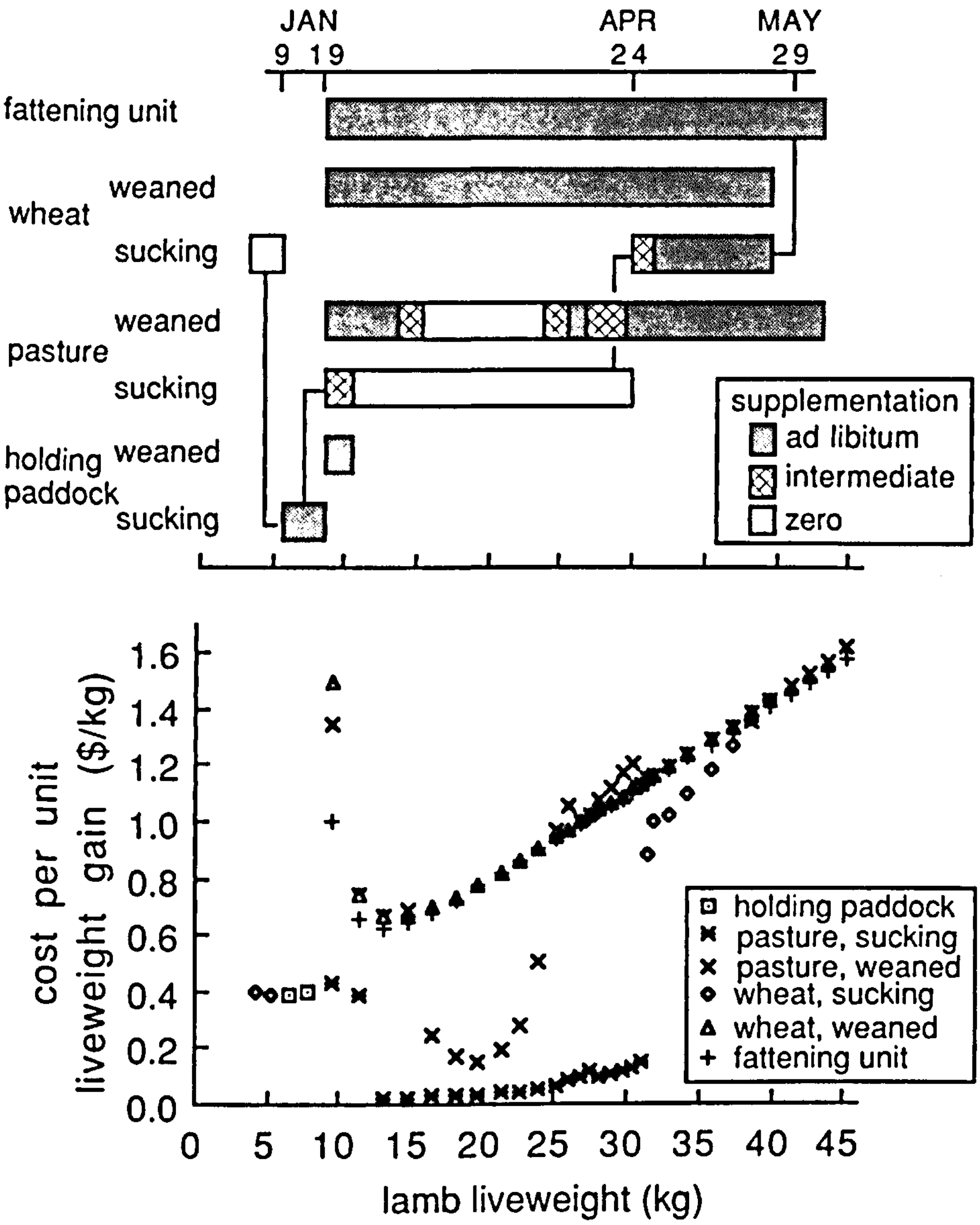

Figure 19. Time course of the cost per unit liveweight gain of the lamb, and the optimum supplementation level, at alternative rearing localities in one season (1964) of the standard run.

pasture does not reach the low values achieved by sucking lambs. Between 20 and 25 kg liveweight, the effect of declining herbage quality on rate of growth outweighs the effect of an increasing voluntary rate of intake and $p\Delta$ rises. Beyond 25 kg, herbage quality is too low to sustain growth and supplementary feeding switches (with small fluctuations) to ad libitum by the end of the green season. When supplementary feeding is ad libitum on pasture and availability of herbage is not limiting, there is virtually complete substitution of supplementary feed for herbage. Thus the only difference between the nutritional localities of weaners on pasture with supplementary feed ad libitum and the fattening unit is a lower requirement for maintenance of the housed animal.

That gives a small advantage in $p\Delta$ to the fattening unit.

- The lambs could have been weaned during grazing on green pasture and moved to the wheat for strip-grazing as an alternative to harvesting for grain. The expected grain yield resulted in a high value of grazed wheat herbage (Equation 24). Consequently, $p\Delta$ was lowest when supplementary feeds were provided ad libitum with complete substitution for wheat herbage.
  At the optimum rate of supplementary feeding, $p\Delta$ was slightly greater than that in the fattening unit through the small difference in energy requirements for maintenance at the two localities.
- Weaning the lambs and moving them to the fattening unit during the period of grazing green pasture would have resulted in a considerable increase in $p\Delta$. The fattening unit cannot compete with a locality that provides both milk and quality herbage.

A second type of pathway of lamb rearing occurs in years of extreme drought or years with exceptionally poor rainfall distribution. The lambs are largely reared in the holding paddock, receiving milk and concentrates ad libitum. Since availability of herbage is low, the options for rearing lambs are the holding paddock on concentrates ad libitum plus milk or the fattening unit on the same diet of concentrates. The fact that part of the ewe's intake of supplementary feed in the holding paddock is used to produce milk is taken into account in computing $p\Delta$. That will tend to counterbalance any reduction in $p\Delta$ arising from a higher rate of growth on a diet of milk plus concentrates than on a concentrate only diet. Nevertheless, in each of the four years characterized by that rearing pattern, the model consistently calculated a lower $p\Delta$ on a diet of milk plus concentrates in the holding paddock. Rates of growth by lambs were extremely high, averaging over 300 g d^{-1} for the four seasons and lactation continued till the lambs reached the weight at sale of 45 kg.

However the difference in $p\Delta$ between the holding paddock (supplementary feeds plus milk) and the fattening unit (supplementary feeds only) was often small and so the selected rearing pathway may be sensitive to inaccuracies. One possible inaccuracy is the assumption that milk does not replace concentrates or vice versa. If there is significant substitution, rates of growth by lambs would be slightly lower in the holding paddock than predicted, and $p\Delta$ in the holding paddock might exceed that in the fattening unit.

A third type of lamb-rearing pattern can be characterized as sucking on pasture until availability of green herbage limits intake, followed by weaning at 25 to 30 kg liveweight, and finishing in the fattening unit. Such a pattern is associated with seasons with rainfall below average. That rearing pathway was followed in 5 out of 21 seasons. In each case, availability of pasture became limiting during the green season and the ewes had to be supplemented on pasture. That resulted in an affirmative reply from the algorithm for late-season grazing of green wheat for the ewe. For the lambs, however, $p\Delta$ on wheat was higher than in the fattening unit and so the lambs were weaned and moved to the fattening unit.

When the option of grazing the green wheat late in the season was blocked to the ewe (Table 16, R4) or when the lamb was forced to follow the ewe to late-season grazing of green wheat (Table 16, R6), weaning was considerably delayed in those five seasons and a different rearing pathway was followed. Such a marked change in rearing pathway was not forced in those two runs. The lambs could have been weaned within a few days of the weaning date in the standard run. Total supplementary feeding of lambs was reduced but that was offset by a greater increase in total supplementary feeding of ewes.

It is seasons of that third type that pose the most difficult decisions. In years with sufficient rainfall or in years of serious drought, the rational decision is either obvious or there are few alternative courses of action. In the intermediate seasons, different management pathways can be triggered by a single decision at a sensitive phase in the season. Here again, robustness of the system to alternative rational pathways of management tends to minimize the financial risk of uncertainty in making decisions.

8.6.2 Effect of a fixed weaning age

In view of the fact that $p\Delta$ is significantly lower when the lamb is receiving milk, one might expect forced early weaning to have a negative effect on profitability. To examine that question, the lamb-rearing algorithm was adjusted to block all weaner localities before the lamb has reached a minimum age and to block all sucking localities after that age.

Forcing weaning at 34 d old reduced mean gross margin by only 7% to 269.3 \$ ha^{-1} (Table 18, R 50). Forcing weaning at 64, 94, 123 or 147 d old (Table 18, R 51, R 52, R 72, R 73, respectively) had virtually no effect on mean gross margin. That remarkable robustness was obtained despite large effects on the management pathway of the ewe and lamb. As the age of forced weaning increased, the ewe increased its total intake of green pasture (through higher energy requirements), decreased its total intake of dry pasture (through a lower availability at the end of the green season) and increased its total intake of wheat aftermath (through lower availability of dry pasture). There was also an increase in time spent in the holding paddock and a reduction in baling of straw through increased utilization of herbage by both ewe and lamb. For the lamb, there was a trade-off between the time spent grazing and the time in the fattening unit. Earlier weaning increased the time spent in the fattening unit and hence total supplementary feeding of lambs, but the additional cost was balanced by a reduction in total supplementary feeding of ewes. The ewe required less purchased supplementary feed with earlier forced weaning because its body condition was higher at critical phases of the physiological cycle, more straw was baled and total energy requirements were slightly reduced.

Meat production is constant over the various management options being examined. That may be an unrealistic assumption, even under target-oriented management, if weaning age influences mortality of lambs or general state of health. One way of interpreting those results is to say that it is precisely manager-

Table 18. Summary of the results for the standard run and runs related to weaning according to age of lamb. Run Number 1: standard run, weaning by normal criteria.

Variable	Value for Run Number					
	1	50	51	52	72	73
age at weaning (d)		30	60	90	120	150
mean gross margin in system ($ ha^{-1})	289.6	269.3	282.1	288.3	288.2	286.7
number of seasons straw baled (1)	8	9	9	9	8	8
total amount of straw baled in system (kg ha^{-1})	14190	18436	17826	17037	15000	13645
total amount of straw utilized in system (kg ha^{-1})	10224	12175	11914	11523	10359	9568
mean intake of concentrates by ewes in system (kg ha^{-1})	547	359	425	485	553	589
mean intake of concentrates by lambs in system (kg ha^{-1})	449	693	579	495	437	417
mean yield of grain harvested in system (kg ha^{-1})	787	805	805	792	772	765
mean age at weaning (d)	93	34	64	94	123	147
mean time spent by ewes in holding paddock (d)	96	88	91	94	100	101
mean intake of herbage and straw by ewes in system (kg ha^{-1})	2041	2007	2055	2086	2047	2032
mean intake of herbage by lambs in system (kg ha^{-1})	330	187	197	229	307	342
mean age of lambs at sale (d)	171	184	160	153	162	165
mean time spent in fattening unit (d)	58	71	56	43	30	16
mean total requirement of metabolic energy per ewe (MJ year^{-1})	6470	6197	6368	6453	6480	6490

related and site-specific factors (such as the effect of weaning age on total meat output) that should dictate the management option, in view of the considerable robustness to weaning age.

8.6.3 Inclusion of sown legume for lamb grazing

Although the inclusion of sown legume in the agropastoral system was defined earlier as a strategic decision, that management option is most appropriately discussed together with tactical decisions about lamb rearing. Viewed in isolation, sown legume swards do possess some advantages over non-leguminous swards (Section 4.1). However within the system, the fact that the area of at least one other component must be reduced in order to include the legume is itself a disadvantage. If an area of wheat is displaced by the introduction of legume, there is a reduction in income from grain and availability of straw. If an area of pasture is displaced by the legume, grazing pressure by ewes on pasture is increased. That will effect the ewe's requirements for supplementary feed through the effect on total production of herbage and the deferment of pasture grazing. Those negative effects must be more than compensated by the saving in supplementary feeding of lambs achieved by the introduction of legume. In the agropastoral model, the costs of sowing and maintaining a legume sward are not included in the financial balance. However, assuming a sward life of 5 years, the mean annual production costs of a legume (medic) sward are about 100 $ ha^{-1} (R. Benjamin, personal communication). Thus the mean gross margin would need to increase by at least 10 $ ha^{-1} to allocate an area of 0.1 ha to medic.

Results of the model did not generally favour use of a special-purpose pasture for the lambs. Relative to the standard run, allocation of an area fraction of 0.45, 0.45, 0.1 to natural pasture, wheat and medic, respectively, decreased mean gross margin by about 1% (Table 19, R 30). Increasing the area fraction of medic to 0.2 and 0.3 of the system, with the remainder divided equally between pasture and wheat, reduced mean gross margin by 3 and 9%, respectively (Table 19, R 31 & R 32). Not only did total supplementary feeding of ewes increase with increasing area under medic, as expected, but total amount of supplementary feed to lambs was also increased in the 3-component systems. That is a surprising result, especially since total utilization of herbage and total utilization of medic by lambs increased with increasing area under medic and the average time spent in the fattening unit decreased with increasing area under medic. However the increase in utilization of medic in R 30, R 31 and R 32 was much greater than the increase in utilization of herbage by the lambs. In other words, a significant portion of utilization of medic simply replaced utilization of herbage at other grazing localities. Furthermore, inclusion of medic resulted in earlier weaning and so a further portion of medic utilization can be regarded as replacing forfeited intake of milk. Whilst the average time spent by the lambs on concentrates ad libitum in the fattening unit was markedly reduced by the inclusion of an area under medic, the lambs did receive supplementary feed for a significant portion of the time spent on medic. That was due to low availability or quality of medic late in the season, supporting only low rates of growth by lambs and yielding a higher $p\Delta$ without supplementary feeds than with intermediate or supplementary feeding ad libitum.

In R 70 and R 71 (Table 19), the area fraction under wheat was maintained at 0.5 of system area and medic was introduced at the expense of natural pasture only. An allocation of an area fraction of 0.1 to medic increased mean gross margin by 1% but increasing the medic allocation to 0.2 reduced mean gross margin by 3%. In R 70, the performance of lambs is similar to that in R 30. Once again, total amount of supplementary feed to lambs was increased relative to R 1. However there was a small increase in utilization of straw by the ewes and a small

Table 19. Summary of results for the standard run and runs related to the inclusion of medic area in the system. Run Number: 1 standard run; 78 with 'improved' medic; 79 with 'improved' medic, medic cannot trigger weaning.

Variable	Value for Run Number							
	1	30	31	32	70	71	78	79
area fraction of system to pasture (1)	0.50	0.45	0.40	0.35	0.40	0.30	0.40	0.40
area fraction of system to wheat (1)	0.50	0.45	0.40	0.35	0.50	0.50	0.50	0.50
area fraction of system to medic (1)	0	0.10	0.20	0.30	0.10	0.20	0.10	0.10
mean gross margin in system ($ ha^{-1})	289.6	286.1	280.2	263.8	292.8	280.2	304.6	297.3
number of seasons straw baled (1)	8	8	8	6	8	8	8	8
total amount of straw baled in system (kg ha^{-1})	14190	11598	9519	7355	13544	11131	14648	12730
total amount of straw utilized in system (kg ha^{-1})	10224	8986	8284	6197	10602	8194	10983	10353
mean intake of concentrates by ewes in system (kg ha^{-1})	547	560	573	610	530	595	512	549
mean intake of concentrates by lambs in system (kg ha^{-1})	449	462	468	489	485	512	453	448
mean yield of grain harvested in system (kg ha^{-1})	787	719	635	554	798	800	800	784
mean age at weaning (d)	128	102	92	80	92	75	87	114
mean age of lambs at sale (d)	167	173	187	195	174	192	176	178
mean time spent on medic (d)	0	37	63	77	44	76	60	44
mean time spent in fattening unit (d)	58	30	24	27	30	25	22	14
mean intake of medic by lambs in system (kg ha^{-1})	0	145	259	335	168	301	265	202
mean rate of intake of medic per lamb (kg d^{-1})	0	0.74	0.78	0.82	0.72	0.75	0.84	0.87
mean intake of herbage by lambs in system (kg ha^{-1})	330	394	469	497	379	454	448	441
mean intake of herbage and straw by ewes in system (kg ha^{-1})	2041	1891	1782	1586	1930	1675	1943	1956

reduction in total supplementary feeding of ewes. That tended to cancel the increase in supplementary feeding of lambs and thus there was little overall effect on gross margin. The difference in total amount of supplementary feed to ewes or lambs between R 1 and R 70 shows a variable pattern (Figure 20). To account fully for the year-to-year differences in rate of supplementary feeding would require a detailed analysis beyond the scope of this study. Carry-over effects from season to season complicate the analysis. Such effects include the body condition

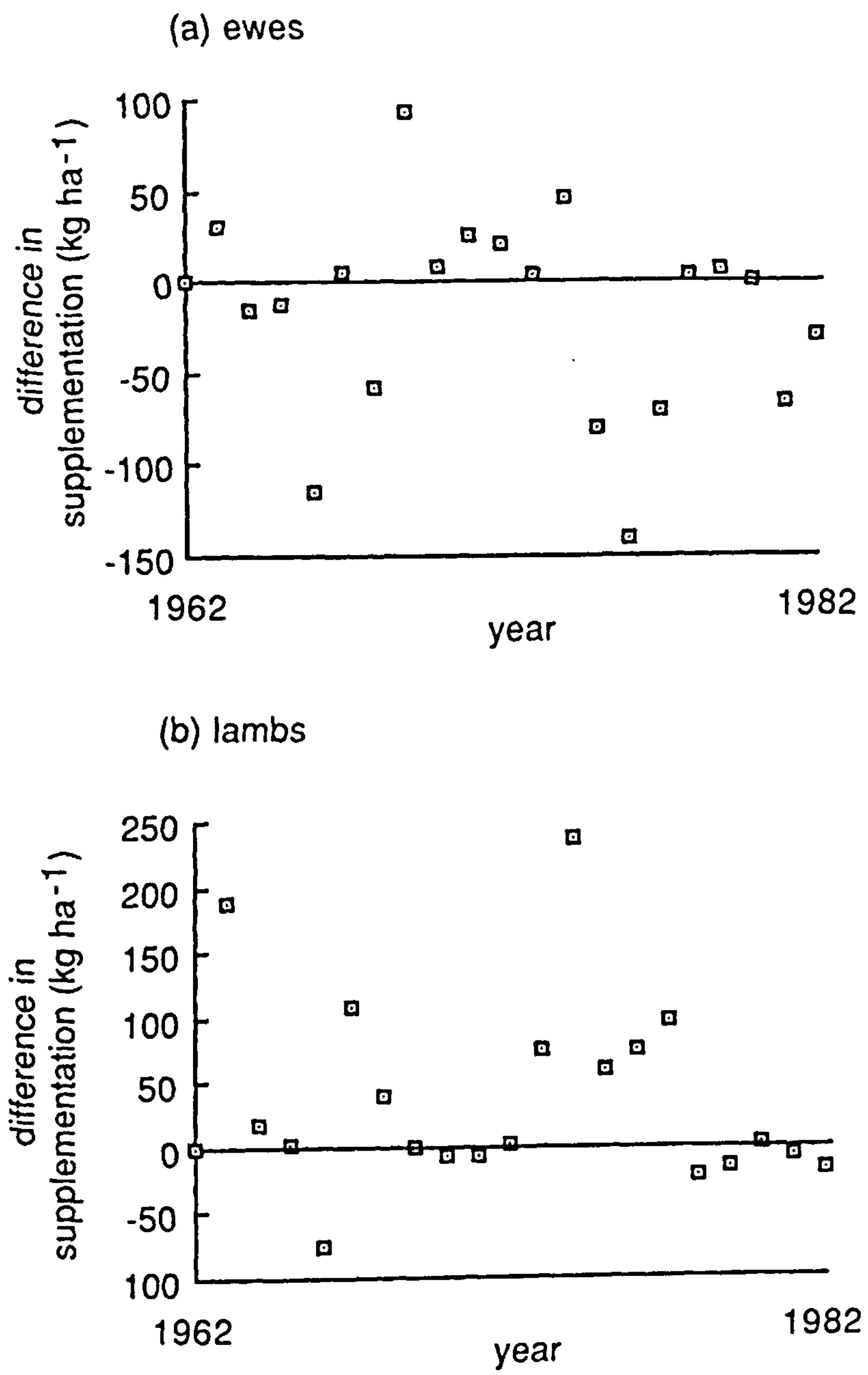

Figure 20. The effect of allocating 10% of system area to a medic sward on total supplementary feed intake over 21 years. Points indicate the difference in total supplementary feed intake each season between a system with 0.4, 0.5, 0.1 ha pasture, wheat, and medic, respectively (R 70), and the standard run (R 1). A. Ewes. B. Lambs.

of the ewe and the amount of dry herbage remaining from the previous green season when the new season begins on 1 October. Not surprisingly though, the difference in total supplementary feeding of lambs correlates with the difference in lamb weight at which the final 'finishing' phase of supplementary feeding ad libitum begins.

The disappointing performance on medic may be due to poor parametrization of the model. To examine the sensitivity of the model to performance on medic, the digestibility of grazed herbage was increased by 30% or set equal to the calculated digestibility of green leaf, whichever was the lower. Those changes were implemented in R 78 (Table 19), which was the same as R 70 in all other respects. Relative to R 70, total utilization of medic was increased by 58% in R 78 but part of that increase replaced intake at other localities. Total amount of supplementary feed for lambs was lower in the 'improved medic' run but it was still higher than in R 1. Mean gross margin increased by 5% relative to R 1.

One possible problem with the selected pathway of lamb rearing in the systems including medic is that the lambs are weaned and moved to the medic sward too early. Besides forfeiting milk, early grazing of the medic may reduce availability at the end of the season of natural green pasture, just when the medic is most needed. To examine that possibility, the lamb-rearing algorithm was adjusted in R 79 to block the option of moving the lambs to the medic sward until after weaning, i.e. the medic sward itself could not trigger early weaning. In lamb performance, R 79 yielded promising results (Table 19). Total supplementary feeding of lambs was lower than in R 1, average weaning age was significantly later than in R 78, average time in the fattening unit was reduced to two weeks and average daily intake on medic was the highest of all the runs with a medic component. But later weaning relative to R 78 increased total utilization of non-medic herbage by the lamb. That ultimately caused total intake of supplementary feed by ewes to increase. The causal chain probably acted through reduced availability of pasture to the ewe, increased wheat aftermath requirement of the ewe, reduced baling of straw and so increased intake of supplementary feed. Mean gross margin in R 79 was slightly lower than in R 78, indicating that the standard lamb-rearing criterion of minimum $p\Delta$ during decision, without any further complications, is a rational policy.

The inclusion of a medic sward in the agropastoral system seems not to improve profitability markedly. Unless there are factors that favour introduction of a medic sward that are not considered in the model, it can probably be regarded as a marginal option. One factor that has weighed in favour of inclusion of a medic sward at Migda has been the poor performance of lambs at natural pasture with a high fraction of *Hordeum murinum*. Late in the green season, the awns of *Hordeum* species can cause serious eye sores and impair performance. Since the model indicates that inclusion of medic in the absence of such problems has little effect on overall performance, one can assume that medic could make a significant contribution to overall performance when such problems exist.

8.7 Prices and price ratios

The prices of meat and purchased concentrates are critical parameters in the agropastoral system. Both the price ratio of meat to feed and the absolute prices have a strong influence on the economic performance of the integrated system. To illustrate this, a price ratio of meat to feed of 5 was taken, using different absolute prices. In R 37, the price of meat was halved to 1.25 $ kg^{-1}. In R 38, the prices of purchased concentrate and wheat grain were doubled to 0.50 and 0.44 $ kg^{-1}, respectively. (A constant ratio between the prices of concentrate and grain was maintained in all runs.)

Mean gross margin in R 37 and R 38 was 5.6 and 245.9 $ ha^{-1}, respectively, compared with 289.6 $ ha^{-1} in the standard run. In both runs, the reduction in amount of meat sold was about 15%. That was because the lower price ratio of meat to grain caused $p\Delta$ to exceed the price of meat before the lambs reached the maximum weight at sale of 45 kg. On average, weaning was a week earlier and lambs were sold about 25 d younger. The average time spent in the fattening unit was reduced from 25 d in R 1 to 6 d at the lower price ratio. The effect on gross margin was largely compensated in R 38 by the higher price received for grain in the wheat component of the system. There were no such compensatory features when the price of meat was changed in R 37 and so mean gross margin was drastically reduced.

The absolute prices of feed and grain can affect lamb-rearing decisions, independently of the price of meat. The price of feed appears in the calculation of the price of milk when the ewes are being supplemented (Equation 98) and the price of grain appears in the calculation of the price of grazed wheat herbage when grazed late in the green season (Equation 24). Thus the ranking of alternative lamb-rearing localities according to $p\Delta$ and hence the rearing pathway could be altered by a change in prices of feed and grain. However one would expect only a small, perhaps negligible, impact on system performance.

8.8 Stocking rate

With target-oriented nutrition (i.e. the output per animal is based on potential production), the relation between gross margin and stocking rate has some predictable features. First, meat output and thus income increases linearly with stocking rate. We make the reasonable assumption that the price with respect to feed value of supplementary feed is greater than that of grazed herbage. Since the amount of nutrients that a grazed sward can provide is finite, the cost of income generated (the 'average cost') must increase over some range of stocking rate. Over this range, the function of total cost will therefore be convex ($f''(x)>0$) and the gross margin function will be concave ($f''(x)<0$). Over a broader range of stocking rate, however, the function of gross margin may increase monotonically or be truly concave, depending on the price ratio of meat to feed (Figure 21). The

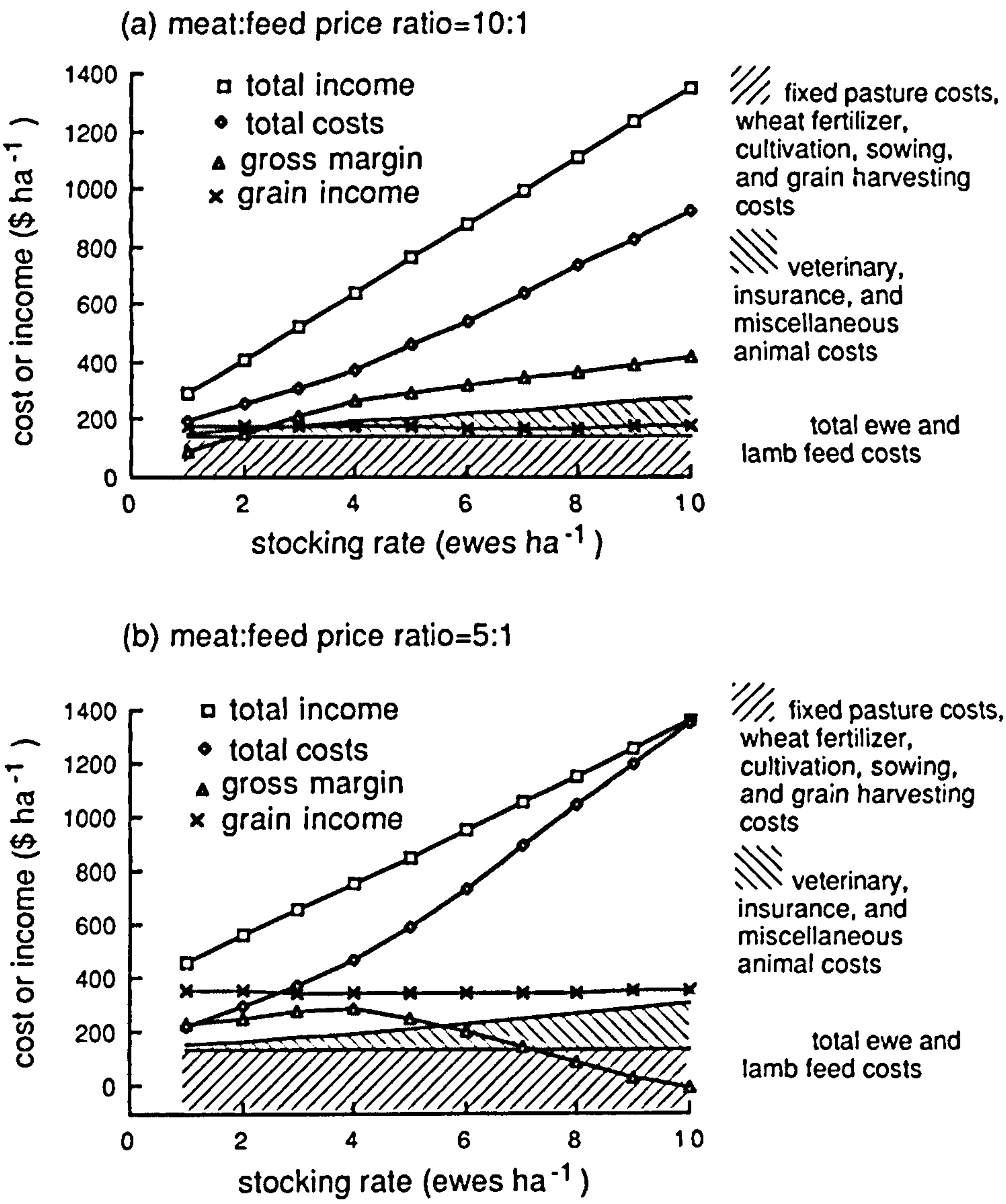

Figure 21. Costs, income, and gross margin as a function of stocking rate, at two meat: feed price ratios. A. Meat: feed price ratio = 10:1. B. Meat: feed price ratio = 5:1.

lower price ratio came about by doubling the price of concentrates and of wheat grain.

The curve for total cost is divided into three components.

- Fixed costs for pasture, wheat fertilizer, cultivation, sowing, and costs of harvesting grain. Since the area fractions are pasture 0.5 and wheat 0.5 over all stocking rates, and the area of green wheat grazed as an alternative to harvesting for grain (and hence costs of harvesting grain) varied only slightly with stocking rate, the sum of those costs is almost constant with stocking rate. Neither is it affected by the price ratio of meat to feed.
- Veterinary, insurance and miscellaneous costs of animals. The veterinary and insurance costs are constant per animal. Miscellaneous costs are defined as 10% of the sum of costs of concentrates for the ewe, veterinary services and insurance. That is almost linear with stocking rate.

- Total costs of feed for ewes and lambs. That is defined as the sum of average annual intake of straw, poultry litter and concentrates by the ewe, plus the average annual intake of concentrates by the lamb multiplied by the respective prices. That function is not linear with stocking rate and indicates that the cost of feed per animal is not constant with stocking rate.

At both price ratios, the function for total cost appears to be comprised of two linear sections, with an inflection point at a stocking rate for ewes of 4 ha^{-1}. That can be explained by examining the intake per ewe of grazed herbage, straw and concentrates (Table 20). Total intake of grazed herbage per ewe decreases monotonically with stocking rate. However up to a stocking rate of 4 ha^{-1}, there is sufficient surplus straw for grazing in the dry season to buffer the decline in intake of grazed herbage per ewe (i.e. total intake of grazed herbage plus baled herbage is almost constant up to 4 ha^{-1}). Thus over that range of stocking rate, intake of concentrates per ewe is almost constant and represents some 'obligatory' minimum requirement of concentrates at even the lowest stocking rate. At a stocking rate above 4 ha^{-1}, the intake of straw per ewe declines steeply with stocking rate and that is compensated by increasing feeding with concentrates at a ratio of about 0.5 kg concentrates per kg straw. So the functions for total cost at different prices of feed are not parallel. The effect of price of feed can be seen in Figure 22, which shows the average cost as a function of stocking rate. Average cost is almost constant up to 4 ha^{-1} and afterwards increases at a slope that depends on the price of feed.

The total income curve in Figure 21 is divided into two components.

- Income from grain. That is defined as the product of the average yield and price of grain. Since the area of green wheat grazed as an alternative to harvesting for grain varied only slightly with stocking rate, the function for income from grain is almost constant with stocking rate for any price of grain.
- Meat income. That is defined as the sum of the income from lamb's meat and meat from culled ewes. The function of meat income is linear with stocking rate, though the slope of the function may vary with price ratio of meat to feed (Figure 21).

