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MODELLING ACTIVITIES IN THE FRAMEWORK OF LIVESTOCK RESEARCH: CONSIDERATIONS OF A WORKSHOP HELD AT ADDIS ABABA, 1983

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I. BACKGROUND

System analysis, simulation and modelling have become accepted techniques in agricultural research, since their introduction in the late sixties (De Wit, 1970b) although they have not been widely used. Various agricultural systems have been modelled in the past decade with varying success (Penning de Vries, 1983). This has created a situation where there is doubt as to whether the technique is useful or appropriate in view of the existing limits of knowledge at the biological level (Monteith, 1981). However, there seems to be as yet no other tool that matches it with respect to its ability for summarizing existing knowledge into a coherent framework, for testing the truthfulness of the consistent opinion expressed in the model and for using that opinion to evaluate the reactions of a system to intentional or chance perturbations.

Within the activities on systems analysis by the Centre for Agrobiological Research (CABO) of the Ministry of Agriculture and Department of Theoretical Production Ecology (TPE) of the Agricultural University the major emphasis has been on the modelling of primary production of crops and vegetations. Parts of these activities were carried out in cooperation with the Agricultural Research Organization (ARO) in Israel, especially with respect to the primary production under (semi-) arid conditions. Within that framework some attention was paid to secondary production, since under those conditions the only economically viable mode of exploitation is through animal husbandry. Moreover, a substantial amount of experimental work in the field on primary and secondary production was carried out by ARO, in part in cooperation with CABO/TPE and the Botany Department of the Hebrew University of Jerusalem (Van Keulen et al., 1982a).

The activities of CABO/TPE in the (semi-) arid zone under the sponsorship of the Dutch Directorate-General for International Cooperation (DGIS) in the past decade, also included a research project in the Sahelian zone in Mali (Penning de Vries and Djiteye, 1982). In the most recent research planning statement of CABO it was emphasized that the Institute will continue to direct a substantial proportion of its scientific capacity to development-oriented research (Meerjarenvisie CABO, 1982-1986). An outline for the organization of that research was submitted to DGIS, including the proposal for two projects to be executed in the first phase. One of these projects is concerned with the integration of the systems approach for primary and secondary production with a special view on the situation in sub-Saharan Africa.

The International Livestock Centre for Africa (ILCA) in Addis Ababa, Ethiopia, one of the research institutes funded by the Consultative Group on International Agricultural Research (GGIAR) has a mandate to improve livestock production throughout sub-Saharan Africa. As part of their activities in this field, ILCA has been working on a model of cattle herd dynamics (Konandreas and Anderson, 1982) with the aim of using it for the study of cattle herd productivity.

The existing models of primary production of the CABO/TPE group and that of secondary production of ILCA seemed a promising starting point for the activities related to the integration of both agricultural systems. In 1981 therefore, a joint meeting of CABO and ILCA was held together with the Institut du Sahel in Bamako, Mali, which is responsible for the coordination of development-related activities in the Sahelian zone. In this meeting it was decided to carry out activities towards the integration of primary and secondary production models in a joint program. However, each of the institutions would be responsible for its own part.

In order to familiarize the parties concerned with each other's activities and to formulate a framework for coordination, a joint workshop of ILCA, CABO and ARO was held during the first week of January 1983, at ILCA's headquarters in Addis Ababa, in which staff members of the three organizations participated (Appendix I).

This report was written as a result of that workshop. It does not claim to be a report of the meeting, but a statement of the positions held by the parties concerned.

II. PRIMARY PRODUCTION MODELS

II.1 State-of-the-art of primary production models (CABO/TPE/ARO)

The activities of CABO/TPE in the field of primary production modelling started at the end of the sixties under the leadership of Prof. de Wit. In the first instance these activities aimed at the quantitative description of growth and production of green crop surfaces, adequately supplied with water, nitrogen and minerals, growing in a disease and weed free environment, i.e.

under optimum conditions (De Wit et al., 1970). This resulted in the Elementary Crop Growth Simulator (ELCROS), a model that has never been published in full. Improvements in and extensions to the structure of the model, especially at the plant physiological level were later introduced. The resulting model was published in full in 1978 (De Wit et al., 1978), with a number of validations especially concerning maize. The model, named Basic Crop Growth Simulator (BACROS) is basically a plant physiological model, containing a great deal of detail with respect to the functioning of various plants organs.

However, the model can (and is) also be(ing) used to generate input data for less detailed models of primary production. Such inputs may for instance be the daily level of gross CO_2 assimilation of plant covers as a function of geographical latitude and time of the year.

The model has subsequently been applied to simulate the primary production of other crops such as Rhodes grass (Dayan et al., 1981).

On the basis of information generated with the model BACROS a simplified model for growth under optimum conditions has been developed. This can, in principle be applied to any annual crop, provided that the crop specific parameters are available in sufficient detail (Van Keulen et al., 1982b).