The function for gross margin in Figure 21 is essentially the difference between the total income and total cost, though the cost of baling straw that was not used was added, since that can represent a significant and unrealistic penalty at low stocking rates. (The other difference between the gross margin plotted in Figure 21 and that computed by the model is interest charges on periods of negative financial balance. Those charges are small and can be ignored for present purposes.)

At a price ratio of meat to feed of 10, the function for gross margin is concave in the region of a stocking rate for ewes of about 4 ha^{-1} but overall increases monotonically. The function does not have a maximum and a completely housed meat production system (without integration of any kind) returns a positive gross margin at that price ratio. At a price ratio of meat to feed of 5, the function for gross margin is overall concave and has a maximum at about 4 ha^{-1}. In other

9 Summary

This study examines the management of intensive integrated agropastoral systems in a semiarid region where conventional pathways of agricultural intensification are technically and economically feasible.

Unpredictability and variability of rainfall creates the need to distinguish between tactical and strategic decisions. A strategic decision is taken independently of the state of the system at the time of decision as well as independently of the expected short-term to medium-term performance of the system. A tactical decision is taken in response to the immediate state of the system or in consideration of the expected performance of the system in the short to medium term. Different approaches are appropriate for treating those two decision classes. Furthermore, imperfect knowledge of the biology of the system, both in terms of understanding (model formulation) and information (monitoring for implementation), is a constraint that should impinge on the approach adopted.

The agropastoral model is comprised of separate management and biological sections. The subroutine for primary production is based upon an existing simulation model (van Keulen, 1975) and secondary production subroutines are based upon a widely adopted feeding system (GB-ARC, 1980). Strategic decisions are defined by a set of parameters that remain constant over each simulation. Tactical decisions are treated individually by a series of optimization subroutines.

Supplementary feeding of ewes is target-oriented. Feeding is adjusted to ensure the achievement of production targets, which are set close to the animal's potential. The ewe's liveweight is allowed to fluctuate during the reproductive cycle when that is not expected to have a detrimental effect on productive performance.

The grazing schedule of the ewe is determined by a user-determined priority-ranking of all possible localities in the system and a series of optimization routines that determine when each locality should be grazed. The ewe is moved to the highest-ranking locality that is deemed grazable by the optimization routines.

Deferment of grazing on pasture can be critical to system dynamics. The optimum time to commence grazing is defined as that maximizing total intake of herbage. Intake of herbage is defined as total intake of green and dry herbage, allowing for utilization of wheat aftermath and the relative nutritive value of green and dry herbage. The solution is found numerically with a simple two-function model. Despite its compactness, the deferment model may well have provided the deepest insight into the general properties of a large class of grazing systems.

Early-season grazing of green wheat (not as an alternative to grain) can

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11 Listing of model

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      PROGRAM AGROPA(TAPE10,TAPE40,TAPE62,TAPE63,TAPE64,TAPE65,TAPE66,
     *               TAPE67,TAPE68,TAPE69,TAPE70,TAPE71,TAPE72,TAPE73,
     *               TAPE74,TAPE75,TAPE76,TAPE77,TAPE78,TAPE79,TAPE80,
     *               TAPE81,TAPE82,TAPE50,TAPE60,TAPE90,TAPE95,TAPE99,
     *               INPUT,OUTPUT)

C                    AGRO-PASTORAL   SYSTEM   MODEL

C                    TAPE10   -  PARAMETERS AND FUNCTION TABLES
C                    TAPE40   -  HISTORICAL RAINFALL RECORDS
C                    TAPE50   -  DIARY ENTRIES
C                    TAPE62-82   MET DATA FILES
C                    TAPE60   -  LAMB REARING SPECIAL TRACE
C                    TAPE90   -  DEBUG OUTPUT
C                    TAPE95   -  TABULAR OUTPUT
C                    TAPE99   -  SUMMARY TABLE

C     ST
      IMPLICIT       REAL(A-Z)

      INTEGER
     *                    BSYS,     COL,    CULL,I1,I2,I3,J1,DAY,     DEB,
     *                    DELT, EWELOC, EWEMAT,     FERT,  FERTD,   GRAZE,
     *                   GRAZL,  GRODY,    HARV,  IRN15,  HYOP,     GEST,
     *                     ELS,      JJ,    JOIN,  JOIND,      K,     LAGE,
     *                    LAMB,  LAMBD, LAMLOC, LAMMAT,     LMM,    MATCH,
     *                  MNGDEL,     MSW,     LLS, NDLACT, NDPREG,     NRO,
     *                      NY,    PLOW,   PLOWD,  PRDEL, PRIORT,  RATING,
     *                   SEADY,    SELL,     SOW,   SOWD, STARDY,    TIME,
     *                    WEAN, WEANED, WST2BL,        Y,   YEAR,      YR,
     *                   STROP, DIDHRV, GDDEC,  NCAFG

      PARAMETER      (NRO=34)
      CHARACTER*7    NAME(NRO)

      DIMENSION
     *                                    ALPHAT(7,25),        AMAX(3),
     *                         AREA(3),        ARF(16),       AVLAR(3),
     *                         CRDL(3),       CRDNL(3),      CRLFAR(3),
     *                        CRLVS(3),      CRNLVS(3),     CSRRT(2,7),
     *                    CSRRTW(2,15),      CTRDEF(3),       DBIOM(3),
     *                         DEB(13),    DISTFT(2,5),   DISTFTM(2,3),
     *                   DISTFTW(2,12),       DLBIO(3),      DNLBIO(3),
     *                       DRF(3,10),      DRR(3,10),         DVR(3),
     *                      DVRT(2,5),         DVS(3),         DVX(3),
     *                                       EB(3,10),    EDPTFT(2,5),
     *                         EFFE(3),        ENGR(3),       ER(3,10),
     *                       EWEMAT(6),    FAMSTT(2,5),      FDMT(2,3),
     *                    FLTRT(2,10),    GRAINT(2,14),       GRLVS(3),
     *                        GRNLV(3),       GRODY(3),
     *                         GRRT(3),       GRRWT(3),       GRSDS(3),
     *                        IBIOM(3),        IRWT(3),      LAGRTR(3),
     *                          LAI(3),      LAMMAT(8),      LFAREA(3),
     *                          LFI(3),      LMBIOM(3),        LMM(8,8),
     *                     LPDMIT(2,6),     MAT(NRO,10),       MATCH(6)
      DIMENSION
     *                    MNEBCT(4,19),      MWATER(10),        PRVTV(3),
     *                       PRIORT(6),       PRVDVS(3),        PUSHD(3),
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     *                        PUSHG(3),    RADTB(2,14),      RATING(6),
     *                       RDAMAX(3),      RDEFFE(3),        RDLFA(3),
     *                        RDLVS(3),      RDNLVS(3),      RDRAT(2,4),
     *                      RDRDT(2,6),       RDTDF(3),   REDFDT(2,10),
     *                     REDTTB(2,7),    RFDVST(2,4),
     *                        RITDF(3),      RRAMAX(3),       RREFFE(3),
     *                          RTD(3),      RTWGHT(3),      RWFB(3,10),
     *                        SLCVR(3),       TADRW(3),         TCK(10),
     *                         TDB(10),      TDRAIN(3),         TDRWT(3),
     *                        TDVS1(3),      TECT(2,8),         TEVAP(3),
     *                       TMPSUM(3),      TOTRAN(3),        TPEVAP(3),
     *                         TRAN(3),      TRR(3,10),         TVEGM(3),
     *                         VRES(3),        W(3,10),          WLVS(3),
     *                        WLVSI(3),       WNLVS(3),        WNLVSI(3),
     *                      WREDT(2,7),         WSDS(3),          WTOT(3),
     *                           Y(21),    TOTA(6,12),      TOTB(6,12),
     *                        WGCMPE(5),      WGCMPL(5)

C      (((
C      =============   OPA(
       COMMON / COM08 /
     *             APCS    , BALEC   , PLOWD   , PSTRW   , STBL    , STLEFT  ,
     *             STROP
       COMMON / COM09 /
     *             FORCPH  , HAYLD   , HVCH    , HYCTR   , HYDVS   , HYHC1   ,
     *             HYHC2   , HYLEFT  , HYOP    , HYPF1   , HYPF2   , HYTOPP  ,
     *             WACH
       COMMON / COM10 /      BCP2    , GAP     , LFP
       COMMON / COM11 /
     *             DMF1    , DMP1    , DMP2    , ELWG    , EUBL    , MCRMN   ,
     *             MCRMX   , MRP1    , MRP2    , MRP3    , MRP4    , QMHY    ,
     *             QMST
       COMMON / COM12 /
     *             ALFEW   , EEP1    , EEP2    , EEP3    , ELP1    , ELP2    ,
     *             ELP3    , EMYMF   , EWMTMF  , KP      , LBW     , MF1     ,
     *             MF2     , MF3     , MFC     , NDPREG  , NEWL    , NLB     ,
     *             PKF4    , RP1     , RP2     , RP3     , RP4     , RP5     ,
     *             SPD     , WEWE
       COMMON / COM13 /      LLWG
       COMMON / COM14 /      PTIME   , TOL
       COMMON / COM15 /
     *             LEP1    , LEP2    , LEP3    , LEP4    , MDMC    , PKF3    ,
     *             PKM3    , QMM
       COMMON / COM16 /
     *             AAP     , FGF1    , FGF2    , GF      , PKF1    , PKF2    ,
     *             PKM1    , PKM2    , WE
       COMMON / COM17 /
     *             CLLWG   , CULL    , EBCLIM  , LAMLOC  , LMM     , SELL    ,
     *             SLVWT   , WAGRL   , WEAN    , WEANED
       COMMON / COM18 /      GRAZL
       COMMON / COM19 /      LAGE
       COMMON / COM20 /
     *             DACS    , FRCS    , GDCS    , GDDEC   , GDF     , GDG     ,
     *             GDI     , GDTEND  , GDVM    , GDVMF   , GDVS    , MNIEW   ,
     *             PGDLIM  , S
       COMMON / COM21 /      DCLV    , DCNLV   , RATING
       COMMON / COM22 /      TADRW
       COMMON / COM23 /      MNGDEL  , WGWF
       COMMON / COM24 /      ARF     , COSTH   , PGRN
       COMMON / COM25 /      PRIORT
       COMMON / COM26 /      WAGRE
       COMMON / COM27 /
     *             ALPHAT  , AMAX    , AMAXB   , CONFS   , CONFSM  , CSRRT   ,
     *             CSRRTW  , DBIOM   , DELT    , DGRRT   , DISTFT  , DISTFTM,
     *             DISTFTW, DRR     , DVR     , DVRT    , DVSSF   , DVX     ,
     *             EB      , EDPTFT  , EFFE    , EFFEB   , ENGR    , ER      ,
     *             EVAP    , FAMSTT  , FDMT    , FLDCP   , FLTRT   , FWDB    ,
     *             GAMMA   , GRAINT  , GRLVS   , GRNLV   , GRRT    , GRRWT   ,
     *             GRSDS   , INFR    , K       , LAGRTR  , LAI     , LAT     ,
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     *           LFARR  , LHVAP  , LMBIOM , MRESF  , MSW    , MWATER ,
     *           MXRTD  , PI     , PROP   , PRVDVS , PRVTV  , PSCH   ,
     *           PUSHD  , PUSHG  , RADTB  , RAIN   , RC     , RCST   ,
     *           RDAMAX , RDEFFE , RDLFA  , RDLVS  , RDNLVS , RDRAT  ,
     *           RDRDT  , RDTDF  , REDFDT , REDTTB , REFCF  , REFT   ,
     *           RFDVST , RHOCP  , RITDF  , RRAMAX , RREFFE , RS     ,
     *           RTD    , RWFB   , SLCVR  , TCDPH  , TCDRL  , TCDRNL ,
     *           TCK    , TCRPH  , TDB    , TDRWT  , TECT   , TMPSUM ,
     *           TRAN   , TRR    , TS     , TSO    , TSUMG  , W      ,
     *           WCLIM  , WLTPT  , WREDT
      COMMON / COM28 /    CTRDEF
      COMMON / COM29 /    IBIOM
      COMMON / COM30 /    SEADY
      COMMON / COM31 /    DAY
      COMMON / COM32 /
     *           CFDM   , CRLFRE , CRLFRL , CRLVE  , CRLVL  , CRNLVE ,
     *           CRNLVL , DDLP   , DDNLP  , DDSL1  , DDSL2  , DGLP   ,
     *           DGNLP  , DGSL1  , DGSL2  , DINTG  , DINTL  , DND1   ,
     *           DND2   , DSLPG  , DSLPL  , ECRDL  , ECRDNL , EPLA   ,
     *           EWEMAT , GEH    , HAY    , LAMMAT , LCRDL  , LCRDNL ,
     *           MINEBC , MNSTR  , NEWM   , NLR    , SPFRC  , STRAW  ,
     *           SUPQ   , TDVS1  , VSATG
      COMMON / COM33 /    MER
      COMMON / COM34 /
     *           EMEPA  , EMY    , ERHI   , ERPLI  , ERSTI  , MEHY   ,
     *           MEPL   , MEST   , QMPL
      COMMON / COM35 /    NDLACT , PKA1   , PKA2
      COMMON / COM36 /    LRPI
      COMMON / COM37 /    LPDMIT
      COMMON / COM38 /    LMEPA  , MEWM
      COMMON / COM39 /    MESU   , QMS
      COMMON / COM40 /    NLAMS  , WGCMPL
      COMMON / COM41 /    EBC
      COMMON / COM42 /    LRMI   , LRSI
      COMMON / COM43 /    LRPIX  , WLAM
      COMMON / COM44 /    PRELF  , WGCMPE
      COMMON / COM45 /    NEWES  , VSATD
      COMMON / COM46 /    ERSI
      COMMON / COM47 /    ERPI
      COMMON / COM48 /    PSUPPS
      COMMON / COM49 /    DLBIO  , DNLBIO , VRES   , WSDS
      COMMON / COM50 /    GRODY  , WGTML
      COMMON / COM51 /    AREA
      COMMON / COM52 /    WAAG
      COMMON / COM53 /    EWELOC
      COMMON / COM54 /    DEB
      COMMON / COM55 /    AVLAR  , TVEGM
      COMMON / COM56 /    WLVS   , WNLVS
      COMMON / COM57 /    DVS
      COMMON / COM58 /    TIME   , YEAR
      SAVE /COM08/,/COM09/,/COM10/,/COM11/,/COM12/,/COM13/,/COM14/,
     *     /COM15/,/COM16/,/COM17/,/COM18/,/COM19/,/COM20/,/COM21/,
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     *     /COM36/,/COM37/,/COM38/,/COM39/,/COM40/,/COM41/,/COM42/,
     *     /COM43/,/COM44/,/COM45/,/COM46/,/COM47/,/COM48/,/COM49/,
     *     /COM50/,/COM51/,/COM52/,/COM53/,/COM54/,/COM55/,/COM56/,
     *     /COM57/,/COM58/
C     )))

C     FN

      NAMELIST/ARIDFT/
     *                     CSRRT, CSRRTW, DISTFT,DISTFTM,DISTFTW,   DVRT,
     *                    EDPTFT, FAMSTT,   FDMT,  FLTRT, GRAINT,  RADTB,
     *                     RDRAT,  RDRDT, REDFDT, REDTTB, RFDVST,   TECT,
     *                     WREDT

      NAMELIST/ARIDAP/ALPHAT
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      NAMELIST/ARIDSL/      DRF,    TCK

      NAMELIST/PARAM1/
     *      AAP,    ADWW,  ALFEW,  AMAXB,   APCS,   AREA,  BALEC,   BCP1,
     *     BCP2,    BCP3,   BCP4,   BCP5,   BSYS, CCULTW,   CFDM, CFERTW,
     *    CONFS,  CONFSM,  COSTH,  CSOWW,  CULBS,   DACS,   DCLV,  DCNLV,
     *     DDLP,   DDNLP,  DDSL1,  DDSL2,   DELT,   DGLP,  DGNLP,  DGRRT,
     *    DGSL1,   DGSL2,  DIGST,  DINTG,  DINTL,   DMP1,   DMP2,
     *     DND1,    DND2,  DSLPG,  DSLPL,  DVSSF, EBCLIM,   EEP1,   EEP2,
     *     EEP3,   EFFEB,   ELP1,   ELP2,   ELP3,   EPLA,   EUBL,   EWHD,
     *   EWMTMF,   FERTD,   FGF1,   FGF2,  FLDCP, FORCPH,   FRCS,   FWDB,
     *     FXPC,   GAMMA,    GAP,   GDCS,    GDF,    GDG,    GDI, GDTEND,
     *     GDVM,   GDVMF,   GDVS,    GEH,   GEST,     GF,  HORMC,  HYCTR,
     *    HYDVS,   HYHC1,  HYHC2, HYLEFT,   HYOP,  HYPF1,  HYPF2, HYTOPP,
     *    INSUR,    IRTD,  JOIND,     KP,    LAT,   LBIB,   LBWS,   LBWT,
     *     LEP1,    LEP2,   LEP3,   LEP4,  LFARR,    LFP,  LHVAP,    LMM,
     *   LMORTS,  LMORTT,  LOANR, LPDMIT,    LPH,    LPM,    LSH,    LSM,
     *    MCRMN,   MCRMX,   MDMC,   MEHY,   MEPL,   MEST,   MESU,   MEWM

      NAMELIST/PARAM2/
     *      MF2,     MF3,    MFC,   MIFT,   MISC, MNEBCT, MNGDEL,  MNIEW,
     *    MNSTR,   MRESF,   MRP1,   MRP2,   MRP3,   MRP4,  MXMF1,  MXRTD,
     *    NEWES,  PGDLIM,   PGRN,     PI,   PKA1,   PKA2,   PKF1,   PKF2,
     *     PKF3,    PKF4,   PKM1,   PKM2,   PKM3,  PLOWD,    PPL,  PRELF,
     *    PRELM,  PRIORT,  PRLAM,   PROP,   PSCH,  PSTRW, PSUPPS,   QMHY,
     *      QMM,    QMPL,    QMS,   QMST,     RC,  REFCF,   REFT,  RHOCP,
     *      RP1,     RP2,    RP3,    RP4,    RP5,     RS,      S,  SLVWT,
     *     SOWD,     SPD,  SPFRC, STARDY, STLEFT,  STROP,   SUPQ,  TCDPH,
     *    TCDRL,  TCDRNL,  TCRPH,   TIMN,   TIMX,    TOL,  TSUMG,   VETC,
     *    VRESD,   VRESG,  VSATD,  VSATG,     WE, WGCMPE, WGCMPL,  WGTML,
     *     WGWF,   WLTPT

      NAMELIST/OUTL/         NAME,  PRDEL,     DEB

      NAMELIST/INCON1/
     *                   CLLWG, CULINC,   CULL,  DBIOM,  DLBIO, DNLBIO,
     *                  DOLDAY,    DVS,    EBC,   ELWG, EWELOC,  GRODY,
     *                     HAY,  IBIOM,   LAGE, LAMLOC,   LLWG,   LRMI,
     *                    LRPI,  LRPIX,   LRSI, NDLACT, NDPREG,  NLAMS,
     *                   NLSEL,   NREP,  NSUKL,  NWNRS, RTWGHT,   SELL,
     *                     SLW,  STRAW,  TADRW,  TDRWT,  TDVS1,  TVEGM,
     *                           WAGRE,  WAGRL,   WEAN, WEANED,   WEWE,
     *                    WLAM,   WLVS,  WNLVS,   WSDS,   TOTB,    DVX

      NAMELIST/SEASONS/       NY,      Y

      NAMELIST/INCON2/
     *                    AMAX,    ARF,  AVLAR, BALANC,
     *                     COL, CTRDEF,         DOLDAY,   EFFE,  GDDEC,
     *                   GRAZE,  GRAZL,    LAI, LFAREA,    MF1,    PGY,
     *                   PRVTV,            RTD,  SLCVR,   STBL, TDRAIN,
     *                    TEMY,  TEVAP,                 TMPSUM, TOTINF,
     *                  TOTRAN, TPEVAP,   TPIE,   TPIL,  TPLIE,  TRAIN,
     *                           TSILF,         PRVDVS, WST2BL,   WTOT,
     *                    TOTA, DIDHRV

      DATA MATCH/3,5,5,3,5,1/
      DATA EWEMAT/1,2,2,1,2,999/
      DATA LAMMAT/999,999,1,1,2,2,3,999/

C     -------------------------------------------------------------
C     READ IN PARAMETERS AND FUNCTION TABLES FROM TAPE10

      REWIND 10
      READ(UNIT=10,FMT=ARIDFT)
      READ(UNIT=10,FMT=ARIDAP)
      READ(UNIT=10,FMT=ARIDSL)
      READ(UNIT=10,FMT=PARAM1)
```

```
      READ(UNIT=10,FMT=PARAM2)
      READ(UNIT=10,FMT=OUTL)
      READ(UNIT=10,FMT=INCON1)
      READ(UNIT=10,FMT=SEASONS)
C
C     ------------------------------------------------------------------
                        INITIALISATION  OF  VARIABLES - ONCE ONLY
      NCAFG=0
      WCLIM      = WLTPT * ADWW
      TDB(1)     = TCK(1)
      MWATER(1)  = FLDCP * TCK(1)

      DO 20 I1   = 2, 10
      TDB(I1)    = TDB(I1-1) + TCK(I1)
      MWATER(I1) = FLDCP * TCK(I1)
   20 CONTINUE

      DO 40 I1=1,6
      DO 30 J1=1,6
      IF(PRIORT(J1) .EQ. I1)RATING(I1)=J1
   30 CONTINUE
   40 CONTINUE

      AFG1 = AFGEN(DISTFT, 0., 5,'AFG1')
      DO 50 I1 = 1,3
      IRWT(I1)    = IBIOM(I1)
      WLVSI(I1)   = IBIOM(I1) * AFG1
      WNLVSI(I1)  = IBIOM(I1) - WLVSI(I1)
      LFI(I1)     = WLVSI(I1) * LFARR
      LMBIOM(I1)  = IBIOM(I1) * LBIB
   50 CONTINUE

      LAMBD =MOD(JOIND+GEST,365)
      NBREW = NEWES/(1.+CULBS)
      NHOGS = NEWES-NBREW
      NCULL = NBREW*CULBS

             NEWL  = NBREW*LPM+NHOGS*LPH*(BSYS-1)
             NLB   = NBREW*LPM*LSM+NHOGS*LPH*LSH*(BSYS-1)
             NPEWS = 2.*NEWL-NLB
             NPEWT = NEWL-NPEWS
             SNGLB = NPEWS
             TWNLB = NPEWT*2.
             SNGLR = SNGLB*(1.-LMORTS)
             TWNLR = TWNLB*(1.-LMORTT)
             NLR   = SNGLR+TWNLR
             NEWM  = SNGLR+TWNLR/2.
             NMEWS = SNGLR
             NMEWT = NEWM-NMEWS
             LBW   = (SNGLR*LBWS+TWNLR*LBWT)/(NLR+NOT(NLR))
             EMYMF = (NMEWS+(NMEWT*MIFT))/(NEWM+NOT(NEWM))
             EMY   = 0.

      IF(LAMBD .GT. JOIND)THEN
         IF(STARDY .LE. LAMBD)NDPREG = MAX0(0,STARDY-JOIND)
      ELSE
         IF(STARDY .GT. JOIND)NDPREG = STARDY-JOIND
         IF(STARDY .LT. LAMBD)NDPREG = 365+STARDY-JOIND
      ENDIF

      WAAG=AREA(2)

C     ------------------------------------------------------------------
C                         YEAR  LOOP
C                         INITIALISATION OF INTEGRALS - EACH YEAR

      DO 1000 YR=1,NY

```

```
      YEAR = Y(YR)
      REWIND YEAR

      CALL DIARY11(YEAR,0.,0,0)

      REWIND 10
      READ(UNIT=10,FMT=INCON2)

      DO 70 JJ = 1,3
      DO 60 I1 = 1,10
   60 W(JJ,I1) = DRF(JJ,I1) * WLTPT * TCK(I1)
   70 CONTINUE

      TS10 = 5. * (TIMN + TIMX)
      TS   = TS10 * 0.1
      TSO  = TS10

      DO 90 JJ = 1, 3
      DO 80 I1 = 1, 10
   80 WTOT(JJ) = WTOT(JJ) + W(JJ,I1)
   90 CONTINUE

      DO 110 I1=1,NRO
      DO 100 J1 =1,10
  100 MAT(I1,J1)=0.
  110 CONTINUE

C     -------------------------------------------------------------------
C                         TIME  LOOP

      DO 500 TIME = 0,364
         SEADY = TIME + 1
         DAY = MOD(STARDY + TIME, 365)

      WEAN=CULL=SELL=JOIN=LAMB=SOW=PLOW=HARV=FERT=WACH=HVCH=STBL=0
      IF(DAY .EQ. JOIND   .AND. NEWES   .GT. 0.)              JOIN   =1
      IF(DAY .EQ. LAMBD   .AND. NEWES   .GT. 0.)              LAMB   =1
      IF(DAY .EQ. SOWD    .AND. AREA(2) .GT. 0.)              SOW    =1
      IF(DAY .EQ. PLOWD   .AND. AREA(2) .GT. 0.)              PLOW   =1
      IF(PLOW .EQ. 1)                                 WAAG = AREA(2)
      IF(DVX(2) .GT. 0.   .AND.
     *  TIME .GT. EWHD    .AND. WAAG    .GT. 0.)              HARV   =1
      IF(HARV .EQ. 1)                                   WST2BL =DAY+1
      IF(DAY .EQ. FERTD   .AND. AREA(2) .GT. 0.)              FERT   =1
      EWSTG=INSW(DAY-JOIND*1.,365.-(JOIND-DAY),1.*DAY-JOIND)
      MINEBC=TWOVAR(MNEBCT,EWSTG,LSM,9,4,'MNEBCT')
C     WEAN, SELL AND CULL DETERMINED IN SUBR LAMOVE

C     ARID CROP MET INPUT SWITCH
      MSW=1

      DO 200 K=1,3

      IF(AREA(K) .GT. 0.)CALL SRATES

  200 CONTINUE

C     SET CONSUMPTION RATES TO ZERO
      ECRDL  = ECRDNL  = CRLVE   = CRNLVE   = CRLFRE   =
     *LCRDL  = LCRDNL  = CRLVL   = CRNLVL   = CRLFRL   =
     *CRDL(1)= CRDNL(1)= CRLVS(1)= CRNLVS(1)= CRLFAR(1)=
     *CRDL(2)= CRDNL(2)= CRLVS(2)= CRNLVS(2)= CRLFAR(2)=
     *CRDL(3)= CRDNL(3)= CRLVS(3)= CRNLVS(3)= CRLFAR(3)=0.

      DO 10 K = 1,3
   10 VRES(K) = INSW(DVS(K)-1., VRESG, VRESD)

      IF(NEWES .GT. 0.)THEN
         CALL INTAK('EWES')
```

```
         GRAZE = 1
         IF(EWELOC .EQ. 6)GRAZE = 0
         CALL EWPERF(GRAZE)
      ENDIF

      IF(LAMLOC .NE. 0)THEN
         CALL INTAK('LAMB'//CHAR(LAMLOC+16))
         GRAZL = 0
         IF(2 .LT. LAMLOC .AND. LAMLOC .LT. 8)GRAZL = 1
         CALL LMPERF(GRAZL)
      ENDIF

      ELS = EWEMAT(EWELOC)
      IF(ELS .NE. 999)THEN
         CRDL  (ELS) = CRDL  (ELS) + ECRDL
         CRDNL (ELS) = CRDNL (ELS) + ECRDNL
         CRLVS (ELS) = CRLVS (ELS) + CRLVE
         CRNLVS(ELS) = CRNLVS(ELS) + CRNLVE
         CRLFAR(ELS) = CRLFAR(ELS) + CRLFRE
      ENDIF

      IF(LAMLOC .NE. 0)THEN
         LLS = LAMMAT(LAMLOC)
         IF(LLS .NE. 999)THEN
            CRDL  (LLS) = CRDL  (LLS) + LCRDL
            CRDNL (LLS) = CRDNL (LLS) + LCRDNL
            CRLVS (LLS) = CRLVS (LLS) + CRLVL
            CRNLVS(LLS) = CRNLVS(LLS) + CRNLVL
            CRLFAR(LLS) = CRLFAR(LLS) + CRLFRL
         ENDIF
      ENDIF

                                 IF(TIME-(TIME/PRDEL)*PRDEL .EQ. 0
                                               .OR. TIME .EQ. 364)THEN

                                 COL=COL+1

                                 MAT(01,COL) = TIME
                                 MAT(02,COL) = DAY
                                 MAT(03,COL) = DVS(1)
                                 MAT(04,COL) = TVEGM(1)
                                 MAT(05,COL) = DBIOM(1)
                                 MAT(06,COL) = WSDS(1)
                                 MAT(07,COL) = TADRW(1)
                                 MAT(08,COL) = DVS(2)
                                 MAT(09,COL) = TVEGM(2)
                                 MAT(10,COL) = DBIOM(2)
                                 MAT(11,COL) = WSDS(2)
                                 MAT(12,COL) = TADRW(2)
                                 MAT(13,COL) = TADRW(3)
                                 MAT(14,COL) = EWELOC
                                 MAT(15,COL) = WEWE
                                 MAT(16,COL) = ELWG
                                 MAT(17,COL) = EBC
                                 MAT(18,COL) = MINEBC
                                 MAT(19,COL) = ERPI
                                 MAT(20,COL) = ERSI
                                 MAT(21,COL) = ERSTI
                                 MAT(22,COL) = ERHI
                                 MAT(23,COL) = ERPLI
                                 MAT(24,COL) = LAMLOC
                                 MAT(25,COL) = LAGE
                                 MAT(26,COL) = WLAM
                                 MAT(27,COL) = LLWG
                                 MAT(28,COL) = LRMI
                                 MAT(29,COL) = LRPI
                                 MAT(30,COL) = LRSI
                                 MAT(31,COL) = WAAG
                                 MAT(32,COL) = HAY
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```
                                  MAT(33,COL) = STRAW
                                  MAT(34,COL) = BALANC

                                  ENDIF

                         IF(COL .EQ. 10 .OR. (TIME .EQ. 364 .AND. COL
     *                              .NE. 0))THEN

                         WRITE(95,300)NAME(1),(MAT(1,J1),J1=1,10),
     *                               NAME(1)
C     ST
  300                    FORMAT('1',A,10(F8.0,4X),1X,A,/)
C     FN
                         DO 320 I1=2,NRO
                         WRITE(95,310)NAME(I1),(MAT(I1,J1),J1=1,10),
     *                               NAME(I1)
C     ST
  310                    FORMAT(' ',A,10(1PG12.4),1X,A)
C     FN
  320                    CONTINUE
                         DO 340 I1=1,NRO
                         DO 330 J1=1,10
  330                    MAT(I1,J1)=0.
  340                    CONTINUE
                         COL=0

                         ENDIF

C     -----------------------------------------------------------------
      IF(NEWES .GT. 0.)THEN
         TPIE   = TPIE  + ERPI   * NEWES
         TEMY   = TEMY  + EMY
         TPIL   = TPIL  + LRPI   * NLAMS
         TSILF  = TSILF + LRSI   * NLAMS * INSW(LAMLOC-8.,0.,1.)
         TPLIE  = TPLIE + ERPLI  * NEWES
         HAY    = HAY   - ERHI   * NEWES
         STRAW  = STRAW - ERSTI  * NEWES

         TOTA(1,12) = TOTA(1,12) + MER
         TOTA(1,EWELOC) = TOTA(1,EWELOC) + 1.
         TOTA(2,EWELOC) = TOTA(2,EWELOC) + ERPI*NEWES
         TOTA(3,EWELOC) = TOTA(3,EWELOC) + ERPI*NEWES*EMEPA
         IF(ERSTI .GT. 0.)THEN
            TOTA(1,9) = TOTA(1,9) + 1.
            TOTA(2,9) = TOTA(2,9) + ERSTI*NEWES
            TOTA(3,9) = TOTA(3,9) + ERSTI*NEWES*MEST
         ENDIF
         IF(ERHI .GT. 0.)THEN
            TOTA(1,10) = TOTA(1,10) + 1.
            TOTA(2,10) = TOTA(2,10) + ERHI*NEWES
            TOTA(3,10) = TOTA(3,10) + ERHI*NEWES*MEHY
         ENDIF
         IF(ERSI .GT. 0.)THEN
            TOTA(1,11) = TOTA(1,11) + 1.
            TOTA(2,11) = TOTA(2,11) + ERSI*NEWES
            TOTA(3,11) = TOTA(3,11) + ERSI*NEWES*MESU
         ENDIF
      ENDIF

      IF(LAMLOC .NE. 0)THEN
         IF(LAMLOC .EQ. 1 .OR. LAMLOC .EQ. 2)THEN
            LI=6
         ELSEIF(LAMLOC .EQ. 3 .OR. LAMLOC .EQ. 4)THEN
            IF(DVS(1) .LT. 1.)THEN
               LI=1
            ELSE
               LI=4
            ENDIF
         ELSEIF(LAMLOC .EQ. 5 .OR. LAMLOC .EQ. 6)THEN
```

```
            IF(DVS(2) .LT. 1.)THEN
               IF(GRODY(2) .LE. WGTML)THEN
                  LI=2
               ELSE
                  LI=5
               ENDIF
            ELSE
               LI=3
            ENDIF
         ELSEIF(LAMLOC .EQ. 7)THEN
            LI=7
         ELSEIF(LAMLOC .EQ. 8)THEN
            LI=8
         ELSE
            PRINT *, ' LAMB ACCOUNTING ERROR '
         ENDIF

         TOTA(4,LI) = TOTA(4,LI) + 1.
         TOTA(5,LI) = TOTA(5,LI) + LRPI*NLAMS
         TOTA(6,LI) = TOTA(6,LI) + LRPI*NLAMS*LMEPA
         IF(LRSI .GT. 0.)TOTA(4,11) = TOTA(4,11) + 1.
         TOTA(5,11) = TOTA(5,11) + LRSI*NLAMS
         TOTA(6,11) = TOTA(6,11) + LRSI*NLAMS*MESU
         IF(LRMI .GT. 0.)TOTA(4,12) = TOTA(4,12) + 1.
         TOTA(5,12) = TOTA(5,12) + LRMI
      ENDIF
      TOTA(5,8)=TOTA(5,8) + NLSEL*SLW*PRLAM + CULINC
C     ----------------------------------------------------------------
C                      MANAGEMENT    SECTION

      IF(TIME-(TIME/MNGDEL)*MNGDEL .EQ. 0)THEN

C        ==================================================== EWMOVE
         IF(NEWES .GT. 0.)CALL EWMOVE

C        ==================================================== LAMOVE
         PTIME = WLAM * PRLAM * LOANR / 365.
         IF(LAMLOC .NE. 0)CALL LAMOVE

C        ==================================================== HAYCUT
         IF(WAAG .GT. 0. .AND. GRODY(2) .GT. WGTML
     *                   .AND. DVS(2)   .LT. 1.)   THEN
            CALL HAYCUT
            WACH      = AMAX1(0., WACH-WAGRE-WAGRL)
            IF(WACH .GT. 0.)THEN
               HAY    = HAY + HAYLD * WACH
               TOTA(3,12) = TOTA(3,12)+HAYLD*WACH
               CALL DIARY13(INT(WACH*100.+0.5),HAYLD*WACH,TIME,DAY)
            ENDIF
         ENDIF

C        =================================================== STRABAL
         IF(DAY .GE. WST2BL .AND. DIDHRV .EQ. 1 .AND. WAAG .GT. 0.)THEN
            WST2BL = 999
            CALL STRABAL
            IF(STBL .GT. 0.)THEN
               STRAW=STRAW+STBL
               TOTA(2,12) = TOTA(2,12)+STBL
               CALL DIARY10(0,STBL,TIME,DAY)
            ENDIF
         ENDIF

         WAAG=WAAG-WAGRE-WAGRL-WACH
      ENDIF

C        =================================================== HARVEST
      IF(HARV .EQ. 1)THEN
         CALL GRYPRO(PGY,SDY,AFY,SEADY,ARF)
         HARV = INSW(PGY*PGRN-COSTH,0.,1.)
```

```
         TOTA(2,6)=PGY
         TOTA(5,6)=PGY*WAAG*HARV
         DIDHRV = HARV
         CALL DIARY9(HARV,PGY,TIME,DAY)
      ENDIF

C     ------------------------------------------------------------------
C                          FINANCIAL  ACCOUNTING

      COSTS =      FERT  * AREA(1) * FXPC
     *           + FERT  * AREA(2) * CFERTW
     *           + PLOW  * AREA(2) * CCULTW
     *           + SOW   * AREA(2) * CSOWW
     *           + HARV  * WAAG    * COSTH
     *           + WACH  * HVCH
     *           + BALEC * STBL
     *           + JOIN  * NEWES   * (VETC  + INSUR)
     *           + JOIN  * NHOGS   * HORMC  * (BSYS-1)
     *           + ERSI  * NEWES   * PSUPPS * PRELF
     *           + ERPLI * NEWES   * PPL
     *           + LRSI  * NLAMS   * PSUPPS
     *           + LOANR * DOLDAY/365. * FCNSW(TIME-360.,0.,1.,0.)
     *           + MISC  * (      (VETC+INSUR) * NEWES
     *                      +  TOTA(2,11)  * PSUPPS * PRELF    )
     *                              * FCNSW(TIME-360.,0.,1.,0.)

      INCOM =      NLSEL * SLW     * PRLAM
     *           + CULINC
     *           + HARV  * WAAG    * PGRN   * PGY

      DOLDAY = DOLDAY + INSW(BALANC, -BALANC, 0.)

      BALANC = BALANC + INCOM - COSTS

C     ------------------------------------------------------------------
C                         PLANT INTEGRATION
      DO 450 K=1,3
      IF(AREA(K) .EQ. 0.)GOTO 450

      PRVTV(K)     = WLVS(K)+WNLVS(K)
      PRVDVS(K)    = DVS(K)
      TPEVAP(K)    = TPEVAP(K) + EVAP
      TMPSUM(K)    = TMPSUM(K) + TS - ENGR(K) - TMPSUM(K)*PUSHD(K)
      TOTRAN(K)    = TOTRAN(K) + TRAN(K)
      W(K,1)       = W(K,1)    + INFR - RWFB(K,1) - TRR(K,1) - ER(K,1)
      DO 400 N1    = 2, 10
  400 W(K,N1)      = W(K,N1)+RWFB(K,N1-1)-RWFB(K,N1)-TRR(K,N1)-ER(K,N1)
      WTOT(K)      = 0.
      DO 410 I1    = 1,10
  410 WTOT(K)      = WTOT(K)   + W(K,I1)
      TEVAP(K)     = TEVAP(K)  + EB(K,10)
      TDRAIN(K)    = TDRAIN(K) + DRR(K,10)

      IF(PUSHG(K) + PLOW * FCNSW(K-2.,0.,1.,0.) .GT. 0.)THEN
              RT = -DLBIO(K)
      ELSEIF(PUSHD(K) + DVX(K) .GT. 0.)THEN
              RT = WLVS(K)
      ELSE
              RT = RDLVS(K) - DLBIO(K)*DCLV - CRDL(K)
     *                      - STBL/(WAAG+NOT(WAAG))
     *                      * DLBIO(K)/(DBIOM(K)+NOT(DBIOM(K)))
     *                      * FCNSW(K-2.,0.,1.,0.)
      ENDIF
      DLBIO(K)     = DLBIO(K) + RT
      IF(PUSHG(K) + PLOW * FCNSW(K-2.,0.,1.,0.) .GT. 0.)THEN
              RT = -DNLBIO(K)
      ELSEIF(PUSHD(K) + DVX(K) .GT. 0.)THEN
              RT = WNLVS(K)
```

```
      ELSE
               RT = RDNLVS(K) - DNLBIO(K)*DCNLV - CRDNL(K)
     *                        - STBL/(WAAG+NOT(WAAG))
     *                        * DNLBIO(K)/(DBIOM(K)+NOT(DBIOM(K)))
     *                        * FCNSW(K-2.,0.,1.,0.)
      ENDIF
      DNLBIO(K)    = DNLBIO(K) + RT
      DBIOM(K)     = DLBIO(K)  + DNLBIO(K)
      IF(PUSHG(K) .GT. 0.)THEN
               RT = WLVSI(K)
      ELSEIF(PUSHD(K) + DVX(K) .GT. 0.)THEN
               RT = -WLVS(K)
      ELSE
               RT = GRLVS(K) - RDLVS(K) - CRLVS(K)
      ENDIF
      WLVS(K)      = WLVS(K) + RT
      IF(PUSHG(K) .GT. 0.)THEN
         RT        = WNLVSI(K)
      ELSEIF(PUSHD(K) + DVX(K) .GT. 0.)THEN
         RT        = -WNLVS(K)
      ELSE
               RT = GRNLV(K) - RDNLVS(K) - CRNLVS(K)
      ENDIF
      WNLVS(K)     = WNLVS(K) + RT
      TVEGM(K)     = WLVS(K)   + WNLVS(K)
      WSDS(K)      = WSDS(K)   + GRSDS(K)
     *                         - WSDS(K)    * PUSHD(K)
     *                         - WSDS(K)    * DVX(K)
      RTWGHT(K)    = RTWGHT(K) + GRRWT(K)
     *                         + IRWT(K)    * PUSHG(K)
     *                         - RTWGHT(K) * PUSHD(K)
     *                         - RTWGHT(K) * DVX(K)
      TADRW(K)     = WLVS(K)   + WNLVS(K) + WSDS(K) + DBIOM(K)
      TDRWT(K)     = TADRW(K)  + RTWGHT(K)
      IF(PUSHG(K) .GT. 0.)THEN
               RT = LFI(K)
      ELSEIF(PUSHD(K).GT. 0.)THEN
               RT = -LFAREA(K)
      ELSE
               RT = LAGRTR(K) - RDLFA(K) - CRLFAR(K)
      ENDIF
      LFAREA(K)    = LFAREA(K) + RT
      LAI(K)       = LFAREA(K) * 1.E-4
      AVLAR(K)     = LFAREA(K)/(WLVS(K)+NOT(WLVS(K)))
      RTD(K)       = RTD(K)    + GRRT(K)
     *                         + IRTD       * PUSHG(K)
     *                         - RTD(K)     * PUSHD(K)
      EFFE(K)      = EFFE(K)   + EFFEB      * PUSHG(K)
     *                         - EFFE(K)    * PUSHD(K)
     *                         - RDEFFE(K)
     *                         + RREFFE(K)
      CTRDEF(K)    = CTRDEF(K) + RITDF(K)
     *                         - RDTDF(K)
     *                         - CTRDEF(K) * PUSHD(K)
      AMAX(K)      = AMAX(K)   + AMAXB      * PUSHG(K)
     *                         - AMAX(K)    * PUSHD(K)
     *                         - RDAMAX(K)
     *                         + RRAMAX(K)
      SLCVR(K)     = SLCVR(K)  + (LAGRTR(K)
     *                         + LFI(K)     * PUSHG(K)
     *                         - SLCVR(K)   * PUSHD(K)   ) * 1.E-4
      IF(DVX(K) .GT. 0.)TDVS1(K) = GRODY(K)
      DVS(K)       = DVS(K)    + DVR(K)
     *                         + PUSHD(K)   * (1.1-DVS(K))
     *                         - DVS(K)     * PUSHG(K)
      GRODY(K)     = GRODY(K)  + 1
     *                         - (GRODY(K) + 1) * PUSHG(K)

  450 CONTINUE
```

```
         IF(RAIN .GT. 0.)THEN
         IRN15    = (SEADY-1)/15+1
         ARF(IRN15)= ARF(IRN15)+RAIN
         ENDIF
         TRAIN    = TRAIN+RAIN
         TOTINF   = TOTINF+INFR
C        TS       = 10 D RUNNING AVE OF AIR TEMP.
         TS       = 0.1*(TS10+RCST)
         TS10     = TS10+RCST

C     -------------------------------------------------------------------

C                         ANIMAL INTEGRATION

      IF(CULL .EQ. 1)CALL DIARY6(EWELOC,AMIN1(NBREW,NCULL),TIME,DAY)
      CULINC=CULL*AMIN1(NBREW,NCULL)*WEWE*PRELM*PRLAM
      WEWE=WEWE+ELWG -SELL*(BSYS-1)*NHOGS*(WEWE-WLAM)/(NBREW+NHOGS)
      NREP    =AMIN1(NCULL,NLAMS)
      NBREW   =NBREW+(NHOGS*SELL)-AMIN1(NBREW,NCULL)*CULL
      NHOGS   =NHOGS+(NREP*SELL)-(NHOGS*SELL)
      NEWES   =NBREW+NHOGS
      NLSEL   =SELL*(NLAMS-NREP)
      SLW     =SELL*WLAM
      IF(SELL .EQ. 1)THEN
         CALL DIARY8(LAMLOC,NLSEL,TIME,DAY)
         LAMLOC=0
         LRSI=LRPI=LRPIX=LRMI=LLWG=CLLWG=0.
      ENDIF
      NWNRS   =NWNRS+(NSUKL*WEAN)-(NWNRS*SELL)-(NSUKL*WEAN*SELL)
      NSUKL   =NSUKL+LAMB*NLR-NSUKL*WEAN
      NLAMS   =NSUKL+NWNRS
      WEANED  =WEANED+WEAN-(SELL*WEANED)-WEAN*SELL
      IF(LAMB .EQ. 1)THEN
         LAMLOC=MATCH(EWELOC)
         CALL DIARY4(LAMLOC,NLAMS,TIME,DAY)
         GRAZL=0
         IF(2 .LT. LAMLOC .AND. LAMLOC .LT. 8)GRAZL=1
      ENDIF

      NDPREG = 0
      IF(LAMBD .GT. JOIND)THEN
         IF(DAY .LE. LAMBD)NDPREG=MAX0(0,DAY-JOIND)
      ELSE
         IF(DAY .GT. JOIND)NDPREG = DAY-JOIND
         IF(DAY .LT. LAMBD)NDPREG = 365+DAY-JOIND
      ENDIF
      NDLACT  =INSW(-NSUKL, NDLACT+1., 0.)
      LAGE    =INSW(-NLAMS, LAGE+1., 0.)
      MF1     =AMIN1(MXMF1,MF1+DMF1)
      WLAM    =WLAM+(LAMB*LBW)+LLWG*(1-SELL)-(SELL*WLAM)
      EBC     =LIMIT(BCP1,BCP2,BCP3+(WEWE-BCP4)/BCP5)


  500 CONTINUE

      CALL DIARY14(INT(TPIE/NEWES+0.5), TOTA(2,11)/NEWES,
     *              INT(TPIL/NLR+0.5),   INT(TOTA(5,11)/NLR+0.5))
      CALL DIARY12(INT(TRAIN+0.5),BALANC,0,0)

      TOTA(6,12) = BALANC
      WRITE(99,600)YEAR,((TOTA(I1,J1),I1=1,2),J1= 1, 6),
     *                  ((TOTA(I2,J2),I2=1,2),J2= 9,11),
     *                   (TOTA(I3,12),I3=1,3)
C     ST
  600 FORMAT(1X,I2,' E',9(F5.0,F6.0),3F9.1)
C     FN

      WRITE(99,610)YEAR,((TOTA(I1,J1),I1=4,5),J1= 1, 8),
```

```
     *                ((TOTA(I2,J2),I2=4,5),J2=11,12),
     *                  TOTA( 6,12)
C     ST
  610 FORMAT(1X,I2,' L',9(F5.0,F6.0),3F9.1)
C     FN

      DO 620 I1=1,6
      DO 620 J1 =1,12
  620 TOTB(I1,J1) = TOTB(I1,J1)+TOTA(I1,J1)

 1000 CONTINUE

      WRITE(99,640)((TOTB(I1,J1),I1=1,2),J1= 1, 6),
     *             ((TOTB(I2,J2),I2=1,2),J2= 9,11),
     *              (TOTB(I3,12),I3=1,3)
C     ST
  640 FORMAT(1X,'-- E',9(F5.0,F6.0),3F9.1)
C     FN

      WRITE(99,650)((TOTB(I1,J1),I1=4,5),J1= 1, 8),
     *             ((TOTB(I2,J2),I2=4,5),J2=11,12),
     *               TOTB( 6,12)
C     ST
  650 FORMAT(1X,'-- L',9(F5.0,F6.0),3F9.1)
C     FN

      DO 630 I1=1,6
      DO 630 J1=1,12
  630 TOTB(I1,J1) = TOTB(I1,J1)/NY

      WRITE(99,640)((TOTB(I1,J1),I1=1,2),J1= 1, 6),
     *             ((TOTB(I2,J2),I2=1,2),J2= 9,11),
     *              (TOTB(I3,12),I3=1,3)

      WRITE(99,650)((TOTB(I1,J1),I1=4,5),J1= 1, 8),
     *             ((TOTB(I2,J2),I2=4,5),J2=11,12),
     *               TOTB( 6,12)
      PRINT *,'NUMBER OF AFGEN CALLS=',NCAFG
      STOP
      END
      SUBROUTINE INTAK(ANIMAL)
C     ***********************************************************************
C     *                                                                     *
C     * ALTERS THE FOLLOWING VARIABLES IN COMMON:     ED        LD          *
C     *                                               EQMP      LQMP        *
C     *                                               EMEPA     LMEPA       *
C     *                                               ERPIX     LRPIX       *
C     *                                               ERPI      LRPI        *
C     *                                               CRLVE     CRLVL       *
C     *                                               CRNLVE    CRNLVL      *
C     *                                               ECRDL     LCRDL       *
C     *                                               ECRDNL    LCRDNL      *
C     *                                               CRLFRE    CRLFRL      *
C     *                                               MER       LRMI        *
C     *                                               ERSI      PMILK       *
C     *                                               ERHI      LPSUBF      *
C     *                                               ERSTI                 *
C     *                                               ERPLI                 *
C     *                                                                     *
C     ***********************************************************************
C     ST
      IMPLICIT REAL(A-Z)

      CHARACTER*(*) ANIMAL

      LOGICAL DAMWGL8

      INTEGER         TIME,  GRODY,     DEB,     YEAR,   EWELOC,  NOLACT,
```

```
*               SELL8,   LCL8,      IL8,  LAMMAT,   EWEMAT

 DIMENSION
*                                  WNLVS(3),     AREA(3),  TDVS1(3),
*                                  AVLAR(3),                  DEB(13),
*                                  DLBIO(3),   DNLBIO(3),      DVS(3),
*                                  GRODY(3),              LPDMIT(2,6),
*                                  TVEGM(3),     VRES(3),     WLVS(3),
*                                  WGCMPE(5),    WGCMPL(5),  WSDS(3),
*                                  SELL8(5), EWEMAT(6), LAMMAT(8)

 (((
 ============   INTA
 COMMON / COM02 /       EQMP
 COMMON / COM03 /       ERPIX
 COMMON / COM04 /       PMILK
 COMMON / COM05 /       LQMP
 COMMON / COM06 /       LPSUBF
 COMMON / COM07 /       EWCS
 COMMON / COM32 /
*              CFDM   , CRLFRE , CRLFRL , CRLVE  , CRLVL  , CRNLVE ,
*              CRNLVL , DDLP   , DDNLP  , DDSL1  , DDSL2  , DGLP   ,
*              DGNLP  , DGSL1  , DGSL2  , DINTG  , DINTL  , DND1   ,
*              DND2   , DSLPG  , DSLPL  , ECRDL  , ECRDNL , EPLA   ,
*              EWEMAT , GEH    , HAY    , LAMMAT , LCRDL  , LCRDNL ,
*              MINEBC , MNSTR  , NEWM   , NLR    , SPFRC  , STRAW  ,
*              SUPQ   , TDVS1  , VSATG
 COMMON / COM33 /       MER
 COMMON / COM34 /
*              EMEPA  , EMY    , ERHI   , ERPLI  , ERSTI  , MEHY   ,
*              MEPL   , MEST   , QMPL
 COMMON / COM35 /       NDLACT , PKA1   , PKA2
 COMMON / COM36 /       LRPI
 COMMON / COM37 /       LPDMIT
 COMMON / COM38 /       LMEPA  , MEWM
 COMMON / COM39 /       MESU   , QMS
 COMMON / COM40 /       NLAMS  , WGCMPL
 COMMON / COM41 /       EBC
 COMMON / COM42 /       LRMI   , LRSI
 COMMON / COM43 /       LRPIX  , WLAM
 COMMON / COM44 /       PRELF  , WGCMPE
 COMMON / COM45 /       NEWES  , VSATD
 COMMON / COM46 /       ERSI
 COMMON / COM47 /       ERPI
 COMMON / COM48 /       PSUPPS
 COMMON / COM49 /       DLBIO  , DNLBIO , VRES   , WSDS
 COMMON / COM50 /       GRODY  , WGTML
 COMMON / COM51 /       AREA
 COMMON / COM52 /       WAAG
 COMMON / COM53 /       EWELOC
 COMMON / COM54 /       DEB
 COMMON / COM55 /       AVLAR  , TVEGM
 COMMON / COM56 /       WLVS   , WNLVS
 COMMON / COM57 /       DVS
 COMMON / COM58 /       TIME   , YEAR
 SAVE /COM02/,/COM03/,/COM04/,/COM05/,/COM06/,/COM07/,/COM32/,
*     /COM33/,/COM34/,/COM35/,/COM36/,/COM37/,/COM38/,/COM39/,
*     /COM40/,/COM41/,/COM42/,/COM43/,/COM44/,/COM45/,/COM46/,
*     /COM47/,/COM48/,/COM49/,/COM50/,/COM51/,/COM52/,/COM53/,
*     /COM54/,/COM55/,/COM56/,/COM57/,/COM58/
 )))
 FN
 ----------------------------------- E W E S
                                       IF(ANIMAL .EQ. 'EWES')THEN
 -----------------------------------
 DAMWGL8=.FALSE.
 VSATL8 =TSBL8  =DGLL8  =DGNLL8 =DDLL8  =DDNLL8 =ED     =RDFDL8 =
*RDFAL8 =EQMP   =EMEPA  =EWCS   =ERPIX  =MEINTL8=ERSI   =MER    =
*ERHI   =ERSTI  =ERFDSL8=MEFRCL8=EPSBFL8=ERPI   =SRL8   =CRLVE  =
```

```
*CRNLVE =ECRDL  =ECRDNL =CRLFRE =FSATL8 =ERPLI  =0.

 LCL8          = EWEMAT(EWELOC)
 IF(EWELOC     .NE. 6)THEN
    IF(TVEGM(LCL8)+DLBIO(LCL8)+DNLBIO(LCL8) .EQ. 0.)LCL8=999
    IF(EWELOC .EQ. 5 .AND. DVS(2) .GE. 1.
*                                .AND. WAAG .EQ. 0.)LCL8=999
 ENDIF
 EBDEFL8       = AMAX1(0.,MINEBC-EBC)
 IF(LCL8       .NE. 999)THEN
    DO 1 IL8   = 1,5
1   SELL8(IL8) = 1
    SELL8(3)   = 0
    VSATL8     = INSW(DVS(LCL8),VSATG,VSATD)
    IF(LCL8    .EQ. 2 .AND. DVS(2) .LT. 1.
*              .AND. GRODY(2) .GT. WGTML)DAMWGL8 = .TRUE.
    IF(.NOT.   DAMWGL8)THEN
               IF(TVEGM(LCL8) .GT. VSATG)THEN
                      SELL8(4)=SELL8(5)=0
               ELSEIF(DLBIO(LCL8) .GT. VSATD)THEN
                      SELL8(5)=0
               ELSE
               ENDIF
    ELSE
               DO 2 IL8=1,5
2              SELL8(IL8)=WGCMPE(IL8)
    ENDIF
    TSBL8      =   WLVS(LCL8)   * SELL8(1)
*              +  WNLVS(LCL8)   * SELL8(2)
*              +   WSDS(LCL8)   * SELL8(3)
*              +  DLBIO(LCL8)   * SELL8(4)
*              + DNLBIO(LCL8)   * SELL8(5)
    DGLL8      = DGLP  - DGSL1  * DVS(LCL8)
    DGNLL8     = DGNLP - DGSL2  * DVS(LCL8)
    DDLL8      = LIMIT(DDLP-DDSL1, DDLP,
*                DDLP-(GRODY(LCL8)-TDVS1(LCL8))*DDSL1/DND1)
    DDNLL8     = LIMIT(DDNLP-DDSL2, DDNLP,
*                DDNLP-(GRODY(LCL8)-TDVS1(LCL8))*DDSL2/DND2)
    ED         = (  DGLL8 *   WLVS(LCL8)   * SELL8(1)
*              +   DGNLL8 *  WNLVS(LCL8)   * SELL8(2)
*              +    DGLL8 *   WSDS(LCL8)   * SELL8(3)
*              +    DDLL8 *  DLBIO(LCL8)   * SELL8(4)
*              +   DDNLL8 * DNLBIO(LCL8)   * SELL8(5) )
*              /    TSBL8
    RDFDL8     = LIMIT(0., 1., DSLPG*ED+DINTG)
    RDFAL8     = LIMIT(0.,1., (TSBL8-VRES(LCL8))/(VSATL8-VRES(LCL8))
    IF           (DAMWGL8)RDFAL8=1.
    EQMP       = ED * CFDM
    EMEPA      = EQMP * GEH
 ENDIF
 IF(LCL8 .NE. 999)THEN
                 CALL EWREQM(1,EQMP)
                 EWCS    = MER/EMEPA
                 ERPIX   = EWCS * AMIN1(RDFDL8,RDFAL8)
                 MEINTL8 = ERPIX * EMEPA
 ELSE
                 CALL EWREQM(0,(2.*QMS+QMPL)/3.)
 ENDIF
 IF((EWELOC .EQ. 1 .OR. EWELOC .EQ. 2 .OR. EWELOC .EQ. 5)
*                                     .AND. LCL8 .NE. 999)THEN
                    ERSI   = EBDEFL8*SUPQ/MESU
 ELSE
     ERPLI = EPLA
     IF(EBDEFL8 .GT. 0. .OR. LCL8 .EQ. 999)THEN
                    MER    = MER+EBDEFL8*SUPQ
        IF(HAY .GT. NEWES*MNSTR)THEN
                    ERHI   = AMAX1(1.5-ERPIX,0.)
        ELSEIF(STRAW .GT. NEWES*MNSTR)THEN
                    ERSTI  = AMAX1(1.5-ERPIX,0.)
```

```
            ELSE
            ENDIF
            MEINTL8            = MEINTL8+ERHI*MEHY+ERSTI*MEST+ERPLI*MEPL
            IF    (MEINTL8 .LT. MER)ERSI=(MER-MEINTL8)/MESU
            MEINTL8            = MEINTL8+ERSI*MESU
         ENDIF
      ENDIF
      IF(LCL8 .NE. 999)THEN
         MEFRCL8   = MEINTL8/MER
         IF          (NDLACT .GT. 0 .AND. MEFRCL8 .LT. SPFRC)
     *   ERSI      = AMAX1(ERSI,(MER-MEINTL8)/MESU)
         IF(EWCS .GT. 0.)FSATL8=ERPIX/(EWCS*RDFDL8)
         EPSBFL8   = FSATL8*FSATL8
         ERPI      = AMAX1(ERPIX-EPSBFL8*ERSI,0.)
         IF    (LCL8 .EQ. 1)THEN
            SRL8  = NEWES/AREA(1)
         ELSEIF(LCL8 .EQ. 2)THEN
            SRL8  = NEWES/WAAG
         ELSE
         ENDIF
         IF(.NOT. DAMWGL8)THEN
         CRLVE   = ERPI  * SRL8 * WLVS(LCL8)    * SELL8(1) / TSBL8
         CRNLVE  = ERPI  * SRL8 * WNLVS(LCL8)   * SELL8(2) / TSBL8
         ECRDL   = ERPI  * SRL8 * DLBIO(LCL8)   * SELL8(4) / TSBL8
         ECRDNL  = ERPI  * SRL8 * DNLBIO(LCL8) * SELL8(5) / TSBL8
         CRLFRE  = CRLVE*AVLAR(LCL8)
         ENDIF
      ENDIF
      IF(DEB(2) .EQ. 1)THEN
      WRITE(90,9)YEAR, TIME, ANIMAL, EWELOC, DGLL8, DDLL8, DGNLL8,
     *          DDNLL8, ED, RDFDL8, EMEPA, EQMP, MER, EWCS, RDFAL8,
     *          ERPI, CRLVE, CRNLVE, CRLFRE, EPSBFL8, ECRDL,
     *          ECRDNL, ERSI
C     ST
    9 FORMAT(5X,'CALL TO SUBROUTINE INTAK',/,
     *'YEAR TIME ANIMAL EWELOC EDGL EDDL EDGNL EDDNL ED EREDFD EMEPA EQM
     *P MER//EWCS EREDFA ERPI CRLVE CRNLVE CRLFRE EPSBF ECRDL ECRDNL ERS
     *I',
     */,I3,I4,1X,A,1X,I1,1X,9(1PG12.4),/,10(1PG12.4))
C     FN
      ELSEIF(DEB(2) .EQ. 2 .OR. EWELOC .EQ. 5)THEN
      WRITE(90,4)YEAR,    TIME,    ANIMAL,  LCL8,    MEINTL8, SELL8,
     *          DAMWGL8, TSBL8,   ED,      EWCS,    ERPIX,   SRL8,
     *          EPSBFL8, ERPI,    ERSI
C     ST
    4 FORMAT(1X,'==INT1= YR=',     I2,    ' T=',    I3,    ' ',      A,
     *  ' LC=',  I1,    ' MEI=',    F4.1, ' SEL=',  5I1,  ' DAM=',  L1,
     *  ' TSB=', F5.0, ' ED=',      F3.2, ' EWCS=', F3.1, ' ERPIX=',F4.2,
     *  ' SR=',  F4.1, ' EPSBF=',  F4.2, ' ERPI/SI=', 2F5.2)
C     FN
      ELSE
      ENDIF

C     ----------------------------------------------- L A M B S
                                                                   ELSE
C     ----------------------------------------------
      DAMWGL8    = .FALSE.
      PMILK=VSATL8=TSBL8=DGLL8=DGNLL8=DDLL8=DDNLL8=LD=DSLPL8=DINTL8=
     *RDFDL8=RDFAL8=LQMP=LMEPA=CSL8=LRPIX=MEINTL8=SRL8=LPSUBF=LRPI=
     *CRLVL=CRNLVL=LCRDL=LCRDNL=CRLFRL=FSATL8=0.