In the early seventies, when the project in the Northern Negev in Israel was carried out, a model was developed to simulate primary production of natural pastures under conditions where water is the main limiting factor. This required the introduction of the water balance of the soil into the model, and the reaction of the crop to suboptimum moisture supply (Van Keulen, 1975). Because in this situation, water exerts such a strong influence on production, the description of some of the plant physiological processes can be much simplified, without affecting the results of the model.

However, during model development, it became clear that phenological parameters, describing the rate of development of the crop had to be quantified. The development stage exerts a strong influence on the dry matter partitioning in the vegetation and hence on the green area development. Similarly, in some situations crop growth ceased as a result of maturity rather than lack of additional available water. For the Mediterranean situation the use of a temperature-dependent development rate yielded good results, but for the Sahelian conditions the effects of photoperiodism had to be taken into account. Application of this model to the Mediterranean situation (250 mm annual winter rainfall) as well as to the Sahelian situation (500 mm annual summer rainfall) showed that the model was able to predict total dry matter production, as well as the production of various plant organs (roots, leaves, stems, seeds) with reasonable accuracy, on the basis of soil and weather parameters (Van Keulen et al., 1981; Stroosnijder, 1982).

One of the problems still left in this type of model is the prediction of the initial biomass, i.e. the above ground biomass present at emergence. That quantity depends on environmental conditions such as the pattern of early rainfall and the heterogeneity of the soil surface. It is also influenced by the history of the site, which determines the quantity and composition of the seed stock in the soil.

Although models of germination of multispecies seed mixtures have been developed (Spitters, 1980; Janssen, 1974), these are in general too detailed to be incorporated in models at this level of resolution. Some estimate of initial biomass must therefore be made on the basis of knowledge of a particular site.

This model, ARID CROP, is still rather detailed and proceeds in time with steps of one day. However, on the basis of the results obtained it has been shown, that more simplified descriptions (models) may yield useful results, for instance for prediction of country-wide yields of certain crops (Van Heemst et al., 1978) or for crop yields at specific regions or sites (Van Keulen and De Milliano, 1984; Van Keulen, 1980).

Essentially the same description is used in the model developed in the frame-work of the Centre for World Food Studies (CWFS) in which CABO is one of the participants. The degree of detail in this model is, however, less than in ARID CROP, since it covers the growth period with time steps of 10 days. The model is basically intended for land evaluation purposes and can be used in connection with an economic model (Van Keulen and Wolf, 1984).

In the research projects carried out in the northern Negev and in the Sahelian zone, it became increasingly clear that under these conditions in the majority of years, not water, but nutrient availability was the major constraint for crop production. A yearly nitrogen balance model was therefore developed for Mediterranean conditions. In that model nitrogen availability to the vegetation was described on the basis of the annual inputs to and losses from the system. Primary production was then calculated on the basis of uptake by the vegetation applying a nitrogen-availability dependent concentration of the element in the biomass (Harpaz, 1975).

A more detailed primary production model was subsequently developed in which growth and production could also be influenced by nitrogen availability to the crop (PAPRAN). This model is in essence an extension of the one dealing with water as a limiting factor only, where the nitrogen balance of the soil is described quantitatively. In addition to the weight of the various plant parts, their nitrogen content is simulated. The model has been validated mainly with data from the natural vegetation in the northern Negev. The validations showed that dry matter production and nitrogen content of the vegetation could be simulated with reasonable accuracy, if the availability of nitrogen from the soil could be predicted accurately enough. However, quantification of the processes affecting the nitrogen cycle in the soil proved to be a major problem (Seligman and Van Keulen, 1981; Van Keulen, 1982b). Apparently, the formulations used in the model are too descriptive in character, rather than explanatory. Application of the model outside the range of conditions for which it has been calibrated and validated should be done with caution. For specific conditions it may however be possible to find suitable descriptive formulations defining the availability of nitrogen in the soil (Stroosnijder and Van der Pol, 1982). Under such conditions it may be possible to apply the model nevertheless.

Along the same line a model has been developed for wheat production under conditions where water and/or nitrogen may be the limiting factor (Van Keulen and Seligman, 1984). In this model, special attention is paid to the influence of external and internal factors on organ formation in the plant, which is of prime importance for the determination of seed yields. It seems at this stage that this model could serve as a useful basis for similar models applicable to other grain crops, such as sorghum, or rice. These exercises have however not been carried out.

Another possibility exists to account for the influence of nitrogen availability on crop production. This is a static, rather than a dynamic procedure. It is based on the observation, that for a particular crop species, a unique relation exists between yield and nutrient uptake, irrespective of environmental or growing conditions. Knowledge of the total amount of a plant nutrient available to the crop during its entire growth cycle may then be translated into the possible yield, using that relation (Van Keulen, 1982b).