      LCL8           = LAMMAT(ICHAR(ANIMAL(5:5))-16)
      IF(LCL8 .EQ. 2 .AND. DVS(2) .GE. 1. .AND. WAAG .EQ. 0.)LCL8=999
      LRMI           = EMY/(NLR/NEWM)
      IF(ERSI        .GT. 0.)
     *PMILK          = PSUPPS*PRELF*MEWM/((PKA1*QMS+PKA2)*MESU)
      IF(LCL8        .NE. 999)THEN
         DO 5 IL8    = 1,5
    5    SELL8(IL8) = 1
```

```
      SELL8(3)   = 0
      VSATL8     = INSW(DVS(LCL8),VSATG,VSATD)
      IF(LCL8    .EQ. 2 .AND. DVS(2) .LT. 1.
     *           .AND. GRODY(2) .GT. WGTML)DAMWGL8 = .TRUE.
      IF(.NOT.   DAMWGL8)THEN
                 IF(TVEGM(LCL8) .GT. VSATG)THEN
                                SELL8(4)=SELL8(5)=0
                 ELSEIF(DLBIO(LCL8) .GT. VSATD)THEN
                                SELL8(5)=0
                 ELSE
                 ENDIF
      ELSE
                 DO 3 IL8=1,5
    3            SELL8(IL8)=WGCMPL(IL8)
      ENDIF
      TSBL8     =   WLVS(LCL8)    * SELL8(1)
     *          +  WNLVS(LCL8)    * SELL8(2)
     *          +   WSDS(LCL8)    * SELL8(3)
     *          +  DLBIO(LCL8)    * SELL8(4)
     *          + DNLBIO(LCL8)    * SELL8(5)
      DGLL8     = DGLP  - DGSL1  * DVS(LCL8)
      DGNLL8    = DGNLP - DGSL2  * DVS(LCL8)
      DDLL8     = LIMIT(DDLP-DDSL1, DDLP,
     *            DDLP-(GRODY(LCL8)-TDVS1(LCL8))*DDSL1/DND1)
      DDNLL8    = LIMIT(DDNLP-DDSL2, DDNLP,
     *            DDNLP-(GRODY(LCL8)-TDVS1(LCL8))*DDSL2/DND2)
      LD        = (  DGLL8 *   WLVS(LCL8)    * SELL8(1)
     *          +   DGNLL8 *  WNLVS(LCL8)    * SELL8(2)
     *          +    DGLL8 *   WSDS(LCL8)    * SELL8(3)
     *          +    DDLL8 *  DLBIO(LCL8)    * SELL8(4)
     *          +   DDNLL8 * DNLBIO(LCL8)    * SELL8(5) )
     *          /    TSBL8
      IF(LCL8 .EQ. 3)THEN
                     DSLPL8 = DSLPL
                     DINTL8 = DINTL
      ELSE
                     DSLPL8 = DSLPG
                     DINTL8 = DINTG
      ENDIF
      RDFDL8    = LIMIT(0., 1., DSLPL8*LD+ DINTL8)
      RDFAL8    = LIMIT(0.,1., (TSBL8-VRES(LCL8))/(VSATL8-VRES(LCL8))
      IF          (DAMWGL8)RDFAL8=1.
      LQMP      = LD * CFDM
      LMEPA     = LQMP * GEH
   ENDIF
   CSL8       = AFGEN(LPDMIT,WLAM,6,'LPDMIT')
   IF(LCL8        .NE. 999)THEN
      LRPIX      = CSL8*AMIN1(RDFDL8,RDFAL8)
      IF     (LCL8 .EQ. 1)THEN
             SRL8 = NLAMS/AREA(1)
      ELSEIF(LCL8 .EQ. 2)THEN
             SRL8 = NLAMS/WAAG
      ELSEIF(LCL8 .EQ. 3)THEN
             SRL8 = NLAMS/AREA(3)
      ELSE
      ENDIF
      IF(CSL8 .GT. 0.)FSATL8=LRPIX/(CSL8*RDFDL8)
      LPSUBF   = FSATL8*FSATL8
      LRPI     = AMAX1(LRPIX-LRSI*LPSUBF,0.)
      IF(.NOT. DAMWGL8)THEN
      CRLVL    = LRPI * SRL8 * WLVS(LCL8)    * SELL8(1) / TSBL8
      CRNLVL   = LRPI * SRL8 * WNLVS(LCL8)   * SELL8(2) / TSBL8
      LCRDL    = LRPI * SRL8 * DLBIO(LCL8)   * SELL8(4) / TSBL8
      LCRDNL   = LRPI * SRL8 * DNLBIO(LCL8)  * SELL8(5) / TSBL8
      CRLFRL   = CRLVL*AVLAR(LCL8)
      ENDIF
   ENDIF
   IF(DEB(3) .EQ. 1)THEN
   WRITE(90,40)YEAR, TIME, ANIMAL, PMILK, ERSI, DGLL8,
```

```
     *             DGNLL8, LD, RDFDL8, LMEPA, LQMP, CSL8, RDFAL8,
     *             LRPIX, CRLVL, CRNLVL, CRLFRL, LPSUBF, LRPI
C     ST
   40 FORMAT(5X,'CALL TO SUBROUTINE INTAK',/,
     *'YEAR TIME ANIMAL PMILK ERSI LDGL LDGNL LD LREDFD LMEPA LQMP LCS//
     *LREDFA LRPIX CRLVL CRNLVL CRLFRL LPSUBF LRPI',/,
     *I3,I4,1X,A,1X,10(1PG12.4),/,10(1PG12.4))
C     FN
      ELSEIF(DEB(3) .EQ. 2)THEN
      WRITE(90,8)YEAR,    TIME,    ANIMAL,  LCL8,    LRMI,    SELL8,
     *           DAMWGL8, TSBL8,   LD,      CSL8,    LRPIX,   SRL8,
     *           LPSUBF,  LRPI
C     ST
    8 FORMAT(1X,'==INTAK2= YR=',    I2,   ' T=',    I3,   ' ANIM=', A,
     *  ' LC=',  I1,    ' LRMI=',   F3.1, ' SEL=',  5I1,  ' DAM=',  L1,
     *  ' TSB=', F5.0, ' LD=',      F3.2, ' CS=',   F3.1, ' LRPIX=',F4.2,
     *  ' SR=',  F4.1, ' LPSUBF=', F4.2, ' LRPI=', F4.2)
C     FN
      ELSE
      ENDIF
      ENDIF
      RETURN
      END
      SUBROUTINE SRATES

C                     PRIMARY PRODUCTION

C     ST
      IMPLICIT REAL(A-Z)

      INTEGER
     *                        DAY,   DELT,   FINI,              J,      K,
     *                                MSW,      N,  SEADY,   TIME,   YEAR

      EXTERNAL AND

      DIMENSION
     *                   ALPHAT(7,25),       AMAX(3),       AVLAR(3),
     *                     AWATER(10),    CSRRT(2,7),   CSRRTW(2,15),
     *                      CTRDEF(3),      DBIOM(3),     DRR(3,10),
     *                   DISTFT(2,5),  DISTFTM(2,3), DISTFTW(2,12),
     *                         DVR(3),     DVRT(2,5),          DVS(3),
     *                      EB(3,10),    EDPTF(10),    EDPTFT(2,5),
     *                        EFFE(3),       ENGR(3),      ER(3,10),
     *                      ERLB(10),         F(10),    FAMSTT(2,5),
     *                     FDMT(2,3),       FINI(3),    FLTRT(2,10),
     *                  GRAINT(2,14),      GRLVS(3),       GRNLV(3),
     *                        DVX(3),     GROWTR(3),        GRRT(3),
     *                       GRRWT(3),      GRSDS(3),       IBIOM(3),
     *                      LAGRTR(3),        LAI(3),      LMBIOM(3),
     *                     MWATER(10),      PRVTV(3),       PUSHD(3),
     *                       PUSHG(3),   RADTB(2,14),      RDAMAX(3),
     *                      RDEFFE(3),      RDLFA(3),       RDLVS(3),
     *                      RDNLVS(3),    RDRAT(2,4),     RDRDT(2,6)
      DIMENSION
     *                       RDTDF(3),  REDFDT(2,10),    REDTTB(2,7),
     *                    RFDVST(2,4),      RITDF(3),      RRAMAX(3),
     *                      RREFFE(3),        RTD(3),        RTL(10),
     *                     RWFB(3,10),      RWRB(10),       SLCVR(3),
     *                       SWPB(10),     PRVDVS(3),        TCK(10),
     *                        TDB(10),      TDRWT(3),     TECT(2,8),
     *                      TMPSUM(3),       TRAN(3),        TRB(10),
     *                     TRR(3,10),      TVEGM(3),        VAR(10),
     *                                      W(3,10),       WLVS(3),
     *                      WNLVS(3),      WRED(10),     WREDT(2,7)

C     (((
C     =============   SRAT
      COMMON / COM27 /
```

```
     *              ALPHAT , AMAX   , AMAXB  , CONFS  , CONFSM , CSRRT  ,
     *              CSRRTW , DBIOM  , DELT   , DGRRT  , DISTFT , DISTFTM,
     *              DISTFTW, DRR    , DVR    , DVRT   , DVSSF  , DVX    ,
     *              EB     , EDPTFT , EFFE   , EFFEB  , ENGR   , ER     ,
     *              EVAP   , FAMSTT , FDMT   , FLDCP  , FLTRT  , FWDB   ,
     *              GAMMA  , GRAINT , GRLVS  , GRNLV  , GRRT   , GRRWT  ,
     *              GRSDS  , INFR   , K      , LAGRTR , LAI    , LAT    ,
     *              LFARR  , LHVAP  , LMBIOM , MRESF  , MSW    , MWATER ,
     *              MXRTD  , PI     , PROP   , PRVDVS , PRVTV  , PSCH   ,
     *              PUSHD  , PUSHG  , RADTB  , RAIN   , RC     , RCST   ,
     *              RDAMAX , RDEFFE , RDLFA  , RDLVS  , RDNLVS , RDRAT  ,
     *              RDRDT  , RDTDF  , REDFDT , REDTTB , REFCF  , REFT   ,
     *              RFDVST , RHOCP  , RITDF  , RRAMAX , RREFFE , RS     ,
     *              RTD    , RWFB   , SLCVR  , TCDPH  , TCDRL  , TCDRNL ,
     *              TCK    , TCRPH  , TDB    , TDRWT  , TECT   , TMPSUM ,
     *              TRAN   , TRR    , TS     , TSO    , TSUMG  , W      ,
     *              WCLIM  , WLTPT  , WREDT
      COMMON / COM28 /      CTRDEF
      COMMON / COM29 /      IBIOM
      COMMON / COM30 /      SEADY
      COMMON / COM31 /      DAY
      COMMON / COM55 /      AVLAR  , TVEGM
      COMMON / COM56 /      WLVS   , WNLVS
      COMMON / COM57 /      DVS
      COMMON / COM58 /      TIME   , YEAR
      SAVE /COM27/,/COM28/,/COM29/,/COM30/,/COM31/,/COM55/,/COM56/,
     *     /COM57/,/COM58/
C     )))
C     FN
      J=10

      DVX(K) = AND(1.-PRVDVS(K),DVS(K)-1.)
      IF(DVS(K) .GT. 1. .AND. TIME .GT. 180)GOTO 10

      FINI(K)=0

C                 GREEN SEASON

      IF(MSW .EQ. 1)THEN
         MSW=0

         IF(SEADY .LE. 210)THEN
         READ(YEAR,9)RAIN,MNT,MXT,DTR,WSR,DPT8,DPT2
C     ST
    9    FORMAT(17X,F6.0,8X,F5.0,F6.0,F7.0,F7.0,F6.0,F6.0)
C     FN
         ELSE
         RAIN   = 0.
         MNT    = 12.
         MXT    = 27.
         DTR    = 600.
         WSR    = 160.
         DPT8   = 9.0
         DPT2   = 7.0
         ENDIF

         DGRCL     = 2.*AFGEN(RADTB,(DAY+0.),14,'RADTB')
         DGROV     = 0.2*DGRCL
         FCL       = (DTR-DGROV)/(DGRCL-DGROV+NOT(DGRCL-DGROV))
         FOV       = 1.-FCL
         LFOV      = LIMIT(0.,1.,FOV)
         TMPA      = (MNT+MXT)/2.
         DPT       = AMIN1((DPT8+DPT2)*0.5,TMPA)
         VPA       = 4.58*EXP(17.4*DPT/(DPT+239.))
         SVPA      = 4.58*EXP(17.4*TMPA/(TMPA+239.))
         INFR      = RAIN
         LWR       = 1.178E-7*(TMPA+273.)**4*(0.58-0.09*SQRT(VPA))
     *               *(1.-0.9*LFOV)
         WSM       = WSR/1.6
```

```
      HZERO      = DTR*(1.-REFCF)-LWR
      EA         = 0.35*(SVPA-VPA)*(0.5+WSM/100.)*LHVAP
      DELTA      = 17.4*SVPA*(1.-TMPA/(TMPA+239.))/(TMPA+239.)
      EVAP       = (HZERO*DELTA/GAMMA+EA)/(1.+DELTA/GAMMA)*1./LHVAP
      DTMPA      = DELAYT(10,TMPA)
      DTMPA      = INSW(TIME-10.,0.1*TSO,DTMPA)
      RCST       = (TMPA-DTMPA)/DELT
      DEC        = -23.4*COS(PI*(DAY+10.173)/182.621)
      RAD        = PI/180.
      SSIN       = SIN(RAD*LAT)*SIN(RAD*DEC)
      CCOS       = COS(RAD*LAT)*COS(RAD*DEC)
      TTE        = (-SIN(8.*RAD)+SSIN)/CCOS
      TT         = SSIN/CCOS
      ASE        = ASIN(TTE)
      AS         = ASIN(TT)
      DAYL       = 12.*(PI+2.*AS)/PI
      EDAYL      = 12.*(PI+2.*ASE)/PI

      RADO       = 0.2*RADC
      VPAM       = 1.33*VPA
      AVTD       = MXT-0.25*(MXT-MNT)
      SVPAM      = 6.11*EXP(17.4*AVTD/(AVTD+239.))
      WSA        = 1.333E5*WSR
      RA         = 3.045E-3*SQRT(1./WSA)+63./WSA
      ELWR       = 1.175E-7*(AVTD+273.)**4*(0.58-0.09*SQRT(VPA))*
*                  (1.0-0.9*LFOV)*DAYL/24.
      HNOT       = 0.75*DTR-ELWR
      SLOPE      = 17.4*SVPAM*(1.-AVTD/(AVTD+239.))/(AVTD+239.)
      S1         = (RA+RS)/RA
      CC         = 1./(SLOPE+S1*PSCH)
      HRAD       = DTR/DAYL

   ENDIF

   WCPR          = (W(K,1)/TCK(1)-WCLIM)/(FLDCP-WCLIM)
   FRLT          = AFGEN(FLTRT,SLCVR(K),10,'FLTRT')
   PEVAP         = FRLT*EVAP
   REDFD         = AFGEN(REDFDT,WCPR,10,'REDFDT')
   AEVAP         = PEVAP*REDFD
   IF(LAI(K) .GT. 0.)THEN
      SLLAE      = SIN((90.+DEC-LAT)*RAD)
      X          = 0.45*EFFE(K)*RADC/(SLLAE*AMAX(K))
      P          = ALOG(1.+X)
      P          = P/(P+1.)
      PS         = SLLAE*P*EDAYL*AMAX(K)
      X          = 0.55*EFFE(K)*RADC/(AMAX(K)*(5.-SLLAE))
      P          = ALOG(1.+X)
      P          = P/(P+1.)
      DGCC       = PS+(5.-SLLAE)*AMAX(K)*EDAYL*P
      DGCCE      = 0.95*DGCC+20.5
      X          = RADO*EFFE(K)/(AMAX(K)*5.)
      P          = X/(X+1.)
      DGCO       = 5.*AMAX(K)*EDAYL*P
      DGCOE      = 0.9935*DGCO+1.1
      IF(LAI(K) .GE. 5.)THEN
         PDTGAS = (LFOV*DGCO+(1.-LFOV)*DGCC)*30./44.
      ELSE
         FINT    = (1.-EXP(-0.8*LAI(K)))
         C1      = FINT*DGCCE
         C2      = DAYL*LAI(K)*AMAX(K)
         O1      = FINT*DGCOE
         O2      = C2
         IF(C1 .LE. C2)THEN
            CO   = C1
            C1   = C2
            C2   = CO
         ENDIF
         DGCCAE = C2*(1.-EXP(-C1/C2))
```

```
            IF(O1 .LE. O2)THEN
               OO  = O1
               O1  = O2
               O2  = OO
            ENDIF
            DGCOAE = O2*(1.-EXP(-O1/O2))
            PDTGAS = (LFOV*DGCOAE+(1.-LFOV)*DGCCAE)*30./44.
         ENDIF
      ELSE

      ENDIF

C     ***************   SOIL WATER DYNAMICS --- PART 1

      VAR(1)         = AMAX1(W(K,1)/TCK(1)-WCLIM,0.)
     *                 *EXP(-PROP*0.001*(0.5*TCK(1)))
      SUM10          = VAR(1)*TCK(1)
      AWATER(1)      = AMAX1(0.,W(K,1)-TCK(1)*WLTPT)
      AFGX           = AWATER(1)/(MWATER(1)-TCK(1)*WLTPT)
      EDPTF(1)       = AFGEN(EDPTFT,AFGX,5,'EDPTFT')
      RTL(1)         = LIMIT(0.,TCK(1),RTD(K))
      ERLB(1)        = RTL(1)*EDPTF(1)
      WCPR           = (W(K,1)/TCK(1)-WCLIM)/(FLDCP-WCLIM)
      WRED(1)        = AFGEN(WREDT,AFGX,7,'WREDT')
      TEC            = AFGEN(TECT,TS,8,'TECT')
      RWFB(K,1)      = AMAX1(0.,INFR-(MWATER(1)-W(K,1))/DELT)
      SWP            = FCNSW(AWATER(1),0.,0.,AND(RTD(K),TDB(1)-RTD(K)))
      SWPB(1)        = SWP
      DRR(K,1)       = RWFB(K,1)*AND(MXRTD,TDB(1)-MXRTD+0.5)
      DO 3 N=2,J
         VAR(N)      = AMAX1(W(K,N)/TCK(N)-WCLIM,0.)
     *                 *EXP(-PROP*0.001*(TDB(N-1)+0.5*TCK(N)))
         SUM10       = SUM10+VAR(N)*TCK(N)
         AWATER(N)   = AMAX1(0.,W(K,N)-TCK(N)*WLTPT)
         AFGX        = AWATER(N)/(MWATER(N)-TCK(N)*WLTPT)
         EDPTF(N)    = AFGEN(EDPTFT,AFGX,5,'EDPTFT')
         RTL(N)      = LIMIT(0.,TCK(N),RTD(K)-TDB(N-1))
         ERLB(N)     = ERLB(N-1)+RTL(N)*EDPTF(N)
         WRED(N)     = AFGEN(WREDT,AFGX,7,'WREDT')
         RWFB(K,N)   = AMAX1(0.,RWFB(K,N-1)-(MWATER(N)-W(K,N))/DELT)
         SWP         = FCNSW(AWATER(N),0.,0.,
     *                 AND(RTD(K)-TDB(N-1),TDB(N)-RTD(K)))
         SWPB(N)     = SWPB(N-1)+SWP
         DRR(K,N)    = DRR(K,N-1)+RWFB(K,N)*AND(MXRTD-TDB(N-1),
     *                 TDB(N)-MXRTD+0.5)
    3 CONTINUE

C     *********   CALCULATION OF POTENTIAL CROP TRANSPIRATION   ********

      ALPHA          = TWOVAR(ALPHAT,HRAD,LAI(K),12,7,'ALPHAT')
      RFDVS          = AFGEN(RFDVST,DVS(K),4,'RFDVST')
      PTRAN          = CC*((1.-EXP(-0.5*LAI(K)))*HNOT*SLOPE+ALPHA*LAI(K)*
     *                 RHOCP/RA*(SVPAM-VPAM)*DAYL/24.)/LHVAP
      APTRAN         = PTRAN*RFDVS
      TRPMM          = APTRAN/(ERLB(J)+NOT(ERLB(J)))
      MWRTD          = RTD(K)*(FLDCP-WLTPT)+NOT(RTD(K))

C     **********   SOIL WATER DYNAMICS  --- PART 2

      F(1)           = TCK(1)*VAR(1)/(SUM10+NOT(SUM10))
      ER(K,1)        = AMIN1(W(K,1)-WCLIM*TCK(1),F(1)*AEVAP)
      EB(K,1)        = ER(K,1)
      TRR(K,1)       = TRPMM*RTL(1)*EDPTF(1)*TEC*WRED(1)
      TRB(1)         = TRR(K,1)
      RAWR           = RTL(1)/TCK(1)*AWATER(1)/MWRTD
      RWRB(1)        = RAWR
C     REST OF WATER DYNAMICS OF OTHER COMPARTMENTS
      DO 2 N         = 2,J
         F(N)        = TCK(N)*VAR(N)/(SUM10+NOT(SUM10))
```

```
      ER(K,N)    = AMIN1(W(K,N)-WCLIM*TCK(N),F(N)*AEVAP)
      EB(K,N)    = EB(K,N-1)+ER(K,N)
      TRR(K,N)   = TRPMM*RTL(N)*EDPTF(N)*TEC*WRED(N)
      TRB(N)     = TRB(N-1)+TRR(K,N)
      RAWR       = RTL(N)/TCK(N)*AWATER(N)/MWRTD
      RWRB(N)    = RWRB(N-1)+RAWR
  2 CONTINUE
    SW           = W(K,1)+W(K,2)+W(K,3)-WLTPT*TDB(3)

C   **************   REST OF POT. CROP TRANSPIRATION   ***************

    TRAN(K)      = TRB(J)
    RTRDEF       = (PTRAN-TRAN(K))/(PTRAN+NOT(PTRAN))
    S1           = (RA+RC)/RA
    CC1          = 1./(SLOPE+S1*PSCH)
    PCTRAN       = PTRAN*CC1/CC
    TRANDF       = (PCTRAN-TRAN(K))*DELT
    FDV          = INSW(TRANDF,1.,-1.)

C   *****************        GERMINATION        **********************

    ENGR (K) = INSW(TSUMG-TMPSUM(K),0.,INSW(SW,TMPSUM(K)/DELT,0.))
    PUSHD(K) = AND(PRVTV(K)-LMBIOM(K),LMBIOM(K)-(WLVS(K)+WNLVS(K)))
    PUSHG(K) = AND(TMPSUM(K)-TSUMG,0.5*IBIOM(K)-(WLVS(K)+WNLVS(K)))
   *     *INSW(TIME-180.,1.,0.)*(1.-PUSHD(K))

C   *****************       CROP PRODUCTION      *********************

    DVR(K)       = AFGEN(DVRT,TMPA,5,'DVRT')
   *            *INSW((WLVS(K)+WNLVS(K))-LMBIOM(K),0.,1.)*(1.-PUSHD(K))
   *                *INSW(                   DVS(K)-1.,  1., 0. )
   *                *INSW(                    (K-2)*1.,  1., 0.8)
    FDM          = AFGEN(FDMT,DVS(K),3,'FDMT')
    RDLVSX       = TRANDF*1.E4/((1.-FDM-FWDB)/FDM)
   *               * WLVS(K) / (TVEGM(K) + NOT(TVEGM(K) ))
    RDNLVX       = TRANDF*1.E4/((1.-FDM-FWDB)/FDM)
   *               * WNLVS(K) / (TVEGM(K) + NOT(TVEGM(K) ))
    RDRD         = AFGEN(RDRDT,DVS(K),6,'RDRDT')
    RDLVSA       = RDLVSX/TCDRL
    RDNLVA       = RDNLVX/TCDRNL
    RDLVS2       = RDRD*WLVS(K)*(1.-PUSHD(K))
    RDNLV2       = RDRD*WNLVS(K)*(1.-PUSHD(K))
    RDLVS1       = AMIN1(RDLVSA/DELT,WLVS(K)/DELT)
    RDNLV1       = AMIN1(RDNLVA/DELT,WNLVS(K)/DELT)
    RDLVS(K)     = INSW(FDV,RDLVS1,RDLVS2)*(1.-PUSHD(K))
    RDNLVS(K)    = INSW(FDV,RDNLV1,RDNLV2)*(1.-PUSHD(K))
    RDLFA(K)     = AVLAR(K)*RDLVS(K)
    TEFR         = 10.**((TMPA-REFT)*ALOG10(2.)/10.)
    MAINT        = (TDRWT(K)-DBIOM(K))*MRESF*TEFR
    PDTGR        = (PDTGAS-MAINT)*CONFS
    IF(K .EQ. 3)PDTGR=(PDTGAS-MAINT)*CONFSM

    IF(PDTGR .GT. 0.)THEN
         WUSEFF        = PDTGR/(PTRAN+NOT(PTRAN))
         TGRWTH        = TRAN(K)*WUSEFF
         FAMST         = AFGEN(FAMSTT,RTRDEF,5,'FAMSTT')
         IF(K .EQ. 2)THEN
         CSRR          = AFGEN(CSRRTW,DVS(K),15,'CSRRTW')*FAMST
         ELSE
         CSRR          = AFGEN( CSRRT,DVS(K), 7, 'CSRRT')*FAMST
         ENDIF
         GRRWT(K)      = TGRWTH*(1.-CSRR)*(1.-PUSHD(K))
         GROWTR(K)     = TGRWTH*CSRR*(1.-PUSHD(K))
         IF(K .EQ. 2)THEN
         FRTS          = AFGEN(GRAINT,DVS(K),14,'GRAINT')
   *                     *INSW(GROWTR(K),0.,1.)
         ELSE
         FRTS          =INSW(DVS(K)-DVSSF,0.,0.3)*INSW(GROWTR(K),0.,1.)
         ENDIF
```

```
        GRSDS(K)      = GROWTR(K)*FRTS
        IF(K .EQ. 1)THEN
        DISTF         = AFGEN( DISTFT, DVS(K), 5,'DISTFT' )
        ELSEIF(K .EQ. 2)THEN
        DISTF         = AFGEN(DISTFTW, DVS(K),12,'DISTFTW')
        ELSE
        DISTF         = AFGEN(DISTFTM, DVS(K), 3,'DISTFTM')
        ENDIF
        GROWTV        = GROWTR(K)*(1.-FRTS)
        GRLVS(K)      = GROWTV*DISTF
        GRNLV(K)      = GROWTV*(1.-DISTF)
        LAGRTR(K)     = GRLVS(K)*LFARR
    ELSE
        WUSEFF=TGRWTH=FAMST=CSRR=GRRWT(K)=GROWTR(K)=FRTS=GRSDS(K)=
   *    DISTF=GROWTV=GRLVS(K)=GRNLV(K)=LAGRTR(K)=0.
    ENDIF

    RFRGT         = AFGEN(REDTTB,TS,7,'REDTTB')
    GRRT(K)       = SWPB(J) * DGRRT * RFRGT
   *                *INSW((WLVS(K)+WNLVS(K))-IBIOM(K),0.,1.)
   *                *INSW(RTD(K)-MXRTD,                1.,0.)
   *                *INSW(DVS(K)-1.,                   1.,0.)
    TCREC         = TVEGM(K)/(GRNLV(K)+GRLVS(K)+NOT(GRNLV(K)+GRLVS(K)))
    IF(RTRDEF .GT. 0.4)THEN
        RDTDF(K)  = 0.
        RITDF(K)  = (1.-CTRDEF(K)) * RTRDEF / TCDPH
        RDRA      = AFGEN(RDRAT,CTRDEF(K),4,'RDRAT')
        RDEFFE(K) = RDRA * EFFE(K) * (1.-PUSHD(K))
        RDAMAX(K) = RDRA * AMAX(K) * (1.-PUSHD(K))
    ELSE
        RITDF(K)  = RDRA = RDEFFE(K) = RDAMAX(K) = 0.
        RDTDF(K)  = CTRDEF(K) / TCRPH
    ENDIF
    IF(TVEGM(K) .GT. 0. .AND. CTRDEF(K) .LE. 0.5)THEN
        RREFFE(K) = (EFFEB-EFFE(K))/(TCREC+NOT(TCREC))
        RRAMAX(K) = (AMAXB-AMAX(K))/(TCREC+NOT(TCREC))
    ELSE
        RREFFE(K) = RRAMAX(K) = 0.
    ENDIF
    RETURN

 10 CONTINUE

C            DRY  SEASON

    IF(FINI(K).EQ. 1)RETURN

    EB(K,10)=DRR(K,10)=PUSHD(K)=PUSHG(K)=GRLVS(K)=GRNLV(K)=GRSDS(K)=
   *DVR(K)=GRRWT(K)=GRRT(K)=RDEFFE(K)=RREFFE(K)=RITDF(K)=RDTDF(K)=
   *INFR=RDAMAX(K)=RRAMAX(K)=RDLVS(K)=RDNLVS(K)=RDLFA(K)=INFR=TRAN(K)=
   *LAGRTR(K)=RCST=RAIN=EVAP=GROWTR(K)=ENGR(K)=0.
    DO 20 I=1,10
    RWFB(K,I)=TRR(K,I)=ER(K,I)=0.
 20 CONTINUE
    FINI(K)=1

    RETURN
    END
    SUBROUTINE EWMOVE

C   EWE LOCATION ALGORITHM
C   ***********************************************************************
C   *                                                                     *
C   * ALTERS THE FOLLOWING VARIABLES IN COMMON:                   WAGRE   *
C   *                                                             EWELOC  *
C   *                                                                     *
C   ***********************************************************************
C   ST
    IMPLICIT REAL(A-Z)
```

```
      INTEGER
     *                             DAY,     DEB,          EWELOC, YEAR,
     *                    GRODY,    IL7,     JL7,          REPL7, OLDEWL7,
     *                   POSBL7, PRSNL7, PRIORT, PPOSL7, PPRSL7, TIME

      DIMENSION
     *                         DEB(13),    AREA(3),               DVS(3),
     *                        GRODY(3),                        POSBL7(6),
     *                      PRSNL7(6), PRIORT(6), PPOSL7(6), PPRSL7(6)

C     (((
C     ============   EWMO
      COMMON / COM25 /      PRIORT
      COMMON / COM26 /      WAGRE
      COMMON / COM31 /      DAY
      COMMON / COM50 /      GRODY  , WGTML
      COMMON / COM51 /      AREA
      COMMON / COM52 /      WAAG
      COMMON / COM53 /      EWELOC
      COMMON / COM54 /      DEB
      COMMON / COM57 /      DVS
      COMMON / COM58 /      TIME   , YEAR
      SAVE /COM25/,/COM26/,/COM31/,/COM50/,/COM51/,/COM52/,/COM53/,
     *     /COM54/,/COM57/,/COM58/
C     )))
C     FN
      DATA PRSNL7/0,0,0,0,0,1/
      DATA PPRSL7/0,0,0,0,0,1/
      DATA PPOSL7/0,0,0,0,0,1/
      DATA OLDEWL7/6/
      WAGRE=0.

C     SETTING OF VECTORS PRSNL7 AND POSBL7
      DO 10 IL7 = 1,6
   10 PRSNL7(IL7)=0
      IF(AREA(1) .GT. 0.)THEN
         IF(DVS(1) .LT. 1.)THEN
            PRSNL7(1)=1
         ELSE
            PRSNL7(4)=1
         ENDIF
      ENDIF
      IF(WAAG .GT. 0.)THEN
         IF(DVS(2) .LT. 1.)THEN
            IF(GRODY(2) .LT. WGTML)THEN
               PRSNL7(2)=1
            ELSE
               PRSNL7(5)=1
            ENDIF
         ELSE
            PRSNL7(3)=1
         ENDIF
      ENDIF
      PRSNL7(6)=POSBL7(6)=1
      DO 40 IL7=1,5
            IF(PPRSL7(IL7) .NE. PRSNL7(IL7))
     *      CALL DIARY2(IL7,PRSNL7(IL7)*1.,TIME,DAY)
            PPRSL7(IL7)=PRSNL7(IL7)
   40 CONTINUE
      DO 50 IL7=1,5
            POSBL7(IL7)=0
            IF(PRSNL7(IL7) .EQ. 1)THEN
            CALL CRITEW(IL7,REPL7)
            POSBL7(IL7)=REPL7
            ENDIF
   50 CONTINUE
      DO 60 IL7=1,5
            IF(PPOSL7(IL7) .NE. POSBL7(IL7))
```

```
     *      CALL DIARY3(IL7,POSBL7(IL7)*1.,TIME,DAY)
            PPOSL7(IL7) = POSBL7(IL7)
   60 CONTINUE
C     SETTING OF EWE LOCATION
      DO 70 IL7=1,6
            JL7=PRIORT(IL7)
            IF(POSBL7(JL7) .EQ. 1)GOTO 80
   70 CONTINUE
   80 EWELOC=JL7
      IF(EWELOC .NE. OLDEWL7)THEN
            CALL DIARY1(OLDEWL7,EWELOC*1.,TIME,DAY)
            OLDEWL7=EWELOC
      ENDIF

      IF(DEB(4) .GT. 0)THEN
      WRITE(90,20) YEAR,      TIME,      DVS(1),    DVS(2),  DVS(3),
     *             GRODY(1),  GRODY(2),  GRODY(3),  EWELOC,  PRIORT,
     *             PRSNL7,    POSBL7,    WAAG,      WAGRE
C     ST
   20 FORMAT(1X,'==EWEMOV= YR=',  I2,    ' T=',     I3,  ' DVS=', 3F5.2,
     *  ' GRODY=', 3I4, ' ELOC=', I1,    ' PRIORT=', 6I1, ' PRSN=',6I1,
     *  ' POSB=',  6I1, ' WAAG=', F4.3, ' WAGRE=',  F4.3)
C     FN
      ENDIF

      RETURN
      END
      SUBROUTINE CRITEW(JL6,REPL6)

C     EWE LOCATION ALGORITHM
C     *****************************************************************
C     *                                                               *
C     * ALTERS THE FOLLOWING VARIABLES IN COMMON:           GDDEC     *
C     *                                                     WAGRE     *
C     *                                                               *
C     *****************************************************************
C     ST
      IMPLICIT REAL(A-Z)

      INTEGER
     *                    AL6,    AOL6,   GDDEC,          DEB,
     *                 EWELOC,  YEAR,    GRODY,     JL6, MNGDEL,
     *                 RATING,  REPL6,   SEADY,    TIME,    T1L6

      DIMENSION
     *                       AREA(3),   ARF(16), WGCMPE(5),
     *                       DEB(13),  DLBIO(3), DNLBIO(3),    DVS(3),
     *                     GRODY(3),  IBIOM(3),              RATING(6),
     *                                TADRW(3),                VRES(3),
     *                       WLVS(3),  WNLVS(3),   WSDS(3)

C     (((
C     ============   CRIT
      COMMON / COM07 /     EWCS
      COMMON / COM20 /
     *            DACS    , FRCS   , GDCS    , GDDEC  , GDF     , GDG     ,
     *            GDI     , GDTEND , GDVM    , GDVMF  , GDVS    , MNIEW   ,
     *            PGDLIM  , S
      COMMON / COM21 /     DCLV    , DCNLV   , RATING
      COMMON / COM22 /     TADRW
      COMMON / COM23 /     MNGDEL  , WGWF
      COMMON / COM24 /     ARF     , COSTH   , PGRN
      COMMON / COM26 /     WAGRE
      COMMON / COM29 /     IBIOM
      COMMON / COM30 /     SEADY
      COMMON / COM44 /     PRELF   , WGCMPE
      COMMON / COM45 /     NEWES   , VSATD
      COMMON / COM46 /     ERSI
      COMMON / COM47 /     ERPI
```

```
      COMMON / COM48 /       PSUPPS
      COMMON / COM49 /       DLBIO  , DNLBIO , VRES   , WSDS
      COMMON / COM50 /       GRODY  , WGTML
      COMMON / COM51 /       AREA
      COMMON / COM52 /       WAAG
      COMMON / COM53 /       EWELOC
      COMMON / COM54 /       DEB
      COMMON / COM56 /       WLVG   , WNLVS
      COMMON / COM57 /       DVS
      COMMON / COM58 /       TIME   , YEAR
      SAVE /COM07/,/COM20/,/COM21/,/COM22/,/COM23/,/COM24/,/COM26/,
     *     /COM29/,/COM30/,/COM44/,/COM45/,/COM46/,/COM47/,/COM48/,
     *     /COM49/,/COM50/,/COM51/,/COM52/,/COM53/,/COM54/,/COM56/,
     *     /COM57/,/COM58/
C     )))
C     FN
      GOTO(10,20,30,40,50),JL6

C     GREEN PASTURE
   10 REPL6=1
      IF(GDDEC .EQ. 0)THEN
         CMCXL6       = 0.
         GDHL6        = NEWES/AREA(1)
         DCL6         = (DCLV+DCNLV)/2.
         DRYQL6       = (365.-GDTEND)*NEWES*GDCS
         D1PL6        = GDCS * GDHL6 / DCL6
         D1WL6        = DGWL6 = 0.
         IF(WAAG .GT. 0.)THEN
            D1WL6     = GDCS * NEWES / (WAAG * DCL6)
            DGWL6     = AMAX1(0.,ALOG((GDVM*(1.-GDI)+D1WL6)
     *                  / (VSATD + D1WL6))/DCL6)
         ENDIF

         DO 11 TENTL6 = 0.,GDTEND
            CUMCL6    = 0.
            VL6       = GDVM/(1.+(((GDVM-IBIOM(1))/IBIOM(1))
     *                  *EXP(-GDG*TENTL6)))
            DO 12 TL6 = TENTL6,GDTEND
               GRL6   = GDG*VL6*(1.-VL6/GDVM)
               CL6    = AMAX1(0.,GDHL6*GDCS
     *                  *(1.-EXP(-(VL6-VRES(1))/(GDVS-VRES(1)))))
               VL6    = AMAX1(0., VL6 + GRL6 - CL6)
               CUMCL6 = CUMCL6+CL6
   12       CONTINUE
            DGPL6     = AMAX1(0., ALOG((VL6+D1PL6)/(VSATD+D1PL6))/DCL6)
            CUMCL6    = CUMCL6*AREA(1)
     *                  + AMIN1((DGPL6+DGWL6)*NEWES*GDCS, DRYQL6) * GDF
            IF(CUMCL6 .GT. CMCXL6)THEN
               CMCXL6 = CUMCL6
               OEDL6  = TENTL6
            ENDIF
   11    CONTINUE
         OEVL6        = GDVM/(1.+(((GDVM-IBIOM(1))/IBIOM(1))
     *                  *EXP(-GDG*OEDL6)))
         GDDEC        = 1

         IF(DEB(5) .GT. 0)THEN
         WRITE(90,2)YEAR,TIME,CMCXL6,DCL6,D1PL6,D1WL6,DRYQL6,
     *              DGPL6,DGWL6,OEDL6,OEVL6
C     ST
    2    FORMAT(1X,'==CRITEW1= YR=',I2,' T=',I3,' CMCX=',F8.1,
     *          ' DC=',F6.5,' D1P=',F8.1,' D1W=',F8.1,' DRYQ=',F6.0,
     *          ' DGP=',F4.0,' DGW=',F4.0,' OED=',F4.0,' OEV=',F6.1)
C     FN
         ENDIF

      ENDIF
      IF(TADRW(1) .LT. OEVL6*GDVMF .AND. GRODY(1) .GT. PGDLIM)
     *WRITE(*,5)YEAR,TIME,GRODY(1),PGDLIM,TADRW(1),OEVL6*GDVMF
```

```
  5 FORMAT(1X,'*** GDEF *** YR,T,GODY,PGDLIM,TADRW,OEV*GDVMF',
   *3I5,3F12.4)
    IF(TADRW(1) .GT. OEVL6*GDVMF .OR. GRODY(1) .GT. PGDLIM)RETURN
    REPL6=0
    RETURN

C     GREEN WHEAT NO DAMAGE GRAZING

 20 REPL6=0
    IF(EWELOC .EQ. 1 .OR. GRODY(2) .EQ. 0)RETURN
    IF(EWELOC .EQ. 2)THEN
       REPL6=1
       RETURN
    ENDIF
    RGR2L6           = ALOG(TADRW(2)/IBIOM(2))/GRODY(2)
    AOL6             = MAXCL6=-1.
    DO 21 AL6        = 0,MNGDEL,MNGDEL
       VL6           = TADRW(2)*EXP(RGR2L6*AL6)
       CUMCL6        = 0.
       DO 22 T1L6    = AL6,WGTML-GRODY(2)
          GRL6       = RGR2L6*VL6
          CL6        = AMAX1(NEWES/WAAG*AMIN1(S*(VL6-VRES(2)),GDCS),0.)
          VL6        = VL6+GRL6-CL6
          CUMCL6     = CUMCL6+CL6
 22    CONTINUE
       IF(CUMCL6 .GT. MAXCL6)THEN
          MAXCL6     = CUMCL6
          AOL6       = AL6
       ENDIF
 21 CONTINUE
    CAVEL6           = MAXCL6*WAAG/((WGTML-GRODY(2))*NEWES)
    IF(AOL6 .EQ. 0 .AND. CAVEL6 .GT. MNIEW)REPL6=1

    IF(DEB(5) .GT. 0)THEN
    WRITE(90,3)YEAR, TIME,     JL6,    EWELOC, NEWES, WAAG,    TADRW(2),
   *          RGR2L6, GRODY(2), WGTML, MAXCL6, AOL6,  CAVEL6, REPL6
C     ST
  3 FORMAT(1X,'==CRITW2= YR=',      I2,     ' T=',       I3,
   *  ' J=',       I1,   ' ELOC=',  I1,     ' NEWES=',  F4.1,
   *  ' WAAG=',    F3.2, ' TADRW2=', F5.0,  ' RGR2=',   F4.3,
   *  ' GRODY2=',  I3,   ' WGTML=',  F3.0,  ' MAXC=',   F6.1,
   *  ' AO=',      I2,   ' CAVE=',   F4.2,  ' REP=',    I1)
C     FN
    ENDIF

    RETURN

C     WHEAT AFTERMATH
 30 REPL6=1
    IF(TADRW(2) .LT. VSATD/3.)REPL6=0
    IF(RATING(6) .LT. RATING(4))RETURN
    IF(DVS(1) .GE. 1. .AND. TADRW(1) .GT. TADRW(2)
   *                   .AND.  AREA(1) .GT. 0.)      REPL6=0
    RETURN

C     DRY PASTURE
 40 REPL6=1
    IF(TADRW(1) .LT. VSATD/3.)REPL6=0
    IF(RATING(6) .LT. RATING(3))RETURN
    IF(DVS(2) .GE. 1. .AND. TADRW(2) .GT. TADRW(1)
   *                   .AND.     WAAG .GT. 0.)      REPL6=0
    RETURN

C     GREEN WHEAT DAMAGE GRAZING
 50 REPL6=0
    WAGRE=0.
    IF(ERSI .EQ. 0. .OR.
   *  ((EWELOC .EQ. 1 .OR. EWELOC .EQ. 4) .AND. ERPI .GT. FRCS*EWCS)
   *  .OR. EWELOC .EQ. 5     )RETURN
```

```
      COPL6=ERSI*NEWES*PSUPPS*PRELF*MNGDEL

      GWVEL6=0.
      IF(WGCMPE(1) .GT. 0.)GWVEL6=GWVEL6+WLVS(2)
      IF(WGCMPE(2) .GT. 0.)GWVEL6=GWVEL6+WNLVS(2)
      IF(WGCMPE(3) .GT. 0.)GWVEL6=GWVEL6+WSDS(2)
      IF(WGCMPE(5) .GT. 0.)GWVEL6=GWVEL6+DNLBIO(2)
      GWVEL6=AMAX1(1.,GWVEL6-VRES(2))

      WAXL6         = AMIN1(WAAG,DACS*NEWES*MNGDEL*(1.+WGWF)/GWVEL6)
      CALL GRYPRO(PGYL6,SDYL6,AFYL6,SEADY,ARF)
      PGL6          = WAXL6*AMAX1(0.,PGYL6*PGRN-COSTH)
C     CALCULATE THRESHOLD CONDITIONS
      BXL6          = DACS * (1. + WGWF) / GWVEL6
      PSPXL6        = BXL6 * (PGYL6 * PGRN - COSTH) / ERSI
      PGNXL6        = (ERSI * PSUPPS*PRELF / BXL6 + COSTH) / PGYL6
      PGYXL6        = (ERSI * PSUPPS*PRELF / BXL6 + COSTH) / PGRN

      IF(PGL6 .LT. COPL6)THEN
         REPL6      = 1
         WAGRE      = WAXL6
      ENDIF

      IF(DEB(5) .EQ. 1)THEN
      WRITE(90,1)YEAR, TIME, JL6, REPL6, ERPI, ERSI, EWCS, COPL6,
     *           WAXL6, PGYL6, AFYL6, PGL6, WAAG, WAGRE,
     *           PSPXL6, PGNXL6, PGYXL6, EWELOC, GWVEL6, TADRW(2)
C     ST
    1 FORMAT(/,' CRITEWS  YEAR TIME JL6 REPL6 ERPI ERSI EWCS COPL6 WAXL6
     * PGYL6 AFYL6 PGL6 WAAG WAGRE PSPXL6 PGNXL6 PGYXL6 ELOC GWV TAD2',
     */,1X,I2,1X,I3,1X,2(I1,1X),3F5.2,1PG12.4,
     *0P,F6.3,2F7.1,1PG12.4,0P,2F6.3,3(1PG12.4),0P,I2,2F6.0)
C     FN
      ELSEIF(DEB(5) .EQ. 2)THEN
      WRITE(90,4)YEAR,   TIME,    EWELOC,   NEWES,   WAAG,    GWVEL6,
     *           WAXL6,  COPL6,   PGL6,     PGYL6,   PGYXL6,  WAGRE,   REPL6
C     ST
    4 FORMAT(1X,'==CRITWS= YR=',     I2, ' T=',     I3,    ' ELOC=', I1,
     *  ' NEWES=', F4.1, ' WAAG=', F3.2, ' GWVE=', F5.0, ' WAX=',  F4.3,
     *  ' COP=',   F5.1, ' PG=',   F5.1, ' PGY=',  F5.0, ' PGYX=', F5.0,
     *  ' WAGRE=', F4.3, ' REP=',  I1)
C     FN
      ELSE
      ENDIF

      RETURN
      END
      SUBROUTINE GRYPRO(PGYGY, SDYGY, AFYGY, SEADYGY, ARFGY)

C     GRAIN YIELD PREDICTION

C     ST
      IMPLICIT REAL(A-Z)

      INTEGER         DEB, IGY, INDGY, JGY, NOYGY, SEADYGY, TIME, YEAR

      DIMENSION         ARFGY(16), DEB(13), GYGY(25), GYCGY(9), HRFGY(16)

C     (((
C     =============   GRYP
      COMMON / COM54 /      DEB
      COMMON / COM58 /      TIME   , YEAR
      SAVE /COM54/,/COM58/
C     )))
C     FN
      DATA HRFGY/16*0./
      DATA GYCGY/18.69,9.55,12.47,12.31,8.68,7.29,4.36,0.,-1151.5/
      DATA AF1GY,AF2GY/0.32,0.00003/
```

```
      REWIND 40
      NOYGY=0
      INDGY=INT((SEADYGY/15.)+0.5)+1
      IF(INDGY .GT. 16)THEN
         PRINT *,' GRYPRO WARNING: YR,T,SEADY,IND=',YEAR,TIME,SEADYGY,
     *   INDGY
         INDGY=16
      ENDIF
    1 READ(40,*,END=5)(HRFGY(IGY),IGY=1,14)
      DO 3 IGY=1,INDGY-1
    3 HRFGY(IGY)    = ARFGY(IGY)
      HRFGY(INDGY) = HRFGY(INDGY)+ARFGY(INDGY)
      NOYGY        = NOYGY+1
      GYGY(NOYGY)  = 0.
      DO 4 IGY=1,8
      JGY          = 2*IGY
      GYGY(NOYGY)  = GYGY(NOYGY)+GYCGY(IGY)*(HRFGY(JGY-1)+HRFGY(JGY))
    4 CONTINUE
      GYGY(NOYGY)  = GYGY(NOYGY)+GYCGY(9)
      GOTO 1
    5 SYGY         = 0.
      SYSGY        = 0.
      DO 6 IGY=1,NOYGY
      SYGY         = SYGY+GYGY(IGY)
      SYSGY        = SYSGY+GYGY(IGY)*GYGY(IGY)
    6 CONTINUE
      PGYGY        = SYGY/NOYGY
      SDYGY        = SQRT(AMAX1(SYSGY-SYGY*SYGY/NOYGY,0.)/(NOYGY-1))
      AFYGY        = PGYGY*(1./(AF1GY+AF2GY*PGYGY)-1.)
      CVGY         =  SDYGY/PGYGY

      IF(DEB(6) .EQ. 1)THEN
      WRITE(90,7)YEAR,  TIME, NOYGY, INDGY, SYGY, SYSGY, PGYGY, SDYGY,
     *           AFYGY, CVGY, HRFGY, ARFGY, (GYGY(IGY), IGY=1, 21)
C     ST
    7 FORMAT(1X,'==GRYPRO= YR=',I2, ' T=', I3, ' NOY=', I3, ' IND=', I3,
     *       ' SYGY SYSGY PGYGY SDYGY AFYGY CVGY',
     *       1X, F7.1, 1X, F12.1, 3F8.1, F7.4,
     *     /,1X,'HRFGY= ', 16F7.1,
     *     /,1X,'ARFGY= ', 16F7.1,
     *     /,1X,'GYGY= ',  21F6.0)
C     FN
      ENDIF

      RETURN
      END
      SUBROUTINE LAMOVE

C     LAMB MOVEMENT ALGORITHM
C     ***************************************************************
C     *                                                             *
C     * ALTERS THE FOLLOWING VARIABLES IN COMMON:     WEAN    GRAZL  *
C     *                                               CULL    PPAST  *
C     *                                               SELL    LRMIX  *
C     *                                               WAGRL   LAMLOC *
C     *                                               LRSI    CLLWG  *
C     *                                                             *
C     ***************************************************************
C     ST
      IMPLICIT REAL(A-Z)

      CHARACTER*8         CHAST, CHAR1*1

      INTEGER
     *                   CULL,            DAY,    DEB, WEANED, EWELOC,
     *                         GRAZL,  GRODY,    ILS,   LAGE, LAMLOC,
     *                    LMM, MNGDEL,   OKLS,OLDLMLS, OPTVLS,   YEAR,
     *                         SEADY,   SELL,   TIME, TOPTLS,    WEAN
```

```
      DIMENSION
     *                                  WSDS(3),     WGCMPL(5),     ARF(16),
     *                                  DEB(13),     DLBIO(3),    DNLBIO(3),
     *                                   DVS(3),     GRODY(3),    COSVLS(8),
     *                                 LMM(8,8),     AREA(3),     OPTVLS(8),
     *                                 SUPVLS(8),     WLVS(3),     WNLVS(3),
     *                                  VRES(3)

C     (((
C     =============   LAMO
      COMMON / COM01 /      CPUG   , LRMIX  , LRSIX  , PPAST
      COMMON / COM06 /      LPSUBF
      COMMON / COM17 /
     *              CLLWG  , CULL   , EBCLIM , LAMLOC , LMM    , SELL   ,
     *              SLVWT  , WAGRL  , WEAN   , WEANED
      COMMON / COM18 /      GRAZL
      COMMON / COM19 /      LAGE
      COMMON / COM23 /      MNGDEL , WGWF
      COMMON / COM24 /      ARF    , COSTH  , PGRN
      COMMON / COM30 /      SEADY
      COMMON / COM31 /      DAY
      COMMON / COM40 /      NLAMS  , WGCMPL
      COMMON / COM41 /      EBC
      COMMON / COM42 /      LRMI   , LRSI
      COMMON / COM43 /      LRPIX  , WLAM
      COMMON / COM49 /      DLBIO  , DNLBIO , VRES   , WSDS
      COMMON / COM50 /      GRODY  , WGTML
      COMMON / COM51 /      AREA
      COMMON / COM52 /      WAAG
      COMMON / COM53 /      EWELOC
      COMMON / COM54 /      DEB
      COMMON / COM56 /      WLVS   , WNLVS
      COMMON / COM57 /      DVS
      COMMON / COM58 /      TIME   , YEAR
      SAVE /COM01/,/COM06/,/COM17/,/COM18/,/COM19/,/COM23/,/COM24/,
     *     /COM30/,/COM31/,/COM40/,/COM41/,/COM42/,/COM43/,/COM49/,
     *     /COM50/,/COM51/,/COM52/,/COM53/,/COM54/,/COM56/,/COM57/,
     *     /COM58/
C     )))
C     FN
      DATA OLDLMLS/8/

      WEAN=CULL=SELL=TOPTLS=OKLS=0
      POSLS=NEGLS=LWIXLS=LPSWXLS=WAGRL=LRSI=0.

      GWVLLS=0.
      IF(WGCMPL(1) .GT. 0.)GWVLLS=GWVLLS+WLVS(2)
      IF(WGCMPL(2) .GT. 0.)GWVLLS=GWVLLS+WNLVS(2)
      IF(WGCMPL(3) .GT. 0.)GWVLLS=GWVLLS+WSDS(2)
      IF(WGCMPL(4) .GT. 0.)GWVLLS=GWVLLS+DLBIO(2)
      IF(WGCMPL(5) .GT. 0.)GWVLLS=GWVLLS+DNLBIO(2)
      GWVLLS=AMAX1(1.,GWVLLS-VRES(2))

      DO 1 ILS     = 1,8
    1 OPTVLS(ILS)  = LMM(LAMLOC,ILS)

      IF(AREA(1) .EQ. 0.)OPTVLS(3)=OPTVLS(4)=0
      IF(WAAG    .EQ. 0.)OPTVLS(5)=OPTVLS(6)=0
      IF(AREA(3) .EQ. 0.)OPTVLS(7)=0

      IF(WEANED .EQ. 0)THEN
           IF(EBC .LT. EBCLIM)THEN
                OPTVLS(1) = OPTVLS(3) = OPTVLS(5) = 0
           ELSE
                IF(EWELOC .EQ. 1 .OR. EWELOC .EQ. 4)THEN
                     OPTVLS(1) = OPTVLS(5) = 0
                ELSEIF(EWELOC .NE. 6)THEN
                     OPTVLS(1) = OPTVLS(3) = 0
                ELSEIF(EWELOC .EQ. 6)THEN
```

```
                  OPTVL5(3) = OPTVL5(5) = 0
               ELSE
                  PRINT *,' LAMOVE ERROR 1'
               ENDIF
            ENDIF
            IF(LAGE .LT. 21)OPTVL5(2) = OPTVL5(4) = OPTVL5(6) =
     *                                OPTVL5(7) = OPTVL5(8) = 0
         ENDIF
         DO 2 IL5      = 1,8
         COSVL5(IL5)   = 20.E7
         SUPVL5(IL5)   = 0.
         CHAST(IL5:IL5)='.'
       2 IF(OPTVL5(IL5) .EQ. 1)TOPTL5=TOPTL5+1
         IF(TOPTL5 .EQ. 0)PRINT *,' LAMOVE ERROR 2'
         DO 3 IL5      = 1,8
            IF(OPTVL5(IL5) .EQ. 1)THEN
               CALL INTAK('LAMB'//CHAR(IL5+16))
               GRAZL  = 0
               IF(2 .LT. IL5 .AND. IL5 .LT. 8)GRAZL = 1
               LRMIX = PPAST = 0.
               IF(IL5 .EQ. 1 .OR. IL5 .EQ. 3 .OR. IL5 .EQ. 5)LRMIX=LRMI

               IF((IL5 .EQ. 5 .OR. IL5 .EQ. 6) .AND. GRODY(2) .GT. WGTML
     *                                .AND. DVS(2) .LT. 1.)THEN
                  CALL GRYPRO(PGYL5,SDYL5,AFYL5,SEADY,ARF)
                  PPAST  = (1.+WGWF)*AMAX1(0.,(PGYL5*PGRN-COSTH)/GWVLL5)
                  LWIXL5  =  LRPIX
                  LPSWXL5 = LPSUBF
               ENDIF

               CALL SUPOPT(CHAR1,IL5)
C                 IF(CPUG .LT. PRLAM)THEN
                  COSVL5(IL5) = CPUG
                  SUPVL5(IL5) = LRGIX
                  CHAST(IL5:IL5)=CHAR1
                  POSL5 = POSL5+INSW(CPUG,0.,1.)
                  NEGL5 = NEGL5+INSW(CPUG,1.,0.)
                  OKL5  = 1
C                 ENDIF
            ENDIF
       3 CONTINUE
         IF(OKL5 .EQ. 0 .OR. WLAM .GE. SLVWT)THEN
            IF(WEANED .EQ. 0)THEN
               WEAN = 1
               CALL DIARYS(LAMLOC,NLAMS,TIME,DAY)
               CULL = 1
            ENDIF
            SELL = 1
         ELSE
            LOL5 = 111111.
            IF(POSL5*NEGL5 .GT. 0.)THEN
               DO 6 IL5 = 1,8
       6       IF(COSVL5(IL5) .LT. 0.)COSVL5(IL5) = LOL5
            ENDIF
            DO 4 IL5=1,8
               IF(ABS(COSVL5(IL5)) .LT. LOL5)THEN
                  LOL5   = COSVL5(IL5)
                  LAMLOC = IL5
                  LRSI   = SUPVL5(IL5)
                  CLLWG  = COSVL5(IL5)
               ENDIF
       4    CONTINUE

            IF((LAMLOC .EQ. 5 .OR. LAMLOC .EQ. 6) .AND.
     *         GRODY(2) .GT. WGTML .AND. DVS(2) .LT. 1.)THEN
               LWIXL5 = AMAX1(0.,LWIXL5-LRSI*LPSWXL5)
               WAGRL  = AMIN1(WAAG,LWIXL5*NLAMS*MNGDEL*(1.+WGWF)/GWVLL5)
            ENDIF

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```
      ELSEIF(MXSIL4 - LRSIX .LT. 0.001)THEN
         CHAR1='A'
      ELSEIF(MXSIL4 .GT. LRSIX)THEN
         CHAR1='I'
      ELSE
         PRINT *,' *-*-* SUPLET *-* ',TIME,MXSIL4,LRSIX
      ENDIF

      IF(DEB(8) .EQ. 1)THEN
      WRITE(90,3)YEAR,    TIME,    WLAM,    GRAZL,  LAGE,    LRPIX,  LRPIL4,
     *           LRMIX,   LRSIX,   PTIME,   PLWGL4, NIL4,    PFDML4, CPUG,
     *           PMILK,   PPAST,   ZL4,     LEVGL4, MXSIL4, LMEPA,   LQMP,
     *           DMIL4,   MEIL4,   LFMDL4, DSUPL4, LPSUBF, QML4,     IL4,
     *           LOCL4,   CHAR1
C     ST
    3 FORMAT(1X,'==SUPOPT= YR=',      I2,    ' T=',    I3,    ' W=',    F6.3,
     *       ' GR=',  I1,    ' AGE=', I3,    ' RPIX=',F5.3, ' RPI=', F5.3,
     *       ' RMIX=',F5.3, ' RSIX=',F5.3, ' PT=',   1PG12.4,          0P,
     *       ' PLWG=',F7.5, ' NI=',   I3,    /,                ' PDM=', F5.3,
     *       ' CPUG=',F9.6, ' PMILK=',F6.3,' PPAST=',F9.6,' Z=',    F6.2,
     *       ' LEVG=',F6.2, ' MXSI=',F6.3, ' MEPA=',F6.2, ' QMP=', F6.3,
     *       ' DMI=', F6.3, /,              ' MEI=', F7.3, ' FMD=', F6.3,
     *       ' DSUP=',F9.6, ' PSUB=',F6.3, ' QM=',   F7.4, ' I=',    F6.3,
     *       ' LOC=', I1,    ' CHAR=',A)
C     FN
      ELSEIF(DEB(8) .EQ. 2)THEN
      WRITE(90,4)YEAR,    TIME,    WLAM,    GRAZL,   LAGE,   LRPIX,  LRPIL4,
     *           LRMIX,   LRSIX,   PTIME,   PLWGL4,  NIL4,   PFDML4, CPUG
C     ST
    4 FORMAT(1X,'==SUPOPT= YR=',      I2,    ' T=',    I3,    ' W=',    F5.2,
     *       ' GR=',  I1,    ' AGE=', I3,    ' RPIX=',F4.2, ' RPI=', F4.2,
     *       ' RMIX=',F4.2, ' RSIX=',F4.2, ' PT=',   F5.2, ' PLWG=',F5.3,
     *       ' NI=',  I3,    ' PDM=', F5.3, ' CPUG=',F6.3)
C     FN
      ELSE
      ENDIF
      RETURN
      END
      SUBROUTINE LMPERF(GRAZL1)

C     LAMB PERFORMANCE PREDICTION
C     *****************************************************************
C     *                                                               *
C     * ALTERS THE FOLLOWING VARIABLES IN COMMON:          LLWG       *
C     *                                                               *
C     *****************************************************************
C     ST
      IMPLICIT REAL(A-Z)

      INTEGER                  LAGE,     DEB,    TIME,    GRAZL1,    YEAR

      DIMENSION                                                  DEB(13)

C     (((
C     =============   LMPE
      COMMON / COM05 /      LQMP
      COMMON / COM13 /      LLWG
      COMMON / COM15 /
     *             LEP1   , LEP2   , LEP3   , LEP4   , MDMC   , PKF3   ,
     *             PKM3   , QMM
      COMMON / COM16 /
     *             AAP    , FGF1   , FGF2   , GF     , PKF1   , PKF2   ,
     *             PKM1   , PKM2   , WE
      COMMON / COM19 /      LAGE
      COMMON / COM36 /      LRPI
      COMMON / COM38 /      LMEPA  , MEWM
      COMMON / COM39 /      MESU   , QMS
      COMMON / COM42 /      LRMI   , LRSI
      COMMON / COM43 /      LRPIX  , WLAM
```

```
      COMMON / COM54 /      DEB
      COMMON / COM58 /      TIME    , YEAR
      SAVE /COM05/,/COM13/,/COM15/,/COM16/,/COM19/,/COM36/,/COM38/,
     *     /COM39/,/COM42/,/COM43/,/COM54/,/COM58/
C     )))
C     FN

      KFL1=IL1=0.

      MEIL1    = LRPI*LMEPA+LRSI*MESU+LRMI*MEWM
      DMIL1    = LRPI+LRSI+LRMI*MDMC
      LFMDL1   = LRMI*MDMC/(DMIL1+NOT(DMIL1))
      ZL1      = (0.245-0.02164*ALOG(LAGE/365.))*WLAM**WE+AAP*WLAM
      IF(GRAZL1 .EQ. 1)THEN
         PCIAL1 = LRPI/(LRPIX + NOT(LRPIX))
         PCGFL1 = FGF1 + FGF2*PCIAL1
         ZL1    = ZL1 * (1. + PCGFL1*GF)
      ENDIF
      QML1     = (LRPI*LMEPA*LQMP+LRSI*MESU*QMS+LRMI*MEWM*QMM)
     *            /(MEIL1+NOT(MEIL1))
      KML1     = (PKM1*QML1+PKM2)*(1.-LFMDL1)+(PKM3*LFMDL1)
      MEML1    = ZL1/KML1
      LEVGL1   = (LEP1+LEP2*WLAM)*(1.-LFMDL1)+(LEP3+LEP4*WLAM)*LFMDL1
      IF(MEIL1 .GT. MEML1)THEN
         KFL1     = (PKF1*QML1+PKF2)*(1.-LFMDL1)+(PKF3*LFMDL1)
         IL1      = MEIL1/ZL1
         LLWG     = ARC1(KML1,KFL1,IL1,ZL1,LEVGL1)
      ELSE
         LLWG     = -(MEML1-MEIL1)*KML1/LEVGL1
      ENDIF

      IF(DEB(9) .EQ. 1)THEN
      WRITE(90,1)YEAR, TIME, LAGE, WLAM, LRPI, LMEPA, LRSI, LRMI, LQMP,
     *           MEIL1, LFMDL1, ZL1, QML1, KML1, MEML1, LEVGL1, KFL1,
     *           LLWG
C     ST
    1 FORMAT(5X,'CALL TO SUBROUTINE LMPERF',/,
     *' YEAR TIME LAGE WLAM LRPI LMEPA LRSI LRMI LQMP MEI LFMD Z QM//KM
     *MEM LEVG KF LLWG',
     */,I3,I4,I4,1X, 10(1PG12.4), /, 10(1PG12.4) )
C     FN
      ELSEIF(DEB(9) .EQ. 2)THEN
      WRITE(90,2)YEAR, TIME, WLAM, GRAZL1, LAGE, LRPIX, LRPI,
     *           LRMI, LRSI, LMEPA, MEIL1, ZL1, MEML1, LLWG
C     ST
    2 FORMAT(1X,'==LMPERF= YR=',I2,      ' T=',I3,       ' W=',F5.2,
     *      ' GR=',I1,      ' AGE=',I3,     ' RPIX=',F4.2, ' RPI=',F4.2,
     *      ' RMI=',F4.2, ' RSI=',F4.2, ' MEPA=',F5.2, ' MEI=',F5.2,
     *      ' Z=',F5.2,     ' MEM=',F5.2, ' LWG=',F5.3)
C     FN
      ELSE
      ENDIF
      RETURN
      END
      SUBROUTINE EWPERF(GRAZL2)

C     EWE PERFORMANCE PREDICTION
C     ****************************************************************
C     *                                                              *
C     * ALTERS THE FOLLOWING VARIABLES IN COMMON:          DMF1      *
C     *                                                    EMY       *
C     *                                                    ELWG      *
C     *                                                              *
C     ****************************************************************
C     ST
      IMPLICIT REAL(A-Z)

      INTEGER     NDPREG,    TIME,   DEB,    YEAR,   GRAZL2,     NDLACT

```

```
      DIMENSION                                                   DEB(13)

C     (((
C     =============   EWPE
      COMMON / COM02 /      EQMP
      COMMON / COM03 /      ERPIX
      COMMON / COM11 /
     *          DMF1   , DMP1   , DMP2   , ELWG   , EUBL   , MCRMN  ,
     *          MCRMX  , MRP1   , MRP2   , MRP3   , MRP4   , QMHY   ,
     *          QMST
      COMMON / COM12 /
     *          ALFEW  , EEP1   , EEP2   , EEP3   , ELP1   , ELP2   ,
     *          ELP3   , EMYMF  , EWMTMF , KP     , LBW    , MF1    ,
     *          MF2    , MF3    , MFC    , NDPREG , NEWL   , NLB    ,
     *          PKF4   , RP1    , RP2    , RP3    , RP4    , RP5    ,
     *          SPD    , WEWE
      COMMON / COM16 /
     *          AAP    , FGF1   , FGF2   , GF     , PKF1   , PKF2   ,
     *          PKM1   , PKM2   , WE
      COMMON / COM34 /
     *          EMEPA  , EMY    , ERHI   , ERPLI  , ERSTI  , MEHY   ,
     *          MEPL   , MEST   , QMPL
      COMMON / COM35 /      NDLACT , PKA1   , PKA2
      COMMON / COM39 /      MESU   , QMS
      COMMON / COM41 /      EBC
      COMMON / COM46 /      ERSI
      COMMON / COM47 /      ERPI
      COMMON / COM54 /      DEB
      COMMON / COM58 /      TIME   , YEAR
      SAVE /COM02/,/COM03/,/COM11/,/COM12/,/COM16/,/COM34/,/COM35/,
     *     /COM39/,/COM41/,/COM46/,/COM47/,/COM54/,/COM58/
C     )))
C     FN
      EVPL2=NEPL2=MEPL2=KLL2=YPL2=NEML2=MELL2=KFL2=IL2=MRFSLL2=
     *MRFBCL2=MRFL2=MNEL2=MF1XL2=DMF1=EMY=PCIAL2=PCGFL2=0.

      ZL2      = ALFEW*WEWE**WE+AAP*WEWE
      ZL2      = ZL2*EWMTMF
      IF(GRAZL2 .EQ. 1)THEN
         PCIAL2 = ERPI/(ERPIX + NOT(ERPIX))
         PCGFL2 = FGF1 + FGF2*PCIAL2
         ZL2    = ZL2 * (1. + PCGFL2*GF)
      ENDIF
      MEIL2    = ERPI*EMEPA+ERSI*MESU+ERSTI*MEST+ERHI*MEHY+ERPLI*MEPL
      QML2     = (ERPI*EMEPA*EQMP + ERSI *MESU*QMS  + ERSTI*MEST*QMST +
     *            ERHI*MEHY *QMHY + ERPLI*MEPL*QMPL)/(MEIL2+NOT(MEIL2))
      KML2     = PKM1*QML2+PKM2
      MEML2    = ZL2/KML2
      IF(NDPREG .GE. SPD)THEN
         EVPL2= 10.**(RP1-RP2*EXP(-RP3*NDPREG))*
     *          (LBW/RP5)*(NLB/NEWL)
         NEPL2= EVPL2*RP4*EXP(-RP3*NDPREG)
         MEPL2= NEPL2/KP
      ENDIF
      EEVGL2   = AMIN1(EEP3,EEP1+EEP2*WEWE)
      IF(NDLACT .GT. 0.)THEN
         KLL2     = PKA1*QML2+PKA2
         MYXL2    = NDLACT**MF2*EXP(-MF3*NDLACT)
         YPL2     = MF1*MYXL2*EMYMF/1000.
         NEML2    = ELP1*MFC+ELP2*NDLACT+ELP3
         MELL2    = YPL2*NEML2/KLL2
         IF(MEIL2 .GT. MEML2+MELL2)THEN
            IL2      = (MEIL2-MELL2)/ZL2
            KFL2     = PKF4*KLL2
            ELWG     = ARC1(KML2,KFL2,IL2,ZL2,EEVGL2)
            EMY      = YPL2
            MYTHL2   = KLL2*(MEIL2-MEML2)/NEML2
            MF1XL2   = 1000.*MYTHL2/(MYXL2*EMYMF)
            DMF1     = (MF1XL2-MF1)*LIMIT(MCRMN,MCRMX,(MCRMX+((MCRMX
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```
     *                -MCRMN)/DMP1)*DMP2)-((MCRMX-MCRMN)/DMP1)*NDLACT)
          ELSE
             MRFSLL2 = LIMIT(0.,1.,1.-MRP1*(NDLACT-MRP2))
             MRFBCL2 = LIMIT(0.,1.,EBC/MRP3-MRP4)
             MRFL2   = AMIN1(MRFSLL2,MRFBCL2)
             IF(MEIL2 .GT. MEML2)THEN
                MNEL2   = AMIN1((MEML2+MELL2-MEIL2)*KLL2,ZL2*MRFL2)
                EMY     = ((MEIL2-MEML2)*KLL2+(MNEL2*EUBL))/NEML2
                ELWG    = -MNEL2/EEVGL2
             ELSE
                MNEL2   = AMIN1(AMAX1(0.,(ZL2*MRFL2)-((MEML2-MEIL2)
     *                    *KML2)),YPL2*NEML2/EUBL)
                EMY     = MNEL2*EUBL/NEML2
                ELWG    = -(MNEL2+((MEML2-MEIL2)*KML2))/EEVGL2
             ENDIF
             MF1XL2  = 1000.*EMY/(MYXL2*EMYMF)
             DMF1    = (MF1XL2-MF1)*LIMIT(MCRMN,MCRMX,(MCRMN-((MCRMX
     *                -MCRMN)/DMP1)*DMP2)+((MCRMX-MCRMN)/DMP1)*NDLACT)
          ENDIF
       ELSE
          IF(MEIL2 .GT. MEML2+MEPL2)THEN
             IL2     = (MEIL2-MEPL2)/ZL2
             KFL2    = PKF1*QML2+PKF2
             ELWG    = ARC1(KML2,KFL2,IL2,ZL2,EEVGL2)
          ELSE
             ELWG    = -(MEML2+MEPL2-MEIL2)*KML2/EEVGL2
          ENDIF
       ENDIF

       IF(DEB(10) .EQ. 1)THEN
       WRITE(90,1)YEAR, TIME, GRAZL2, NDPREG, NDLACT, ZL2, MEIL2, QML2,
     *            KML2, MEML2, EVPL2, NEPL2, MEPL2, EEVGL2, KLL2, YPL2,
     *            NEML2, MELL2, MRFSLL2, MRFBCL2, MNEL2, EMY, MF1XL2,
     *            DMF1, KFL2, ELWG
C      ST
     1 FORMAT(5X,'CALL TO SUBROUTINE EWPERF',/,
     *        ' YEAR TIME GRAZ NDPREG NDLACT Z MEI QM KM MEM EVP NEP MEP
     * EEVG KL YP NEM MEL//MRFSL MRFBC MNE EMY MF1X DMF1 KF ELWG',
     *        /,I3,I4,I2,2I4,13F9.4,/,14F9.4)
C      FN
       ELSEIF(DEB(10) .EQ. 2)THEN
       WRITE(90,2)YEAR, TIME, WEWE, GRAZL2, QML2, NDPREG, NDLACT,
     *            ZL2, MEML2, MEIL2, EMY, MF1, DMF1, ELWG
C      ST
     2 FORMAT(1X,'==EWPERF= YR=',I2,     ' T=',I3,     ' WEWE=',F4.1,
     *        ' GR=',I1,   ' QM=',F4.3,  ' NP=',I3,    ' NL=',I3,
     *        ' Z=',F5.2,  ' MEM=',F5.2, ' MEI=',F5.2,' EMY=',F4.2,
     *        ' MF1=',F5.1,' DMF1=',F5.1,' LWG=',F5.3)
C      FN
       ELSE
       ENDIF
       RETURN
       END
       SUBROUTINE EWREQM(GRAZL3,QML3)

C      EWE REQUIREMENTS
C      ***************************************************************
C      *                                                             *
C      * ALTERS THE FOLLOWING VARIABLES IN COMMON:          MER      *
C      *                                                             *
C      ***************************************************************
C      ST
       IMPLICIT REAL(A-Z)

       INTEGER EWELOC,NDPREG,   TIME,   DEB,    GRAZL3,   NDLACT,   YEAR

       DIMENSION                                                DEB(13)

C      (((
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```
C      ============   EWRE
       COMMON / COM03 /       ERPIX
       COMMON / COM10 /       BCP2    , GAP     , LFP
       COMMON / COM12 /
      *             ALFEW   , EEP1    , EEP2    , EEP3    , ELP1    , ELP2    ,
      *             ELP3    , EMYMF   , EWMTMF  , KP      , LBW     , MF1     ,
      *             MF2     , MF3     , MFC     , NDPREG  , NEWL    , NLB     ,
      *             PKF4    , RP1     , RP2     , RP3     , RP4     , RP5     ,
      *             SPD     , WEWE
       COMMON / COM16 /
      *             AAP     , FGF1    , FGF2    , GF      , PKF1    , PKF2    ,
      *             PKM1    , PKM2    , WE
       COMMON / COM33 /       MER
       COMMON / COM35 /       NDLACT  , PKA1    , PKA2
       COMMON / COM41 /       EBC
       COMMON / COM47 /       ERPI
       COMMON / COM53 /       EWELOC
       COMMON / COM54 /       DEB
       COMMON / COM58 /       TIME    , YEAR
       SAVE /COM03/,/COM10/,/COM12/,/COM16/,/COM33/,/COM35/,/COM41/,
      *     /COM47/,/COM53/,/COM54/,/COM58/
C      )))
C      FN
       KLL3=YPL3=NEML3=MELL3=MEGL3=LL3=LFCFL3=EVPL3=NEPL3=MEPL3=RL3=KL3=
      *IL3=BL3=PCIAL3=PCGFL3=AELWL3=0.

       ZL3      = ALFEW*WEWE**WE+AAP*WEWE
       ZL3      = ZL3*EWMTMF
       IF(GRAZL3 .EQ. 1)THEN
          PCIAL3 = ERPI/(ERPIX + NOT(ERPIX))
          PCGFL3 = FGF1 + FGF2*PCIAL3
          ZL3    = ZL3 * (1. + PCGFL3*GF)
       ENDIF
       KML3     = PKM1*QML3+PKM2
       MEML3    = ZL3/KML3
       EEVGL3   = AMIN1(EEP3,EEP1+EEP2*WEWE)
       IF(EWELOC .NE. 6)
      *AELWL3   = INSW(BCP2-EBC, 0., GAP)*LIMIT(0.,1.,10.*QML3-4.)
       IF(NDLACT .GT. 0)THEN
          KLL3     = PKA1*QML3+PKA2
          YPL3     = MF1*NDLACT**MF2*EXP(-MF3*NDLACT)/1000.*EMYMF
          NEML3    = ELP1*MFC+ELP2*NDLACT+ELP3
          MELL3    = YPL3*NEML3/KLL3
          KFL3     = PKF4*KLL3
          MEGL3    = AELWL3*EEVGL3/KFL3
          LL3      = 1.+(MELL3+MEGL3)/MEML3
          LFCFL3   = 1.+LFP*(LL3-1.)
          MER      = LFCFL3*(MELL3+MEGL3+MEML3)
C         COMPUTE   MER WITHOUT ALLOWANCE FOR GAIN
          XLL3     = 1.+MELL3/MEML3
          XLFCFL3  = 1.+LFP*(XLL3-1.)
          XMERL3   = XLFCFL3*(MELL3+MEML3)
       ELSE
          IF(NDPREG .GE. SPD)THEN
             EVPL3= 10.**(RP1-RP2*EXP(-RP3*NDPREG))*(LBW/RP5)
      *             *(NLB/NEWL)
             NEPL3= EVPL3*RP4*EXP(-RP3*NDPREG)
             MEPL3= NEPL3/KP
          ENDIF
          KFL3     = PKF1*QML3+PKF2
          BL3      = KML3/(KML3-KFL3)
          KL3      = KML3*ALOG(KML3/KFL3)
          RL3      = AELWL3*EEVGL3/ZL3
          IF(RL3 .GT. BL3-1.)THEN
             PRINT *,YEAR,TIME,RL3,BL3
             RL3=BL3-1.1
             PRINT *,'RL3=',RL3
          ENDIF
          IL3      = ALOG(BL3/(BL3-RL3-1.))/KL3
```

```
         MER      = ZL3*IL3+MEPL3
C        COMPUTE   MER WITHOUT ALLOWANCE FOR GAIN
         XIL3     = ALOG(BL3/(BL3-1.))/KL3
         XMERL3   = ZL3*XIL3+MEPL3
      ENDIF

      IF(DEB(11) .EQ. 1)THEN
      WRITE(90,1)YEAR, TIME, GRAZL3, NDPREG, NDLACT, QML3, ZL3, KML3,
     *            MEML3, EEVGL3, AELWL3, KLL3, YPL3, NEML3, MELL3,
     *            MEGL3, LL3, LFCFL3, EVPL3, NEPL3, MEPL3, RL3, KFL3,
     *            BL3, KL3, IL3, MER,XMERL3
C     ST
    1 FORMAT(5X,'CALL TO SUBROUTINE EWREQM',/,
     *' YEAR TIME GRAZ NDPREG NDLACT QM Z KM MEM EEVG AELW KL YP NEM MEL
     * MEG L//LFCF EVP NEP MEP R KF B K I MER XMER',
     * /I3,I4,I2,2I4,12F9.4,/,14F9.4)
C     FN
      ELSEIF(DEB(11) .EQ. 2)THEN
      WRITE(90,2)YEAR,TIME,WEWE,GRAZL3,QML3,NDPREG,NDLACT,ZL3,MEML3,
     *            AELWL3,MELL3,MEPL3,IL3,MER,XMERL3
C     ST
    2 FORMAT(1X,'==EWREQM= YR=',I2,    ' T=',I3,     ' WEWE=',F4.1,
     *        ' GR=',I1,   ' QM=',F4.3, ' NP=',I3,     ' NL=',I3,
     *        ' Z=',F4.2,  ' MEM=',F4.1,' AELW=',F4.3,' MEL=',F4.1,
     *        ' MEP=',F4.1,' I=',F4.2,  ' MER=',F5.2, ' XM=',F5.2)
C     FN
      ELSE
      ENDIF
      RETURN
      END
      SUBROUTINE HAYCUT
C     ***************************************************************
C     *                                                             *
C     * ALTERS THE FOLLOWING VARIABLES IN COMMON:         HAYLD     *
C     *                                                  HVCH      *
C     *                                                  WACH      *
C     *                                                             *
C     ***************************************************************
C     ST
      IMPLICIT REAL(A-Z)

      INTEGER HYOP, SEADY, TIME, YEAR, DEB

      DIMENSION ARF(16), TADRW(3), CTRDEF(3), DEB(13), DVS(3)

C     (((
C     ============   HAYC
      COMMON / COM09 /
     *            FORCPH , HAYLD  , HVCH   , HYCTR  , HYDVS  , HYHC1  ,
     *            HYHC2  , HYLEFT , HYOP   , HYPF1  , HYPF2  , HYTOPP ,
     *            WACH
      COMMON / COM22 /      TADRW
      COMMON / COM24 /      ARF    , COSTH  , PGRN
      COMMON / COM28 /      CTRDEF
      COMMON / COM30 /      SEADY
      COMMON / COM52 /      WAAG
      COMMON / COM54 /      DEB
      COMMON / COM57 /      DVS
      COMMON / COM58 /      TIME   , YEAR
      SAVE /COM09/,/COM22/,/COM24/,/COM28/,/COM30/,/COM52/,/COM54/,
     *     /COM57/,/COM58/
C     )))
C     FN
      WACH      = 0.
      PRCHY     = LIMIT(HYTOPP/HYPF1,HYTOPP,HYPF2*HYTOPP*(1.-DVS(2)))
      IF          (FORCPH .GE. 0.)PRCHY = FORCPH
      HAYLD     = AMAX1(0., TADRW(2)-HYLEFT)
      HVCH      = HYHC1 + HYHC2 * HAYLD
      PRFHY     = PRCHY * HAYLD - HVCH
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      CALL        GRYPRO(PGYHY,SDYHY,AFYHY,SEADY,ARF)
      GPRFHY     = PGYHY * PGRN  - COSTH
C     BEYGHY     = COSTH/PGRN
C     GREQHY     = (PRFHY+COSTH)/PGRN
C     PRB1HY     = CUMPR(GREQHY,PGYHY,SDYHY)
C     PRB2HY     = CUMPR(BEYGHY,PGYHY,SDYHY)

      IF(HYOP .LT. O .OR. PRFHY .LE. O.    )GOTO 1
      IF(HYOP .GT. O .OR. PRFHY .GT. GPRFHY)WACH=WAAG
C     IF TOMORROW'S HAY IS LIKELY TO BE BETTER  -  WAIT
      IF(CTRDEF(2) .LT. HYCTR .AND. DVS(2) .LT. HYDVS)WACH=O.

    1 IF(DEB(12) .GT. O)THEN
             WRITE(90,2)YEAR,TIME,TADRW(2),DVS(2),WAAG,CTRDEF(2),HYOP,
     *                  PRCHY,HVCH,PRFHY,PGYHY,GPRFHY,WACH
C     ST
    2        FORMAT(1X,'==HAYCT= YR=', I2,   ' T=',    I3,
     *       ' TAD=',  F6.0, ' DVS=',  F4.2, ' WAA=', F4.2,
     *       ' DEF=',  F4.2, ' OP=',   I2,   ' PRC=', F4.2,
     *       ' HVC=',  F4.0, ' PRF=',  F5.0, ' PGY=', F5.0,
     *       ' GPRF=', F5.0, ' WCH=',  F4.2)
C     FN
      ENDIF
      RETURN
      END
      SUBROUTINE STRABAL
C     ***************************************************************
C     *                                                             *
C     * ALTERS THE FOLLOWING VARIABLES IN COMMON:          STBL     *
C     *                                                             *
C     ***************************************************************
C     ST
      IMPLICIT REAL(A-Z)

      INTEGER DAY, PLOWD, SECTSB, STROP, TIME, YEAR, DEB, RATING,
     *        ISB, JSB, FRACSB

      DIMENSION AREA(3), DEB(13), RATING(6), TADRW(3)

C     (((
C     ============   STRA
      COMMON / COM08 /
     *           APCS   , BALEC  , PLOWD  , PSTRW  , STBL   , STLEFT ,
     *           STROP
      COMMON / COM21 /      DCLV   , DCNLV  , RATING
      COMMON / COM22 /      TADRW
      COMMON / COM31 /      DAY
      COMMON / COM45 /      NEWES  , VSATD
      COMMON / COM51 /      AREA
      COMMON / COM52 /      WAAG
      COMMON / COM54 /      DEB
      COMMON / COM58 /      TIME   , YEAR
      SAVE /COM08/,/COM21/,/COM22/,/COM31/,/COM45/,/COM51/,/COM52/,
     *     /COM54/,/COM58/
C     )))
C     FN
      STMNSB=DCRSB=SECTSB=DVSB=ISB=JSB=
     *FRACSB=STBL=VSURPSB=STMXSB=O.
      STMNSB = STLEFT
      IF(STROP .LT. O .OR. TADRW(2) .LE. STMNSB
     *                .OR. BALEC    .GE. PSTRW  )GOTO 3
      STMXSB = (TADRW(2)-STLEFT)*WAAG
      DCRSB  = (DCLV+DCNLV)*0.5
      IF(STROP .GT. O .OR. NEWES .EQ. O.)THEN
                      SECTSB  = 1
                      STBL    = STMXSB
      ELSEIF(RATING(6) .GT. RATING(4) .AND.
     *       RATING(6) .GT. RATING(3) .AND. AREA(1) .GT. O.)THEN
                      SECTSB  = 2
```

```
C                      AFTERMATH AND DRY PASTURE GRAZED
                       D1PSB    = APCS*NEWES/(AREA(1)*DCRSB)
                       DGPSB    = ALOG((VSATD + D1PSB)
     *                            /(TADRW(1)+D1PSB))/(-DCRSB)
                       JSB      = AMAX1(0.,PLOWD-DAY-DGPSB)
                       D1WSB    = APCS*NEWES/(WAAG*DCRSB)
                       DVSB     = (VSATD + D1WSB)
     *                            /EXP(-DCRSB*JSB) - D1WSB
                       VSURPSB = AMAX1(0.,TADRW(2)-AMAX1(DVSB, STLEFT))
                       STBL     = VSURPSB*WAAG
      ELSEIF(RATING(4) .GT. RATING(6) .AND.
     *       RATING(6) .GT. RATING(3))THEN
                       SECTSB   = 3
C                      AFTERMATH ONLY GRAZED
                       D1WSB    = APCS*NEWES/(WAAG*DCRSB)
                       DVSB     = (VSATD + D1WSB)
     *                            /EXP(-DCRSB*(PLOWD-DAY))-D1WSB
                       VSURPSB = AMAX1(0.,TADRW(2)-AMAX1(DVSB, STLEFT))
                       STBL     = VSURPSB*WAAG
      ELSEIF(RATING(6) .GT. RATING(4) .AND.
     *       RATING(3) .GT. RATING(6) .AND. AREA(1) .GT. 0.)THEN
                       SECTSB   = 4
C                      DRY PASTURE ONLY GRAZED
                       STBL     = STMXSB
      ELSE
                       SECTSB   = 5
C                      NEITHER GRAZED
                       STBL     = STMXSB
      ENDIF
      FRACSB = 100. * STBL/STMXSB

    3 IF(DEB(13) .GT. 0)THEN
                  WRITE(90,4)YEAR, TIME, SECTSB, STMNSB, STMXSB, STROP,
     *            TADRW(1), TADRW(2), DGPSB, JSB, DVSB, FRACSB, STBL
C     ST
    4             FORMAT(1X,'==STRABAL= YR=',     I2,    ' T=',      I3,
     *            ' SECT=',     I1, ' STMN=',    F5.0, ' STMX=',   F5.0,
     *            ' STROP=',    I1, ' TADRW1=',  F5.0, ' TADRW2=', F5.0,
     *            ' DGP=',    F4.0, ' J=',         I3,    ' DV=',    F5.0,
     *            ' FRAC=',     I3, ' STBL=',    F5.0)
C     FN
      ENDIF
      RETURN
      END
      FUNCTION CUMPR(YCM,AVEYCM,SDCM)
      IMPLICIT REAL(A-Z)
C     CALCULATE CUMULATIVE PROBABILITY ON NORMAL DISTRIBUTION
C     CURVE UPTO A POINT YCM FOR MEAN OF AVEYCM AND SD OF SDCM.
      XCM=AMAX1((YCM-AVEYCM)/(SDCM+NOT(SDCM)), -5.)
      CUMPR  = 0.5*ERFC(-XCM/SQRT(2.))
      RETURN
      END
      FUNCTION ARC1(KMARC,KFARC,IARC,ZARC,EVGARC)
      IMPLICIT REAL(A-Z)
      BARC  = KMARC/(KMARC-KFARC)
      KARC  = KMARC*ALOG(KMARC/KFARC)
      RARC  = BARC*(1.-EXP(-KARC*IARC))-1.
      LWGARC= RARC*ZARC/EVGARC
      ARC1  = LWGARC
      RETURN
      END
      FUNCTION AFGEN(TAF,IVAF,NDAF,NMAF)
      REAL IVAF
      CHARACTER*(*) NMAF
      DIMENSION TAF(2,NDAF)
      COMMON / COM59 /      NCAFG
      SAVE COM59
      NCAFG=NCAFG+1
```

```
      EVAF=IVAF
      IF(EVAF .LT. TAF(1,1))THEN
            AFGEN=TAF(2,1)
            WRITE(*,1)NMAF,EVAF
 1          FORMAT(' ===AFGEN LOW IN ',A,'; X=',F20.10)
      ELSEIF(EVAF .GT. TAF(1,NDAF))THEN
            AFGEN=TAF(2,NDAF)
            WRITE(*,2)NMAF,EVAF
 2          FORMAT(' ===AFGEN HIGH IN ',A,'; X=',F20.10)
      ELSE
            NAF=1
10          IF(EVAF .GT. TAF(1,NAF))THEN
                  NAF    = NAF+1
                  GOTO 10
            ENDIF
            IF(NAF .EQ. 1)THEN
                  AFGEN  = TAF(2,1)
            ELSE
                  X1AF   = TAF(1,NAF-1)
                  X2AF   = TAF(2,NAF-1)
                  SLPAF  = (TAF(2,NAF)-X2AF)/(TAF(1,NAF)-X1AF)
                  AFGEN  = (EVAF-X1AF)*SLPAF+X2AF
            ENDIF
      ENDIF
      RETURN
      END
      FUNCTION DELAYT(NMDL,PRESDL)
C     FUNCTION TO RETURN AVE AIR TMPDL OF "NMDL" DAYS AGO
      DIMENSION TMPDL(20)
      DATA TMPDL/ 20*0./
      DELAYT=TMPDL(1)
      DO 1 NDL=1,NMDL-1
      TMPDL(NDL)=TMPDL(NDL+1)
 1    CONTINUE
      TMPDL(NMDL)=PRESDL
      RETURN
      END
      REAL FUNCTION LIMIT(P1LM,P2LM,XLM)
         IF(P1LM .GE. P2LM)PRINT *,'LIMIT CHEC'
         IF(XLM .LT. P1LM)THEN
            LIMIT=P1LM
         ELSEIF(XLM .GT. P2LM)THEN
            LIMIT=P2LM
         ELSE
            LIMIT=XLM
         ENDIF
      RETURN
      END
      REAL FUNCTION INSW(X1IN,X2IN,X3IN)
         IF(X1IN .LT. 0.)THEN
            INSW=X2IN
         ELSE
            INSW=X3IN
         ENDIF
      RETURN
      END
      FUNCTION FCNSW(X1FC,X2FC,X3FC,X4FC)
         IF(X1FC .LT. 0.)THEN
            FCNSW=X2FC
         ELSEIF(X1FC .EQ. 0.)THEN
            FCNSW=X3FC
         ELSE
            FCNSW=X4FC
         ENDIF
      RETURN
      END
      REAL FUNCTION NOT(XNT)
         IF(XNT .LE. 0.)THEN
            NOT=1.
```

```
         ELSE
            NOT=0.
         ENDIF
      RETURN
      END
      FUNCTION AND(X1AD,X2AD)
         IF(X1AD .GT. 0. .AND. X2AD .GT. 0.)THEN
            AND=1.
         ELSE
            AND=0.
         ENDIF
      RETURN
      END
      FUNCTION TWOVAR(MTV,IV1TV,IV2TV,MD1TV,NP2TV,NMTV)
      IMPLICIT REAL(A-Z)
      INTEGER ITV, LTV, MD1TV, NP2TV, NTV
      LOGICAL BADTV
      CHARACTER*(*) NMTV
      DIMENSION MTV(NP2TV,26)
      BADTV=.FALSE.
      EV1TV=IV1TV
      EV2TV=IV2TV
      IF(EV2TV .LT. MTV(1,1))THEN
          TWOVAR=MTV(1,3)
          BADTV=.TRUE.
      ELSEIF(EV2TV .GT. MTV(NP2TV,1))THEN
          TWOVAR=MTV(NP2TV,3)
          BADTV=.TRUE.
      ELSE
          NTV=1
   10     IF(EV2TV .GE. MTV(NTV,1))THEN
              NTV=NTV+1
              GOTO 10
          ENDIF
          DO 1 ITV=NTV-1,NTV
              LTV=2
   20         IF(EV1TV .GE. MTV(ITV,LTV) .AND. LTV .LT. 2*MD1TV)THEN
                  LTV=LTV+2
                  GOTO 20
              ENDIF
              IF(LTV .EQ. 2)THEN
                  TWOVAR=MTV(ITV,LTV)
                  BADTV=.TRUE.
              ELSEIF(LTV .EQ. 2*MD1TV .AND. MTV(ITV,LTV) .LT. EV1TV)THEN
                  TWOVAR=MTV(ITV,LTV)
                  BADTV=.TRUE.
              ELSE
                  MIL1TV=MTV(ITV,LTV-1)
                  MIL2TV=MTV(ITV,LTV-2)
                  SLPTV =(MTV(ITV,LTV+1)-MIL1TV)/(MTV(ITV,LTV)-MIL2TV)
                  IF(ITV .EQ. NTV-1)THEN
                      AP1TV=SLPTV*(EV1TV-MIL2TV)+MIL1TV
                  ELSE
                      AP2TV=SLPTV*(EV1TV-MIL2TV)+MIL1TV
                  ENDIF
              ENDIF
    1     CONTINUE
      ENDIF
      IF(BADTV)THEN
          WRITE(*,4)NMTV,EV1TV,EV2TV
    4     FORMAT(' ===TWOVAR PROB IN ',A,'; X=',F20.10,' Y=',F20.10)
      ELSE
          TWOVAR=(((AP2TV-AP1TV)/(MTV(NTV,1)-MTV(NTV-1,1)))
     *                    *(EV2TV-MTV(NTV-1,1)))+AP1TV
      ENDIF
      RETURN
      END
      SUBROUTINE DIARY1(IDY,XDY,TIMEDY,DAYDY)
C     ST
```

```
      INTEGER IDY,JDY,TIMEDY,DAYDY
      CHARACTER*15 EDY(6), LDY(8), C2DY, DATE*12, C1DY*12, C3DY*11
C     FN
      DATA EDY/'  GREEN PASTURE','    EARLY WHEAT','WHEAT AFTERMATH',
     *         '    DRY PASTURE','   DAMAGE WHEAT','HOLDING PADDOCK'/
      DATA LDY/'HOLDING PADDOCK','HOLDING PADDOCK','  GR/DR PASTURE',
     *         '  GR/DR PASTURE','    GR/DR WHEAT','    GR/DR WHEAT',
     2         'SPECIAL PASTURE',' FATTENING UNIT'/

      JDY=XDY
      C1DY=' EWE  MOVE  '
      WRITE(50,10)C1DY,EDY(IDY),EDY(JDY),TIMEDY,DATE(DAYDY)
   10 FORMAT(A,1X,A,' TO  ',A,', TIME=',I3,1X,A)
      RETURN

      ENTRY DIARY2(IDY,XDY,TIMEDY,DAYDY)
      JDY=XDY
      C1DY='NOT PRESENT '
      IF(JDY .EQ. 1)C1DY='PRESENT     '
      WRITE(50,20)EDY(IDY),C1DY,TIMEDY,DATE(DAYDY)
   20 FORMAT(' LOCATION',4X,A,1X,A,7X,', TIME=',I3,1X,A)
      RETURN

      ENTRY DIARY3(IDY,XDY,TIMEDY,DAYDY)
      JDY=XDY
      C1DY='NOT GRAZABLE'
      IF(JDY .EQ. 1)C1DY='GRAZABLE    '
      WRITE(50,20)EDY(IDY),C1DY,TIMEDY,DATE(DAYDY)
      RETURN

      ENTRY DIARY4(IDY,XDY,TIMEDY,DAYDY)
      C2DY=' LAMBS BORN IN '
      C3DY=' LAMBING    '
      WRITE(50,30)C3DY,XDY,C2DY,LDY(IDY),TIMEDY,DATE(DAYDY)
   30 FORMAT(A,F6.3,A,1X,A,', TIME=',I3,1X,A)
      RETURN

      ENTRY DIARY5(IDY,XDY,TIMEDY,DAYDY)
      C3DY=' WEANING    '
      C2DY=' LAMBS WEAN IN '
      WRITE(50,30)C3DY,XDY,C2DY,LDY(IDY),TIMEDY,DATE(DAYDY)
      RETURN

      ENTRY DIARY6(IDY,XDY,TIMEDY,DAYDY)
      C3DY=' CULLING    '
      C2DY=' EWES  CULL IN '
      WRITE(50,30)C3DY,XDY,C2DY,EDY(IDY),TIMEDY,DATE(DAYDY)
      RETURN

      ENTRY DIARY7(IDY,XDY,TIMEDY,DAYDY)
      JDY=XDY
      C1DY=' LAMB MOVE  '
      WRITE(50,10)C1DY,LDY(IDY),LDY(JDY),TIMEDY,DATE(DAYDY)
      RETURN

      ENTRY DIARY8(IDY,XDY,TIMEDY,DAYDY)
      C2DY=' LAMBS SOLD IN '
      C3DY=' LAMB SALE '
      WRITE(50,30)C3DY,XDY,C2DY,LDY(IDY),TIMEDY,DATE(DAYDY)
      RETURN

      ENTRY DIARY9(IDY,XDY,TIMEDY,DAYDY)
      C1DY=' GRAIN HARV '
      C2DY=' KG/HA          '
      C3DY = ' FORGET IT '
      IF(IDY .EQ. 1)C3DY=' HARVESTED '
      WRITE(50,40)C1DY,XDY,C2DY,C3DY,TIMEDY,DATE(DAYDY)
   40 FORMAT(A,4X,F6.0,A,A,', TIME=',I3,1X,A)
      RETURN
```

```
      ENTRY DIARY10(IDY,XDY,TIMEDY,DAYDY)
      C1DY=' STRAW BALE '
      C2DY=' KG/HA SYSTEM  '
      WRITE(50,50)C1DY,XDY,C2DY,TIMEDY,DATE(DAYDY)
   50 FORMAT(A,4X,F6.0,A,11X,', TIME=',I3,1X,A)
      RETURN

      ENTRY DIARY11(IDY,XDY,TIMEDY,DAYDY)
      C1DY=' NEW YEAR   '
      WRITE(50,60)C1DY,IDY
   60 FORMAT(/,' ************************************************************
     ***************',/,A,15X,I4,/)
      RETURN

      ENTRY DIARY12(IDY,XDY,TIMEDY,DAYDY)
      C3DY=' BALANCE    '
      C2DY='RETURN TO LABOU'
      C1DY='R & CAPITAL '
      WRITE(50,70)C3DY,XDY,C2DY,C1DY,IDY
   70 FORMAT(A,F7.1,'$/HA ',A,A,'(RAIN=',I4,'MM)')
      RETURN

      ENTRY DIARY13(IDY,XDY,TIMEDY,DAYDY)
      C1DY=' WHT HAY CUT'
      C2DY=' KG/HA SYSTEM ,'
      C3DY='% OF SYSTEM'
      WRITE(50,80)C1DY,IDY,C3DY,XDY,C2DY,TIMEDY,DATE(DAYDY)
   80 FORMAT(A,I4,A,F7.0,A,' TIME=',I3,1X,A)
      RETURN

      ENTRY DIARY14(IDY,XDY,TIMEDY,DAYDY)
      IXDY=INT(XDY+0.5)
      WRITE(50,90)IDY,IXDY,TIMEDY,DAYDY
   90 FORMAT(' INTAKE   TPIE/E: ', I3, '  TSIE/E: ', I3,
     *               '  TPIL/L: ', I3, '  TSIL/L: ', I3)
      RETURN
      END
      FUNCTION DATE(DAYDT)
      IMPLICIT            INTEGER(A-Z)
      DIMENSION           CMDT(13)
      CHARACTER*12        MDT(12),DATE
      DATA MDT            /'JANUARY  ','FEBRUARY','MARCH   ','APRIL   ',
     *                     'MAY      ','JUNE    ','JULY    ','AUGUST  ',
     *                     'SEPTEMBER','OCTOBER ','NOVEMBER','DECEMBER'/
      DATA CMDT         /0,31,59,90,120,151,181,212,243,273,304,334,365/
C     ACCEPTS DAY NUMBER (1=JAN 1) AND RETURNS THE DATE.
      DO 1 NDT=2,13
         IF(DAYDT .LE. CMDT(NDT))THEN
            N1DT               = NDT-1
            DDT                = DAYDT-CMDT(N1DT)
            BDT                = DDT/10
            ADT                = DDT-BDT*10
            MDT(N1DT)(11:11)   = CHAR(BDT+16)
            MDT(N1DT)(12:12)   = CHAR(ADT+16)
            DATE               = MDT(N1DT)
            RETURN
         ENDIF
    1 CONTINUE
      END
```

12 Model directory

12.1 Local variables

The following naming convention was adopted:

variables ending with	are local variables in subroutine ...
L8	INTAK
L7	EWMOVE
L6	CRITEW
GY	GRYPRO
L5	LAMOVE
L4	SUPOPT
L1	LMPERF
L2	EWPERF
L3	EWREQM
HY	HAYCUT
SB	STRABAL
DY	DIARY1

All other variables in these subroutines appear in COMMON.

Codes after acronyms are

- P: parameters defined in the parameter file (TAPE10), with the exception of AF1GY, AF2GY, EWEMAT, GYCGY, LAMMAT and MATCH, which are defined in DATA statements, and NRO that is defined in a PARAMETER statement, in the programme.
- F: function tables defined in the parameter file.
- IR: variables that are initialized once only at the start of a run. Initialization is always to zero, with the exception of DBIOM (3*1000), DLBIO (3*400), DNLBIO (3*600), DVS (3*1.1), EBC (3), EWELOC (6), GRODY (3*270), IBIOM (50,50,40), TADRW (3*1000), TDVS1 (3*140) and WEWE (60).
- IY: variables that are initialized at the start of each year. Initialization is always to zero, with the exception of MF1 (400), PRVDVS (1.1), and WST2BL (999).

Local variables in subroutine SRATES are not listed below.

12.2 Acronyms, definitions and units of measure

AAP	P	allowance for activity in equation for maintenance requirement	MJ kg^{-1} d^{-1}
ADT		auxiliary variable of DATE function	1

ADWW	P	content of water in air-dry soil relative to content at wilting point	1
AELWL3		allowance for ewe's gain in liveweight in calculation of ewe's energy requirements	$kg\ d^{-1}$
AF1GY	P	intercept of linear function relating harvest index to yield of grain	1
AF2GY	P	slope of linear function relating harvest index to yield of grain	$ha\ kg^{-1}$
AFG1		allocation of aerial biomass between leaves and stems at emergence	1
AFGEN		linearly interpolated value returned by AFGEN function	1
AFY		predicted yield of wheat aftermath	$kg\ ha^{-1}$
AFYGY		dummy argument in GRYPRO subroutine: predicted yield of wheat aftermath	$kg\ ha^{-1}$
AFYHY		predicted yield of wheat aftermath	$kg\ ha^{-1}$
AFYL5		predicted yield of wheat aftermath	$kg\ ha^{-1}$
AFYL6		predicted yield of wheat aftermath	$kg\ ha^{-1}$
AL6		time of entry of stock in algorithm for early-season grazing of green wheat	d
ALFEW	P	coefficient for energy requirement of fasting ewes	$MJ\ kg^{-0.75}\ d^{-1}$
ALPHAT	F	proportionality factor for contribution of drying power of the air to crop transpiration (ALPHA) as a function of average hourly irradiance during daylight (HRAD) and of leaf area index (LAI)	1
AMAX	IY	current maximum rate of gross CO_2 assimilation (single leaf)	$kg\ ha^{-1}\ h^{-1}$
AMAXB	P	potential maximum rate of gross CO_2 assimilation (single leaf)	$kg\ ha^{-1}\ h^{-1}$
AND		value (0 or 1) returned by AND function	1
ANIMAL		character string of dummy argument in subroutine INTAK ('EWES' or 'LAMB')	1
AOL6		optimum time of entry of stock in algorithm for early-season grazing of green wheat. 0 = today	d
AP1TV		TWOVAR function variable. 1st estimate, based on lower bounding row	1
AP2TV		TWOVAR function variable. 2nd estimate, based on upper bounding row	1
APCS	P	approximate rate of intake of dry biomass for satiation	$kg\ d^{-1}$

ARC1		rate of gain in liveweight returned by ARC1 function	kg d^{-1}
AREA	P	area fraction of system of the 3 localities	1
ARF	IY	vector of 15-day totals of daily rainfall for the current season	mm
ARFGY		dummy argument in GRYPRO subroutine: vector of 15-day totals of daily rainfall for the current season	mm
AVEYCM		dummy argument in CUMPR function: mean predicted yield of wheat grain	kg ha^{-1}
AVLAR	IY	quotient of area to mass of leaf at the 3 localities	m^2 kg^{-1}
BADTV		extrapolation warning indicator in TWOVAR function	1
BALANC	IY	annual financial balance	\$ ha^{-1}
BALEC	P	cost of baling wheat straw	\$ kg^{-1}
BARC		ARC1 function parameter in equation for retention of energy	1
BCP1	P	body condition parameter; minimum score	1
BCP2	P	body condition parameter; maximum score	1
BCP3	P	body condition parameter; acceptable score	1
BCP4	P	body condition parameter; liveweight corresponding to BCP3	kg
BCP5	P	body condition parameter; difference quotient of liveweight change to body score change	kg
BDT		auxiliary variable in DATE function	1
BL3		parameter in equation for retention of energy	1
BSYS	P	switch for breeding system. 1 = conventional 18-months, 2 = hoggets at 6 months	1
BXL6		auxiliary variable	ha d^{-1}
C1DY		character string variable of DIARY subroutine	1
C2DY		character string variable of DIARY subroutine	1
C3DY		character string variable in DIARY subroutine	1
CAVEL6		mean rate of intake during early-season period of grazing green wheat	kg d^{-1}
CCULTW	P	cost of land preparation for wheat	\$ ha^{-1}
CFDM	P	conversion factor from digestibility to metabolizability	1
CFERTW	P	cost of dressing wheat with fertilizer	\$ ha^{-1}

CHAR1		character returned by subroutine SUPOPT indicating optimum rate of supplementary feeding	'A', 'I', 'Z'
CHAST		character string indicating optimum rate of supplementary feeding at each locality for lambs: used in output option for lamb-rearing trace	'A'. 'I'. 'Z'. '.'
CL6		rate of intake of herbage in algorithms for deferment of grazing of green pasture and early-season grazing of green wheat	kg ha^{-1} d^{-1}
CLLWG	IR	cost of gain in liveweight of lamb at the selected locality	\$ kg^{-1}
CMCXL6		maximum cumulative intake in algorithm for deferment of grazing of green pasture	kg ha^{-1}
CMDT		array for DATE function (cumulative time)	d
COL	IY	output matrix column	1
CONFS	P	efficiency of conversion of primary photosynthetic product (CH_2O) to structural plant material (dry matter) for pasture and wheat	1
CONFSM	P	efficiency of conversion of primary photosynthetic product (CH_2O) to structural plant material (dry matter) for medic	1
COPL6		cost of keeping flock on pasture and not grazing green wheat as an alternative to grain for 1 management time step	\$ ha^{-1}
COSTH	P	costs of harvesting wheat grain with reference to area	\$ ha^{-1}
COSTS		running costs	\$ ha^{-1} d^{-1}
COSVL5		vector of lamb's cost of gain for each nutritional locality of the lamb	\$ kg^{-1}
CPUG		cost of gain in liveweight of lamb	\$ kg^{-1}
CRDL		rate of intake of dead leaf by ewe plus lamb for the 3 localities	kg ha^{-1} d^{-1}
CRDNL		rate of intake of dead non-leaf by ewe plus lamb for the 3 localities	kg ha^{-1} d^{-1}
CRLFAR		rate of intake of leaf area by ewe plus lamb for the 3 localities	m^2 ha^{-1} d^{-1}
CRLFRE		rate of intake of leaf area by ewe	m^2 ha^{-1} d^{-1}
CRLFRL		rate of intake of leaf area by lamb	m^2 ha^{-1} d^{-1}
CRLVE		rate of intake of live leaf by ewe	kg ha^{-1} d^{-1}
CRLVL		rate of intake of live leaf by lamb	kg ha^{-1} d^{-1}
CRLVS		rate of intake of live leaf by ewe plus lamb for the 3 localities	kg ha^{-1} d^{-1}
CRNLVE		rate of intake of live non-leaf by ewe	kg ha^{-1} d^{-1}

CRNLVL		rate of intake of live non-leaf by lamb	$kg\ ha^{-1}\ d^{-1}$
CRNLVS		rate of intake of live non-leaf by ewe plus lamb for the 3 localities	$kg\ ha^{-1}\ d^{-1}$
CSL8		rate of intake of concentrate ad libitum by lamb, also taken as maximum rate of intake of herbage for satiation	$kg\ d^{-1}$
CSOWW	P	cost of sowing wheat	$\$\ ha^{-1}$
CSRRT	F	mass fraction of photosynthetic product allocated to shoot (CSRR) as a function of stage of development of the crop (DVS) for pasture and medic	1
CSRRTW	F	mass fraction of photosynthetic product allocated to shoot (CSRR) as a function of stage of development of the crop (DVS) for wheat	1
CTRDEF	IY	cumulative transpiration deficit for the 3 localities	1
CULBS	P	culling rate of mature ewes	1
CULINC	IR	income from culled ewes	$\$\ ha^{-1}$
CULL	IR	switch for culling ewes. 0 = no, 1 = yes	1
CUMCL6		cumulative intake in algorithms for deferment of grazing of green pasture and early-season grazing of green wheat	$kg\ ha^{-1}$
CUMPR		integral of normal curve returned by CUMPR function	1
CVGY		coefficient of variation of predicted set of yields of wheat grain	1
D1PL6		auxiliary variable in computing DGPL6	1
D1PSB		auxiliary variable in computing DGPSB	1
D1WL6		auxiliary variable in computing DGWL6	1
D1WSB		auxiliary variable in computing DVSB	1
DACS	P	approximate rate of intake for satiation with grazing green wheat as an alternative to grain	$kg\ d^{-1}$
DAM-WGL8		indicator for grazing of green wheat as an alternative to grain. TRUE = being grazed, FALSE = not being grazed	character string
DATE		date returned by DATE function	character string
DAY		time in year from 31 December	d
DAYDT		dummy argument of DATE function. Time in year from 31 December	d
DAYDY		dummy argument of DIARY subroutine. Time in year from 31 December	d

DBIOM	IR	total mass of dead leaf and dead non-leaf for the 3 localities	kg ha^{-1}
DCL6		mean relative rate of disappearance of dead plant material	d^{-1}
DCLV	P	relative rate of disappearance of dead leaf	d^{-1}
DCNLV	P	relative rate of disappearance of dead non-leaf	d^{-1}
DCRSB		mean relative rate of disappearance of dead plant material	d^{-1}
DDLL8		digestibility of grazed dry leaf	1
DDLP	P	maximum digestibility of dry leaf (pasture or wheat)	1
DDNLL8		digestibility of grazed dry non-leaf	1
DDNLP	P	maximum digestibility of dry non-leaf (pasture or wheat)	1
DDSL1	P	range in digestibility of dead leaf during dry season	1
DDSL2	P	range in digestibility of dead non-leaf during dry season	1
DDT		auxiliary variable of DATE function	1
DEB	P	array of switches for debug output	1
DELAYT		value returned by DELAYT function	1
DELT	P	integration time step	d
DGLL8		digestibility of grazed green leaf	1
DGLP	P	maximum digestibility of green leaf (pasture or wheat)	1
DGNLL8		digestibility of grazed green non-leaf	1
DGNLP	P	maximum digestibility of green non-leaf (pasture or wheat)	1
DGPL6		time of grazing to satiation provided by dry pasture	d
DGPSB		time of grazing to satiation provided by dry pasture	d
DGRRT	P	rate of extension of roots under optimum conditions	mm d^{-1}
DGSL1	P	decrease in digestibility of green leaf between DVS = 0 and DVS = 1	1
DGSL2	P	decrease in digestibility of green non-leaf between DVS = 0 and DVS = 1	1
DGWL6		time of grazing to satiation provided by wheat aftermath	d
DIDHRV	IY	indicator for harvest of wheat grain. 0 = grain not yet harvested, 1 = grain harvested	1
DINTG	P	intercept of linear function relating ERDFDL8 to ED for ewes and LRDFDL8	

		to LD for lambs, on pasture and wheat	1
DINTL	P	intercept of linear function relating LRDFDL8 to LD for lambs, on legume	1
DINTL8		intercept of function relating reduction factor of digestibility to digestibility, for lambs	1
DISTFT	F	fraction of aerial vegetative growth to leaves (DISTF) as a function of stage of development of the crop (DVS) for pasture	1
DISTFTM	F	fraction of aerial vegetative growth to leaves (DISTF) as a function of stage of development of the crop (DVS) for medic	1
DISTFTW	F	fraction of aerial vegetative growth to leaves (DISTF) as a function of stage of development of the crop (DVS) for wheat	1
DLBIO	IR	biomass of dead leaf for the 3 localities	kg ha^{-1}
DMF1		change in parameter MF1 in equation for rate of production of milk with rate of feeding	d^{-1}
DMIL1		rate of intake of dry matter	kg d^{-1}
DMIL4		rate of intake of dry matter	kg d^{-1}
DMP1	P	parameter in equation for DMF1	1
DMP2	P	parameter in equation for DMF1	1
DND1	P	time interval over which DDSL1 declines	d
DND2	P	time interval over which DDSL2 declines	d
DNLBIO	IR	biomass of dead non-leaf for the 3 localities	kg ha^{-1}
DOLDAY	IY	cumulative negative financial balance	d
DRF	P	dryness factors of consecutive soil compartments at start of season relative to content of moisture at wilting point, for the 3 localities	1
DRR		cumulative deep drainage beyond potential rooting zone for the three localities	mm d^{-1}
DRYQL6		total dry-season requirement of the flock with respect to system area	kg ha^{-1}
DSLPG	P	slope of linear function relating ERDFDL8 to ED for ewes and LRDFDL8 to LD for lambs, on pasture and wheat	1
DSLPL	P	slope of linear function relating LRDFDL8 to LD for lambs, at legume	1
DSLPL8		slope of function relating factor for reduction in digestibility to digestibility, for lambs	1
DSUPL4		increment in rate of supplementary feeding in algorithm for optimizing supplementary feeding of lambs	kg d^{-1}
DVR		rate of development of plant for the three localities	1

DVRT	F	rate of development of crop (DVR) as a function of average daily air temperature (TMPA)	1
DVS	IR	stage of development of the crop at the 3 localities	1
DVSB		biomass of wheat aftermath required to provide intake for satiation for a given period of time with respect to locality area	kg ha^{-1}
DVSSF	P	stage of development at which seed fill starts for pasture and medic	1
DVX	IR	indicator for end of growing season for the 3 localities. 0 = DVS〈1, 1 = DVS〉1	1
EB		cumulative evaporation over soil compartments for the three localities	mm d^{-1}
EBC	IR	ewe's body condition score	1
EBCLIM	P	threshold of ewe's body condition score below which weaning is forced	1
EBDEFL8		deficit of ewe's body condition	1
ECRDL		ewe's rate of intake of dead leaf	kg $ha^{-1}d^{-1}$
ECRDNL		ewe's rate of intake of dead non-leaf	kg $ha^{-1}d^{-1}$
ED		(ewe) digestibility of pasture or wheat herbage	1
EDPTFT	F	root activity coefficient (EDPTF) as a function of relative amount of available water in a soil compartment (AFGX)	1
EDY		array for ewe's locality in DIARY subroutine	character string
EEP1	P	parameter in function for energy content of gain by ewes: intercept	MJ kg^{-1}
EEP2	P	parameter in function for energy content of gain by ewes: slope	MJ kg^{-1} kg^{-1}
EEP3	P	parameter in function for energy content of gain by ewes: maximum	MJ kg^{-1}
EEVGL2		energy content of gain by ewes	MJ kg^{-1}
EEVGL3		energy content of gain by ewes	MJ kg^{-1}
EFFE	IY	actual effectiveness of utilization of solar energy for production of dry matter at light compensation point	kg ha^{-1} h^{-1}/ (J m^{-2} s^{-1})
EFFEB	P	basic potential effectiveness of utilization of solar energy at the light compensation point	kg ha^{-1} h^{-1} W^{-1} m^2
ELP1	P	parameter in equation for net energy content of milk	1
ELP2	P	parameter in equation for net energy content of milk	1

ELP3	P	parameter in equation for net energy content of milk	1
ELS		crop locality corresponding to ewe's current nutritional locality	1, 2 or 3
ELWG	IR	ewe's rate of change in liveweight	kg d^{-1}
EMEPA		content of metabolizable energy in herbage grazed by ewes	MJ kg^{-1}
EMY		ewe's actual rate of production of milk	kg d^{-1}
EMYMF		factor for increase in yield of ewe's milk for average litter size	1
ENGR		rate of emptying of temperature sum when no seeds are germinating, for the three localities	1
EPLA	P	ewe's allowance of poultry litter at dry localities or holding paddock	kg d^{-1}
EPSBFL8		ratio of substitution of herbage for concentrates to ewe	1
EQMP		metabolizability of herbage grazed by the ewes	1
ER		rate of evaporation from a soil compartment, for the three localities	mm d^{-1}
ERFDSL8		reduction factor for digestibility with intake of straw by ewe	1
ERHI		ewe's rate of intake of (wheat) hay	kg d^{-1}
ERPI		ewe's rate of intake of herbage	kg d^{-1}
ERPIX		expected rate of intake of herbage by ewe in the absence of supplementary feed	kg d^{-1}
ERPLI		ewe's rate of intake of poultry litter	kg d^{-1}
ERSI		ewe's rate of intake of supplementary feed	kg d^{-1}
ERSTI		ewe's rate of intake of (wheat) straw	kg d^{-1}
EUBL	P	efficiency of utilization of body energy for lactation	1
EV1TV		variable of TWOVAR function set equal to dummy argument IV1TV for computational efficiency	1
EV2TV		variable of TWOVAR function set equal to dummy argument IV2TV for computational efficiency	1
EVAF		variable of AFGEN function set to dummy argument IVAF for computational efficiency	1
EVAP		potential evaporation of moisture from soil	mm d^{-1}
EVGARC		dummy argument of ARC1 function: energy content of gain	MJ kg^{-1}
EVPL2		total energy content of products of gestation	MJ
EVPL3		total energy content of products of gestation	MJ

EWCS		ewe's mass rate of intake to meet energy requirements	kg d^{-1}
EWELOC	IR	ewe's current nutritional locality	1
EWEMAT	P	array for matching ewe's nutritional locality to crop locality	1
EWHD	P	earliest time for wheat harvest from 31 December	d
EWMTMF	P	multiplication factor for ewe's energy requirement for maintenance (set to 1 and therefore inoperative)	1
EWSTG		ewe's physiological stage from time of mating	d
FAMSTT	F	reduction factor for allocation of photosynthetic products to shoot (FAMST) as a function of relative transpiration deficit (CTRDEF)	1
FCNSW		value returned by FCNSW function	1
FDMT	F	mass fraction of dry matter in canopy (FDM) as a function of stage of development of the crop (DVS)	1
FERT		switch for application of fertilizer. 0 = no, 1 = yes	1
FERTD	P	time of applying fertilizer from 31 December	d
FGF1	P	intercept in equation defining fraction of maximum allowance for grazing activity (GF) to add to requirements for maintenance	1
FGF2	P	slope in equation defining fraction of maximum allowance for grazing activity (GF) to add to requirements for maintenance	1
FLDCP	P	field capacity expressed as volume fraction of moisture	1
FLTRT	F	fraction of solar energy transmitted through vegetation (FRLT) as a function of soil cover (SLCVR)	1
FORCPH	P	forced price of hay (overrides calculated value if greater than or equal to zero)	\$ kg^{-1}
FRACSB		mass fraction of STMXSB that is actually baled	1
FRCS	P	fraction of EWCS above which the option of grazing green wheat as an alternative to grain is not considered	1
FSATL8		fraction of digestibility-limited intake achieved in absence of supplementary feed	1
FWDB	P	mass fraction of water in dead plant material	1
FXPC	P	fixed costs of pasture, including fertilizer	\$ ha^{-1} $year^{-1}$

GAMMA	P	psychrometer constant	mmHg °C^{-1}
GAP	P	maximum allowance for gain in liveweight by ewe	kg d^{-1}
GDCS	P	rate of intake per animal for satiation in algorithms for deferment of grazing of green pasture and early-season grazing of green wheat	kg d^{-1}
GDDEC	IY	switch indicating whether the algorithm for deferment of grazing on green pasture has been invoked. 0 = no, 1 = yes	1
GDF	P	relative nutritional value of dry to green herbage for algorithm for deferment of grazing on green pasture	1
GDG	P	long-term average relative rate of growth at low biomass in logistic growth function in algorithm for deferment of grazing on green pasture	d^{-1}
GDHL6		stocking rate at pasture for algorithm for deferment of grazing on green pasture	ha^{-1}
GDI	P	harvest index in algorithm for deferment of grazing on green pasture: 1 − GDI = fraction of peak biomass that remains for grazing after harvest	1
GDTEND	P	last possible time of entry of stock, i.e. average duration of green season, in algorithm for deferment of grazing on green pasture	d
GDVM	P	long-term average peak undisturbed aerial biomass in logistic growth function in algorithm for deferment of grazing on green pasture	kg ha^{-1}
GDVMF	P	multiplication factor for optimum biomass at entry of stock, for error analysis in algorithm for deferment of grazing on green pasture	1
GDVS	P	biomass at 0.63 satiation intake in negative exponential function of intake in algorithm for deferment of grazing on green pasture	kg ha^{-1}
GEH	P	gross energy content of herbage dry matter	MJ kg^{-1}
GEST	P	gestation period	d
GF	P	maximum energy requirement for grazing activity relative to requirements for maintenance	1
GPRFHY		expected mean profit from wheat grain	\$ ha^{-1}
GRAINT	F	fraction of photosynthetic product allocated	

		to seeds (FRTS) as a function of stage of development of the crop (DVS). (DVS at which allocation to seeds commences in pasture and medic is given by parameter DVSSF)	1
GRAZE	IY	indicator of grazing by ewe. 0 = ewe not grazing, 1 = ewe grazing	1
GRAZL	IY	indicator of grazing by lamb. 0 = lamb not grazing, 1 = lamb grazing	1
GRAZL1		dummy argument of grazing by lamb to subroutine LMPERF	1
GRAZL2		dummy argument of grazing by ewe to subroutine EWPERF	1
GRAZL3		dummy argument of grazing by ewe to subroutine EWREQM	1
GRL6		rate of growth of green pasture in algorithms for deferment of grazing of green pasture and early-season grazing of green wheat	kg ha^{-1} d^{-1}
GRLVS		rate of growth of leaf for the 3 localities	kg ha^{-1} d^{-1}
GRNLV		rate of growth of non-leaf for the 3 localities	kg ha^{-1} d^{-1}
GRODY	IR	time interval since emergence for the 3 localities	d
GRRT		rate of vertical extension of the root system for the 3 localities	mm d^{-1}
GRRWT		rate of growth of the roots for the 3 localities	kg ha^{-1} d^{-1}
GRSDS		rate of growth of the seeds for the 3 localities	kg ha^{-1} d^{-1}
GWVEL6		biomass of plant components grazed by ewe when grazing green wheat as an alternative to grain	kg ha^{-1}
GWVLL5		biomass of plant components grazed by lambs when grazing green wheat as an alternative to grain	kg ha^{-1}
GYCGY	P	array of coefficients for multiple linear regression equation relating yield of wheat grain to 30-day rainfall	kg mm^{-1}
GYGY		vector of predicted yields of wheat grain	kg ha^{-1}
HARV		switch for harvesting of wheat grain. 0 = no, 1 = yes	
HAY	IR	amount of hay in store	kg ha^{-1}
HAYLD		expected yield of wheat hay with respect to wheat area	kg ha^{-1}
HORMC	P	cost of hormone per ewe in early-breeding system (BSYS = 2)	$
HRFGY		historical rainfall vector from data file for 15-d periods	mm

HVCH		costs of cutting wheat for hay	\$ ha^{-1}
HYCTR	P	cumulative transpiration deficit above which cutting for hay, if feasible, is not delayed	1
HYDVS	P	stage of development above which cutting for hay, if feasible, is not delayed	1
HYHC1	P	cost function of harvesting hay: intercept	\$ ha^{-1}
HYHC2	P	cost function of harvesting hay: slope	\$ kg^{-1}
HYLEFT	P	biomass of wheat left in field by baler	kg ha^{-1}
HYOP	P	option of cutting hay. <0, do not cut hay; $=0$, cut according to normal criteria; >0, cut if value greater than costs of harvesting	1
HYPF1	P	ratio of top to bottom price of hay	1
HYPF2	P	parameter in function of price of hay: effect of stage of development	1
HYTOPP	P	top price of hay: price for best hay	\$ kg^{-1}
I1		looping index	1
I2		looping index	1
I3		looping index	1
IARC		dummy argument of function ARC1: scaled rate of intake of energy	1
IBIOM	IR	initial aerial biomass at full emergence for the 3 localities	kg ha^{-1}
IDY		dummy argument of DIARY subroutine	1
IGY		index variable of GRYPRO subroutine	1
IL1		scaled rate of intake of energy	1
IL2		scaled rate of intake of energy	1
IL3		scaled rate of intake of energy	1
IL4		scaled rate of intake of energy	1
IL5		index variable in subroutine LAMOVE	1
IL7		index variable in subroutine EWMOVE	1
IL8		index variable in subroutine INTAK	1
INCOM		rate of income from sale of products	\$ ha^{-1} d^{-1}
INDGY		current decision time expressed in number of 15-day periods since start of season	1
INFR		rate of infiltration of water into the soil	mm d^{-1}
INSUR	P	insurance costs per ewe	\$ year^{-1}
INSW		value returned by INSW function	1
IRN15		15-day group number since the start of the season. 1-15 October = 1	1
IRTD	P	rooting depth at emergence for the 3 localities	mm
IRWT		mass of roots with respect to area at emergence for the 3 localities	kg ha^{-1}
ITV		variable of TWOVAR function: current bounding row	1

IV1TV		dummy argument of TWOVAR function: 1st independent variable	1
IV2TV		dummy argument of TWOVAR function: 2nd independent variable	1
IVAF		dummy argument of AFGEN function: independent variable	1
IXDY		auxiliary variable of DIARY subroutine	1
J1		looping index	1
J2		looping index	1
JDY		auxiliary variable of DIARY subroutine	1
JGY		index variable of GRYPRO subroutine	1
JJ		looping index	1
JL6		dummy argument of CRITEW subroutine: ewe's locality	1
JL7		index variable in subroutine EWMOVE	1
JOIN		joining (mating) switch. 0 = no, 1 = yes	1
JOIND	P	time of joining from 31 December	d
JSB		grazing time needed on wheat aftermath after allowing for availability of dry pasture	d
K		crop locality	1
KARC		variable of ARC1 function: parameter in equation for retention of energy	1
KFARC		dummy argument in ARC1 function: efficiency of utilization of metabolic energy for weight gain	1
KFL1		efficiency of utilization of metabolic energy for weight gain	1
KFL2		efficiency of utilization of metabolic energy for weight gain	1
KFL3		efficiency of utilization of metabolic energy for weight gain	1
KFL4		efficiency of utilization of metabolic energy for weight gain	1
KL3		parameter in equation for retention of energy	1
KLL2		efficiency of utilization of metabolic energy for lactation	1
KLL3		efficiency of utilization of metabolic energy for lactation	1
KMARC		dummy argument in ARC1 function: efficiency of utilization of metabolic energy for maintenance	1
KML1		efficiency of utilization of metabolic energy for maintenance	1

KML2		efficiency of utilization of metabolic energy for maintenance	1
KML3		efficiency of utilization of metabolic energy for maintenance	1
KML4		efficiency of utilization of metabolic energy for maintenance	1
KP	P	efficiency of utilization of metabolic energy for pregnancy	1
LAGE	IR	age of lamb	d
LAGRTR		rate of growth of leaf in area for the 3 localities	$m^2\ ha^{-1}\ d^{-1}$
LAI	IY	leaf area index for the 3 localities	1
LAMB		switch for lambing. 0 = no, 1 = yes	1
LAMBD		time of lambing from 31 December	d
LAMLOC	IR	code for present locality of lambs	1
LAMMAT	P	array for matching locality for lambs to crop locality	1
LAT	P	latitude of locality (for Migda farm in northern Negev)	°
LBIB	P	limiting biomass to be considered, as fraction of initial biomass	1
LBW		mean birth weight of lamb	kg
LBWS	P	birth weight of single lambs	kg
LBWT	P	birth weight of twin lambs	kg
LCL8		locality in system corresponding to ewe's current locality or lamb's locality	1
LCRDL		lamb's rate of intake of dead leaf	$kg\ ha^{-1}\ d^{-1}$
LCRDNL		lamb's rate of intake of dead non-leaf	$kg\ ha^{-1}\ d^{-1}$
LD		digestibility of grazed herbage by lamb	1
LDY		array for locality of lambs in DIARY subroutine	1
LEP1	P	parameter in function for energy content of gain by lambs on solid diet: intercept	$MJ\ kg^{-1}$
LEP2	P	parameter in function for energy content of gain by lambs on solid diet: slope	$MJ\ kg^{-1}\ kg^{-1}$
LEP3	P	parameter in function for energy content of gain by milk-fed lambs: intercept	$MJ\ kg^{-1}$
LEP4	P	parameter in function for energy content of gain by milk-fed lambs: slope	$MJ\ kg^{-1}\ kg^{-1}$
LEVGL1		energy content of gain for lambs	$MJ\ kg^{-1}$
LEVGL4		energy content of gain for lambs	$MJ\ kg^{-1}$
LFAREA	IY	leaf area for the 3 localities	$m^2\ ha^{-1}$
LFARR	P	quotient of area to mass of leaf	$m^2\ kg^{-1}$

LFCFL3		correction factor for relative rate of feeding in calculation of ewe's requirement	1
LFI		area of leaf at emergence relative to land area for the 3 localities	m^2 ha^{-1}
LFMDL1		mass fraction of milk in dry matter of lamb's diet	1
LFMDL4		mass fraction of milk in dry matter of lamb's diet	1
LFP	P	correction parameter for relative rate of feeding	1
LHVAP	P	enthalpy of vaporization of water	10^4 cal kg^{-1} = 4 200 J kg^{-1}
LI		TOTA matrix index	1
LIMIT		value returned by LIMIT function	1
LL3		approximate relative rate of feeding in calculation of ewe's requirement	1
LLS		crop locality corresponding to current nutritional locality of lamb (1 to 8)	1, 2, 3
LLWG	IR	lamb's rate of gain in liveweight	kg d^{-1}
LMBIOM		limiting aerial biomass below which plant is considered dead for the 3 localities	kg ha^{-1}
LMEPA		content of metabolic energy of herbage grazed by lambs	MJ kg^{-1}
LMM	P	matrix for lamb movement	1
LMORTS	P	mortality of lambs at birth for singletons	1
LMORTT	P	mortality of lambs at birth for twins	1
LOANR	P	interest rate on overdraft	yr^{-1}
LOCL4		nutritional locality of lamb passed to subroutine SUPOPT by subroutine LAMOVE	1
LOL5		lowest value in COSVL5 array	\$ kg^{-1}
LPDMIT	F	rate of intake of concentrate ad libitum by lamb in relation to lamb liveweight	kg d^{-1}
LPH	P	proportion of hoggets lambing (if tupped)	1
LPM	P	proportion of mature ewes lambing	1
LPSUBF		substitution ratio of concentrates for herbage intake by lamb	1
LPSWXL5		substitution ratio of concentrates for herbage intake by lamb if moved to green wheat as an alternative to grain	1
LQMP		metabolizability of herbage grazed by lambs	1
LRMI	IR	lamb's actual rate of intake of whole milk	kg d^{-1}
LRMIX		lamb's expected rate of intake of whole milk if moved to a sucking locality	kg d^{-1}

LRPI	IR	lamb's actual rate of intake of herbage	$kg\ d^{-1}$
LRPIL4		lamb's rate of intake of herbage	$kg\ d^{-1}$
LRPIX	IR	lamb's expected rate of intake of herbage in absence of supplementary feeding	$kg\ d^{-1}$
LRSI	IR	lamb's actual rate of intake of supplementary feed	$kg\ d^{-1}$
LRSIX		optimum rate of supplementary feeding of lamb at a locality	$kg\ d^{-1}$
LSH	P	litter size of hoggets (if tupped)	1
LSM	P	litter size of mature ewes	1
LTV		variable in TWOVAR function: upper bounding column	1
LWGARC		variable in ARC1 function: rate of gain in liveweight	$kg\ d^{-1}$
LWIXL5		lamb's rate of intake of herbage if moved to green wheat as an alternative to grain	$kg\ d^{-1}$
MAT		output matrix	1
MATCH	P	array for matching ewe's locality to locality for lambs	1
MAXCL6		maximum cumulative intake in algorithm for early-season grazing of green wheat	$kg\ ha^{-1}$
MCRMN	P	minimum proportion of difference between MF1X and MF1 that can be restored or reduced in one day	1
MCRMX	P	maximum proportion of difference between MF1X and MF1 that can be restored or reduced in one day	1
MD1TV		dummy argument in TWOVAR function: maximum number of data pairs along a row of the data matrix	1
MDMC	P	mass fraction of solids in ewe's milk	1
MDT		array for name of month in DATE function	character string
MEFRCL8		fraction of ewe's requirement for metabolic energy met before considering stage of lactation	1
MEGL3		ewe's requirement of metabolic energy for gain in liveweight	$MJ\ d^{-1}$
MEHY	P	content of metabolic energy in wheat hay	$MJ\ kg^{-1}$
MEIL1		rate of intake of metabolic energy	$MJ\ d^{-1}$
MEIL2		rate of intake of metabolic energy	$MJ\ d^{-1}$
MEIL4		rate of intake of metabolic energy	$MJ\ d^{-1}$
MEINTL8		rate of intake of metabolic energy by ewe (auxiliary variable)	$MJ\ d^{-1}$

MELL2		rate of metabolic energy required for lactation for rate of production YPL2	$MJ\ d^{-1}$
MELL3		rate of metabolic energy required for lactation for rate of production YPL3	$MJ\ d^{-1}$
MEML1		rate of metabolic energy required for maintenance	$MJ\ d^{-1}$
MEML2		rate of metabolic energy required for maintenance	$MJ\ d^{-1}$
MEML3		rate of metabolic energy required for maintenance	$MJ\ d^{-1}$
MEPL	P	content of metabolic energy in poultry litter	$MJ\ kg^{-1}$
MEPL2		rate of metabolic energy required for pregnancy	$MJ\ d^{-1}$
MEPL3		rate of metabolic energy required for pregnancy	$MJ\ d^{-1}$
MER		rate of metabolic energy required by the ewe	$MJ\ d^{-1}$
MEST	P	content of metabolic energy in wheat straw	$MJ\ kg^{-1}$
MESU	P	content of metabolic energy in supplementary feed	$MJ\ kg^{-1}$
MEWM	P	content of metabolic energy in ewe's whole milk	$MJ\ kg^{-1}$
MF1	IY	calculated parameter in equation for rate of production of milk	1
MF1XL2		parameter MF1 that would cause lactation trajectory to pass through yield resulting from all surplus energy being used for milk production	1
MF2	P	parameter in equation for rate of production of milk	1
MF3	P	parameter in equation for rate of production of milk	1
MFC	P	mass fraction of fat in ewe's milk	$g\ kg^{-1} = 10^{-3}$
MIFT	P	increase factor for ewe's milk yield with twins: ratio of rate of production of milk for twins to that for singletons	1
MIL1TV		auxiliary variable in TWOVAR function	1
MIL2TV		auxiliary variable in TWOVAR function	1
MINEBC		ewe's minimum acceptable body condition for current stage in physiological cycle and litter size	1
MISC	P	ewe's miscellaneous rate of expenditure as fraction of total variable costs of ewe	

		(veterinary, insurance and supplementary feed)	1
MNEBCT	F	ewe's minimum acceptable body condition as function of physiological stage and litter size	1
MNEL2		net rate of energy mobilization from body reserves for lactation	$MJ\ d^{-1}$
MNGDEL	P	time-step between management decisions	d
MNIEW	P	minimum acceptable mean rate of intake during early-season grazing of green wheat	$kg\ d^{-1}$
MNSTR	P	minimum store of hay or straw per ewe to permit feeding	kg
MRESF	P	respiration factor for maintenance: mass fraction rate of CH_2O to plant mass	d^{-1}
MRFBCL2		reduction factor for ewe's mobilization of body reserves with respect to body condition	1
MRFL2		reduction factor for ewe's actual mobilization of body reserves	1
MRFSLL2		reduction factor for ewe's mobilization of body reserves with respect to stage of lactation	1
MRP1	P	parameter for mobilization of body reserves with stage of lactation: rate of change	d^{-1}
MRP2	P	parameter for mobilization of body reserves with stage of lactation: time of start of decline	d
MRP3	P	parameter for mobilization of body reserves with body condition	1
MRP4	P	parameter for mobilization of body reserves with body condition	1
MSW		switch for input of meteorological data	1
MTV		dummy argument of TWOVAR function: data matrix	1
MWATER		maximum amount of water that can be held in a soil compartment	mm
MXMF1	P	maximum permissible value of parameter MF1	1
MXRTD	P	maximum rooting depth	mm
MXSIL4		rate of intake of concentrate ad libitum by lamb	$kg\ d^{-1}$
MYTHL2		theoretical rate of production of milk if all energy surplus to maintenance were used for milk production	$kg\ d^{-1}$
MYXL2		auxiliary variable in equation for rate of production of milk	1
N1		looping index	1

N1DT		auxiliary variable in DATE function	1
NAF		variable in AFGEN function: upper bounding column	1
NAME	P	variable names in output table	1
NBREW		stocking rate of mature breeding ewes for system area	ha^{-1}
NCULL		rate of culling of mature breeding ewes	ha^{-1} $year^{-1}$
NDAF		dummy argument in AFGEN function: number of data pairs	1
NDL		variable in DELAYT function	1
NDLACT	IR	time in ewe's lactation	d
NDPREG	IR	time in ewe's pregnancy	d
NDT		auxiliary variable in DATE function	1
NEGL5		indicator of negative cost in liveweight. 0 = no	1
NEML2		net energy content of ewe's whole milk	MJ kg^{-1}
NEML3		net energy content of ewe's whole milk	MJ kg^{-1}
NEPL2		rate of deposition of net energy in products of pregnancy	MJ d^{-1}
NEPL3		rate of deposition of net energy in products of pregnancy	MJ d^{-1}
NEWES	P	stocking rate of reproductive stock (ewes + hoggets) with respect to system	ha^{-1}
NEWL		stocking rate of ewes lambing in system	ha^{-1}
NEWM		stocking rate of lactating ewes in system	ha^{-1}
NHOGS		stocking rate of hoggets (breeding or not breeding) in system	ha^{-1}
NIL4		number of iterations	1
NLAMS	IR	stocking rate of lambs, including replacements, in system	ha^{-1}
NLB		stocking rate of lambs born in the system	ha^{-1}
NLR		stocking rate of lambs reared in the system	ha^{-1}
NLSEL	IR	stocking rate of lambs to be sold in the system	ha^{-1}
NMAF		dummy argument in AFGEN function: name of function table	character string
NMDL		dummy argument in DELAYT function	1
NMEWS		stocking rate of lactating ewes with singletons in system	ha^{-1}
NMEWT		stocking rate of lactating ewes with twins in system	ha^{-1}
NMTV		dummy argument in TWOVAR function: name of function table	character string

NOT		value returned by NOT function	0, 1
NOYGY		number of predictions of yield of grain	1
NP2TV		dummy argument in TWOVAR function: number of rows in data matrix	1
NPEWS		stocking rate of pregnant ewes with singletons	ha^{-1}
NPEWT		stocking rate of pregnant ewes with twins	ha^{-1}
NREP	IR	stocking rate of lambs to be retained as replacers	ha^{-1}
NRO	P	number of rows in output matrix	1
NSUKL	IR	stocking rate of sucking lambs	ha^{-1}
NTV		variable in TWOVAR function: upper bounding row	1
NWNRS	IR	stocking rate of weaners (including replacers)	ha^{-1}
NY	P	duration of simulation run	year
OEDL6		optimum time of stock entry in algorithm for deferment of grazing on green pasture	d
OEVL6		optimum biomass at stock entry corresponding to OEDL6 in algorithm for deferment of grazing on green pasture	kg ha^{-1}
OKL5		indicator in subroutine LAMOVE	1
OLDEWL7		ewe's locality at previous decision time-step	1
OLDLML5		locality of lambs at previous decision time-step	1
OPTVL5		vector of current options for lamb movement	1
P1LM		dummy argument in LIMIT function	1
P2LM		dummy argument in LIMIT function	1
PCGFL1		proportion of GF parameter to use for increment to requirement for maintenance due to grazing activity	1
PCGFL2		proportion of GF parameter to use for increment to requirement for maintenance due to grazing activity	1
PCGFL3		proportion of GF parameter to use for increment to requirement for maintenance due to grazing activity	1
PCGFL4		proportion of GF parameter to use for increment to requirement for maintenance due to grazing activity	1
PCIAL1		actual rate of intake of herbage as a proportion of rate of intake of herbage in the absence of supplementary feeding	1
PCIAL2		actual rate of intake of herbage as a proportion of rate of intake of herbage in the absence of supplementary feeding	1

PCIAL3		actual rate of intake of herbage as a proportion of rate of intake of herbage in the absence of supplementary feeding	1
PCIAL4		actual rate of intake of herbage as a proportion of rate of intake of herbage in the absence of supplementary feeding	1
PFDML4		price of dry matter in lamb's diet	$ kg^{-1}
PGDLIM	P	time limit for deferment of grazing from emergence in algorithm for deferment of grazing on green pasture	d
PGL6		cost of grazing green wheat as an alternative to grain instead of providing supplementary feed on pasture	$ ha^{-1}
PGNXL6		threshold price of wheat grain at which grazing of green wheat as an alternative to grain becomes feasible	$ kg^{-1}
PGRN	P	price of wheat grain	$ kg^{-1}
PGY	IY	mean predicted yield of wheat grain	kg ha^{-1}
PGYGY		dummy argument in GRYPRO subroutine: mean predicted yield of wheat grain	kg ha^{-1}
PGYHY		mean predicted yield of wheat grain	kg ha^{-1}
PGYL5		mean predicted yield of wheat grain	kg ha^{-1}
PGYL6		mean predicted yield of wheat grain	kg ha^{-1}
PGYXL6		threshold yield of wheat grain at which grazing of green wheat as an alternative to grain becomes feasible	kg ha^{-1}
PI	P	pi constant	1
PKA1	P	parameter in equation for efficiency of utilization of metabolic energy for lactation	1
PKA2	P	parameter in equation for efficiency of utilization of metabolic energy for lactation	1
PKF1	P	parameter in equation for efficiency of utilization of metabolic energy for gain	1
PKF2	P	parameter in equation for efficiency of utilization of metabolic energy for gain	1
PKF3	P	efficiency of utilization of metabolic energy for gain of milk-fed lambs	1
PKF4	P	parameter in equation for efficiency of utilization of metabolic energy for gain during lactation	1
PKM1	P	parameter in equation for efficiency of utilization of metabolic energy for maintenance	1
PKM2	P	parameter in equation for efficiency of	

		utilization of metabolic energy for maintenance	1
PKM3	P	efficiency of utilization of metabolic energy for maintenance for milk-fed lambs	1
PLOW		switch for cultivation. 0 = no, 1 = yes	1
PLOWD	P	time of ploughing from 31 December	d
PLWGL4		predicted rate of gain in liveweight by lamb	kg d^{-1}
PMILK		cost ascribed to ewe's whole milk in lamb diet	\$ kg^{-1}
POSBL7		array of possible localities for stock. 1 = could be stocked, 0 = could not be stocked	1
POSL5		indicator of positive cost of gain. 0 = none, >0 = yes	1
PPAST		cost ascribed to lamb's intake of herbage	\$ kg^{-1}
PPL	P	price of dry matter of poultry litter	\$ kg^{-1}
PPOSL7		equal to array POSBL7 at previous decision time-step	1
PPRSL7		equal to array PRSNL7 at previous decision time-step	1
PRCHY		price of hay	\$ kg^{-1}
PRDEL	P	time interval between entries in output table	d
PRELF	P	price ratio of supplementary feed for ewe to lamb	1
PRELM	P	price ratio of ewe's meat to lamb's meat	1
PRESDL		dummy argument in DELAYT function: current temperature	°C
PRFHY		profit from cutting for hay	\$ ha^{-1}
PRIORT	P	user-defined priority ranking array for ewe locality: PRIORT(1) = highest ranked locality, etc.	1
PRLAM	P	price of lamb's meat	\$ kg^{-1}
PROP	P	proportionality factor for division of evaporation of water from soil over various soil compartments	1
PRSNL7		array indicating presence of ewe's locality. 1 = present, 0 = not	1
PRVDVS	IY	stage of development at previous time-step for the three localities	1
PRVTV	IY	total biomass of green leaf plus non-leaf at previous time-step for the three localities	kg ha^{-1}
PSCH	P	psychrometric constant	mbar $°C^{-1}$ = 100 Pa K^{-1}
PSPXL6		threshold price of supplementary feed at which grazing of green wheat as an alternative to grain becomes feasible	\$ kg^{-1}

PSTRW	P	price of straw	$ kg^{-1}
PSUPPS	P	price of supplementary feed suitable for fattening of lambs	$ kg^{-1}
PTIME		time-dependent rate of expenditure for lamb rearing	$ d^{-1}
PUSHD		switch to kill vegetation for the 3 localities	1
PUSHG		switch for emergence at the 3 localities	1
QMHY	P	metabolizability of wheat hay	1
QML1		metabolizability of diet	1
QML2		metabolizability of diet	1
QML3		estimated dummy parameter for metabolizability of diet from subroutine INTAK to subroutine EWREQM	1
QML4		metabolizability of diet	1
QMM	P	metabolizability of ewe's milk	1
QMPL	P	metabolizability of poultry litter	1
QMS	P	metabolizability of supplementary feed	1
QMST	P	metabolizability of wheat straw	1
RADTB	F	time integral of daily global irradiance with clear sky (DGRCL) as function of time from 1 October (DAY)	J m^{-2}
RAIN		rainfall rate	mm d^{-1}
RARC		variable in ARC1 function: scaled rate of retention of energy	1
RATING		array for priority ranking of all localities: RATING(1) = priority ranking of Locality 1; higher value means lower priority; computed from user-defined PRIORT array	1
RC	P	cuticular resistance	d cm^{-1}
RCST		rate of change of temperature of soil	°C d^{-1}
RDAMAX		rate of decline in light-saturated photosynthesis (areic mass of CO_2 fixed with respect to ground area and to fraction of day) for individual leaves in the 3 localities	kg ha^{-1} h^{-1} d^{-1}
RDEFFE		rate of decline in effectiveness of photosynthesis (areic mass rate of CO_2) for individual leaves at the 3 localities	kg ha^{-1} h^{-1} W^{-1} m^2 d^{-1}
RDFAL8		reduction factor for intake of herbage with availability	1
RDFDL8		reduction factor for intake of herbage with digestibility	1

RDLFA		rate of reduction in area of live leaf with death of leaf for the 3 localities	$m^2\ ha^{-1}\ d^{-1}$
RDLVS		rate of dying of leaf for the 3 localities	$kg\ ha^{-1}\ d^{-1}$
RDNLVS		rate of dying of non-leaf for the 3 localities	$kg\ ha^{-1}\ d^{-1}$
RDRAT	F	relative rate of decline in parameters AMAX and EFFE (RDRA) as a function of cumulative relative deficit of transpiration (CTRDEF)	1
RDRDT	F	relative death rate (RDRD) as a function of stage of development of the crop (DVS)	1
RDTDF		rate of decrease in transpiration deficit for the 3 localities	$mm\ d^{-1}$
REDFDT	F	reduction factor for evaporation due to drying of soil (REDFD) as a function of dimensionless water content of top soil compartment (WCPR)	1
REDTTB	F	multiplication factor for root growth (RFRGT) as a function of temperature of soil (TS)	1
REFCF	P	reflectance of water	1
REFT	P	reference temperature for maintenance of respiration	°C
REPL6		dummy argument in CRITEW subroutine: code returned to subroutine EWMOVE indicating possibility of stocking the locality with ewes	1
REPL7		code returned from subroutine CRITEW to subroutine EWMOVE indicating possibility of stocking the locality with ewes. 1 = could be stocked, 0 = could not be stocked	1
RFDVST	F	reduction factor for transpiration (RFDVS) as a function of stage of development of the crop (DVS)	1
RGR2L6		relative growth from emergence to current time of decision in algorithm for early-season grazing of green wheat	d^{-1}
RHOCP	P	volumic heat capacity of air	$cal\ cm^{-3}\ °C^{-1} = 4.2 \times 10^6\ J\ m^{-3}\ K^{-1}$
RITDF		rate of increase in transpiration deficit for the 3 localities	$mm\ d^{-1}$
RL3		scaled rate of retention of energy	1
RP1	P	parameter in equation for content of net energy in the sheep foetus and gravid uterus	1

RP2	P	parameter in equation for content of net energy in the sheep foetus and gravid uterus	1
RP3	P	parameter in equation for content of net energy in the sheep foetus and gravid uterus	1
RP4	P	parameter in equation for requirement of net energy for pregnancy	1
RP5	P	birth weight assumed in equation for content of net energy in the sheep foetus and gravid uterus	kg
RRAMAX		rate of recovery of light-saturated photosynthesis (areic mass of CO_2 with respect to ground area and to fraction of day) for leaves in the 3 localities	kg ha^{-1} h^{-1} d^{-1}
RREFFE		rate of recovery in effectiveness of photosynthesis (areic mass rate of CO_2) for individual leaves in the 3 localities	kg ha^{-1} h^{-1} W^{-1} m^2 d^{-1}
RS	P	minimum stomatal resistance	d cm^{-1}
RT		auxiliary variable in computation of rates	1
RTD	IY	rooting depth for the 3 localities	mm
RTWGHT	IR	root biomass for the 3 localities	kg ha^{-1}
RWFB		rate of flow of water from bottom of previous soil compartment in the 3 localities	mm d^{-1}
S	P	'grazing efficiency' or slope of the rising section of the ramp function of intake per animal in algorithm for early-season grazing of green wheat	ha d^{-1}
SDCM		dummy argument in CUMPR function: standard deviation of mean predicted yield of wheat grain	kg ha^{-1}
SDY		standard deviation of mean predicted yield of wheat grain	kg ha^{-1}
SDYGY		dummy argument in GRYPRO subroutine: standard deviation of mean predicted yield of wheat grain	kg ha^{-1}
SDYHY		standard deviation of mean predicted yield of wheat grain	kg ha^{-1}
SDYL5		standard deviation of mean predicted yield of wheat grain	kg ha^{-1}
SDYL6		standard deviation of mean predicted yield of wheat grain	kg ha^{-1}
SEADY		time in season (from 30 September)	d
SEADYGY		dummy argument in GRYPRO subroutine: time in season (from 30 September)	d

SECTSB		indicator of pathway in algorithm	1
SELL	IR	switch for selling lambs. 0 = no, 1 = yes	1
SELL8		array of components of plant for grazing: leaf; non-leaf; seed; dead leaf; dead non-leaf. 0 = not grazed, 1 = grazed	1
SLCVR	IY	soil cover used in calculation of light transmission for the 3 localities	m^2 ha^{-1}
SLPAF		variable for linear interpolation in AFGEN function	1
SLPTV		variable for linear interpolation in TWOVAR function	1
SLVWT	P	maximum liveweight of lambs at sale	kg
SLW	IR	liveweight of lambs at sale	kg
SNGLB		stocking rate of single lambs at birth	ha^{-1}
SNGLR		stocking rate of single lambs during rearing	ha^{-1}
SOW		switch for sowing	1
SOWD	P	time of sowing from 31 December	d
SPD	P	stage of pregnancy from which pregnancy requirements are calculated	d
SPFRC	P	threshold value of MEFRCL8 below which supplementary feeds for lactating ewes are given on green or dry pasture	1
SRL8		stocking rate of ewe or lamb at current locality	ha^{-1}
STARDY	P	time of starting simulation from 31 December	d
STBL	IY	biomass of wheat straw baled with respect to system area at time of current decision	kg ha^{-1}
STLEFT	P	biomass of straw left in field by baler	kg ha^{-1}
STMNSB		biomass of aftermath that would exactly cover cost of baling straw with respect to locality area	kg ha^{-1}
STMXSB		maximum baleable biomass of wheat straw for system	kg ha^{-1}
STRAW	IR	total stock of baled straw with respect to system area	kg ha^{-1}
STROP	P	switch for baling of straw; <0 = do not bale, 0 = bale according to normal criteria, >0 = bale maximum if value greater than costs of baling	1
SUPQ	P	metabolizable energy rate of supplementary feed given to ewe per unit deficit of body condition score	MJ d^{-1}
SUPVL5		vector of optimum rate of supplementary feeding to lamb for each locality	kg d^{-1}

SYGY		sum of predicted values of yield of wheat grain	kg ha^{-1}
SYSGY		sum of squares of predicted values of yield of wheat grain	kg^2 ha^{-2}
T1L6		time index in DO loop for integration of grazing dynamics in algorithm for early-season grazing of green wheat	d
TADRW	IR	total aerial (live + dead) biomass for the 3 localities	kg ha^{-1}
TAF		dummy argument in AFGEN function: data matrix	1
TCDPH	P	time constant for build-up of cumulative transpiration deficit	d
TCDRL	P	time constant for dying of leaf through shortage of water	d
TCDRNL	P	time constant for dying of non-leaf through shortage of water	d
TCK	P	thickness of consecutive soil compartments	mm
TCRPH	P	time constant for decline in cumulative transpiration deficit	d
TDB		depth to bottom of soil compartment	mm
TDRAIN	IY	cumulative loss of water by deep drainage below depth of 180 cm for the 3 localities	mm
TDRWT	IR	total aerial and subterranean biomass for the 3 localities	kg ha^{-1}
TDVS1	IR	time from emergence at which DVS reached 1 for the 3 localities	d
TECT	F	reduction factor for root conductivity (TEC) as a function of temperature of soil (TS)	1
TEMY	IY	ewe's cumulative production of milk from start of current lactation	kg
TENTL6		time of entry by stock in algorithm for deferment of grazing on green pasture	d
TEVAP	IY	cumulative evaporative loss of water from soil for the 3 localities	mm
TIME		time from start of simulation	d
TIMEDY		dummy argument in DIARY subroutine: run time	d
TIMN	P	initial minimum temperature of soil	°C
TIMX	P	initial maximum temperature of soil	°C
TL6		time index in DO loop for integration of grazing dynamics in algorithm for deferment of grazing on green pasture	d
TMPDL		temperature array in DELAYT function	°C

TMPSUM	IY	temperature sum from onset of germination for the 3 localities	°C d
TOL	P	tolerance limit of CPUG for finding optimum rate of supplementary feeding for lambs	$ kg^{-1}
TOPTL5		number of feasible lamb movements	1
TOTA	IY	annual summary matrix of performance of system	1
TOTB	IR	between-year summary matrix of performance of system	1
TOTINF	IY	cumulative infiltration of water into the soil	mm
TOTRAN	IY	cumulative transpiration for the 3 localities	mm
TPEVAP	IY	cumulative potential evaporative loss from soil for the 3 localities	mm
TPIE	IY	cumulative intake of herbage (pasture or wheat) by ewes	kg ha^{-1}
TPIL	IY	cumulative intake of herbage at all localities by lambs	kg ha^{-1}
TPLIE	IY	cumulative intake of poultry litter by ewes	kg ha^{-1}
TRAIN	IY	cumulative rainfall	mm
TRAN		actual rate of transpiration for the 3 localities	mm d^{-1}
TRR		rate of uptake for transpiration from a single soil compartment for the 3 localities	mm d^{-1}
TS		average temperature of soil: 10-day running average of air temperature	°C
TS10		auxiliary variable in computation of TS	1
TSBL8		total availability of biomass selected at locality	kg ha^{-1}
TSILF	IY	cumulative intake of concentrates by lambs at fattening	kg ha^{-1}
TSO		auxiliary variable in computation of TS	1
TSUMG	P	temperature sum required for emergence	°C d
TVEGM	IR	total biomass of green leaf and green non-leaf at the 3 localities	kg ha^{-1}
TWNLB		stocking rate of twin lambs born	ha^{-1}
TWNLR		stocking rate of twin lambs reared	ha^{-1}
TWOVAR		value returned by linear interpolation in TWOVAR function	1
VETC	P	veterinary costs per ewe	$ year^{-1}
VL6		aerial biomass in algorithms for deferment of grazing on green pasture and early-season grazing on green wheat	kg ha^{-1}
VRES		ungrazable residual biomass for the 3 localities	kg ha^{-1}
VRESD	P	ungrazable residual biomass for dry herbage	kg ha^{-1}

VRESG	P	ungrazable residual biomass for green herbage	$kg\ ha^{-1}$
VSATD	P	dry biomass at which rate of intake per animal reaches satiation for locality	$kg\ ha^{-1}$
VSATG	P	green biomass at which rate of intake per animal reaches satiation for locality	$kg\ ha^{-1}$
VSATL8		biomass at which rate of intake per animal reaches satiation	$kg\ ha^{-1}$
VSURPSB		surplus baleable biomass of aftermath remaining after deducting expected requirements for grazing for locality	$kg\ ha^{-1}$
W		amount of water in a soil compartment for the 3 localities	mm
WAAG		area fraction of system to wheat available for grazing	1
WACH		area fraction of system to green wheat to be cut for hay	1
WAGRE	IR	area fraction of system to green wheat allocated for grazing by ewe as an alternative to grain at current decision time in system	1
WAGRL	IR	area fraction of system to green wheat allocated for grazing by lamb as an alternative to grain at current decision time in system	1
WAXL6		area fraction of system to green wheat that would be allocated for grazing as an alternative to grain	1
WCLIM		volume fraction of water in air-dry soil	$m^3\ m^{-3} = 1$
WE	P	exponent of liveweight in equation for requirement for maintenance	1
WEAN	IR	switch for weaning lamb. 0 = no, 1 = yes	1
WEANED	IR	indicator of weaning status. 0 = not weaned 1 = weaned	1
WEWE	IR	liveweight of ewe	kg
WGCMPE	P	array of components of green wheat selected by ewes during strip-grazing as an alternative to grain. Order: live leaf; live non-leaf; seed; dead leaf; dead non-leaf. 0 = not grazed, 1 = grazed	1
WGCMPL	P	array of components of green wheat selected by lambs during strip-grazing as an alternative to grain. Order: live leaf; live non-leaf; seed; dead leaf; dead non-leaf. 0 = not grazed, 1 = grazed	1

WGTML	P	time limit of early-season grazing of green wheat from emergence	d
WGWF	P	wastage factor in strip-grazing of green wheat as an alternative to grain	1
WLAM	IR	liveweight of lamb	kg
WLTPT	P	volume fraction of water in soil at wilting point	1
WLVS	IR	biomass of live leaf for the 3 localities	kg ha^{-1}
WLVSI		initial biomass of leaf for the 3 localities	kg ha^{-1}
WNLVS	IR	biomass of live non-leaf for the 3 localities	kg ha^{-1}
WNLVSI		initial biomass of non-leaf for the 3 localities	kg ha^{-1}
WREDT	F	reduction factor for uptake of water by roots (WRED) as a function of relative amount of water available in a soil compartment (AFGX)	1
WSDS	IR	biomass of seeds for the 3 localities	kg ha^{-1}
WST2BL	IY	switch for time of baling wheat straw	1
WTOT	IY	total amount of water in the soil profile for the 3 localities	mm
X1AD		dummy argument in AND function	1
X1AF		auxiliary variable in AFGEN function	1
X2AF		auxiliary variable in AFGEN function	1
X1FC		dummy argument in FCNSW function	1
X1IN		dummy argument in INSW function	1
X2AD		dummy argument in AND function	1
X2FC		dummy argument in FCNSW function	1
X2IN		dummy argument in INSW function	1
X3FC		dummy argument in FCNSW function	1
X3IN		dummy argument in INSW function	1
X4FC		dummy argument in FCNSW function	1
XCM		variable in CUMPR function: yield expressed as number of standard deviations from the mean	1
XDY		dummy argument in DIARY subroutine	1
XIL3		same as IL3 but excluding allowance for gain	1
XLFCFL3		same as LFCFL3 but excluding allowance for gain	1
XLL3		same as LL3 but excluding allowance for gain	1
XLM		dummy argument in LIMIT function	1
XMERL3		same as MER but excluding allowance for gain	1
XNT		dummy argument in NOT function	1
Y	P	array of year numbers to be simulated	year
YCM		dummy argument in CUMPR function: yield	kg ha^{-1}

YEAR	current year number being simulated	year
YPL2	current potential rate of production of milk by ewe given adequate nutrition	kg d^{-1}
YPL3	current potential rate of production of milk by ewe given adequate nutrition	kg d^{-1}
YR	number of simulated year	1
Z1L4	CPUG value 2 iterations ago	\$ kg^{-1}
Z2L4	CPUG value of previous iteration	\$ kg^{-1}
ZARC	dummy argument in ARC1 function: net energy requirement for maintenance	MJ d^{-1}
ZBASL4	net energy requirement for maintenance (excluding activity)	MJ d^{-1}
ZL1	net energy requirement for maintenance (including grazing activity)	MJ d^{-1}
ZL2	net energy requirement for maintenance (including grazing activity)	MJ d^{-1}
ZL3	net energy requirement for maintenance (including grazing activity)	MJ d^{-1}
ZL4	net energy requirement for maintenance (including grazing activity)	MJ d^{-1}

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