A disadvantage of this method, especially with respect to annual herbaceous species is that the relation between uptake and yield changes with the degree of maturity of the vegetation. It can hardly be used therefore in situations where exploitation may take place at different stages of the plant's life cycle. It might however be possible to combine the descriptive dynamics of nitrogen in the soil with the phenology-dependent characteristic nitrogen contents to arrive at a time-dependent nitrogen concentration in the vegetation.

Natural vegetations always consist of a mixture of species, which vary widely in their physiological properties (Breman et al., 1982; Lof, 1976). Some attention has been paid therefore to the growth of plant mixtures. An early theoretical treatise on the subject was developed by De Wit (1960) and in subsequent years this theory was applied within CABO to various competitive phenomena (De Wit et al., 1966, De Wit, 1970a). This early work was still relatively simply and could hardly be used to analyze the dynamics of multi-species vegetations in the field. In recent years, simulation models for the behaviour of plant mixtures have been developed, based on the quantitative description of relevant plant parameters (Spitters and Aerts, 1983). It appears that the relative availability of essential resources, particularly plant nutrients, is already determined at an early stage in plant development and the quantitative description of those early stages is therefore important. In this respect, the simulation of multi-species vegetations is therefore linked to the problem of simulating initial biomass. In fact, however, little has been done to evaluate the behaviour of these models for the field situation.

II.2 Critical evaluation of the state-of-the-art

As detailed in the preceding section, a wide range of primary production models are available, varying in detail, applicable under different conditions and providing predictions of various plant characteristics. However, for applicability in integrated primary/secondary production models (without specifying at this stage what form the integration should take) a number of limitations are apparent.

- The descriptive character of the processes of the nitrogen cycle in the soil is a serious limitation for the use of these models for extrapolation and prediction. That part of the models must therefore be improved so as to define the explanatory character of the functional relations used in the models.

- Little attention has been paid to simulation of the processes of the phosphorus cycle in the soil and its consequences for the availability of this element to the vegetation. Even well-validated descriptive formulations are lacking at present although some attempts in this direction have been made (Stroosnijder and Van der Pol, 1982).

- Virtually all of the models have been applied to describe and predict growth of annual plants, growing from seed each year. An exception is the optimum-production model that has been validated for such perennials as Rhodes grass and rye-grass. However, one of the major phenomena related to growth of perennials is the process of internal circulation of both carbon and nitrogen. Some experience has been gained with the former (Van Keulen and Zipori, 1980) but very little has been modelled or is known indeed for the latter. For a complete description of semi-arid grazing ecosystems, models of the growth of perennials, both under undisturbed conditions and under exploitation, seem indispensable.

- Various plant characteristics can be predicted by the models. These include weight of plant organs and their nutritional status, especially nitrogen content, throughout their growing cycle. However, to enable proper interfacing with secondary production models, an additional characteristic of quality is necessary. This characteristic is most often referred to as digestibility and has been related to plant age, its chemical composition or its morphogenetic properties. However, at this stage none of these allow valid prediction of this parameter. It is necessary therefore to develop practical concepts to enable the description of such a quality characteristic.

- Little attention has been paid to long-term dynamics of ecosystems. That holds for the influence of exploitation on chemical soil properties (exhaustion) as well as for the influence on physical soil properties (crust formation; degradation). For a quantitative description of grazing systems such information is necessary, because (over)-exploitation may lead to irreversible changes in these properties. Moreover, exploitation may result in changes in the species composition and as such may have an influence on primary production. Attention must therefore be paid to these effects in an integrated primary/secondary production model.

III. SECONDARY PRODUCTION MODELS

III.1. State-of-the-art of secondary production models

The ILCA model for cattle herd production is an outgrowth of the modelling team in the Department of Animal Science at Texas A & M University (TAMU) which developed a general cattle production systems model (Sanders and Cartwright, 1979a, b). The primary objective for the development of both the ILCA and the TAMU models was to study differences in both biological and economic efficiency of beef production systems involving different cattle types, various management schemes and variable environmental conditions.

The TAMU model is essentially a nutritional model. Inputs from the environment are the feed resources specified as energy available to animals. The model simulates the flow and partitioning of this energy in a herd as influenced by animal characteristics and management decisions. Animal performance primarily in terms of milk and live animals and secondary in meat and animal draft as derived from energy balances, constitutes the output.

Differences in environments are mainly represented by variable feed resources. Differences in cattle genotypes are introduced as different production potentials, which means that animals differ in their capacity to absorb and utilize energy for biological functions such as growth and milk production. The model can simulate an unlimited number of management options. For instance, length of breeding season, weaning policy, culling and selling policy, supplementation programmes can all be varied separately or as combinations of alternatives. The TAMU model was one of the first models dealing with a whole herd. In the original model all animal categories, apart from sires, are included. Running the model gives the opportunity to evaluate a system over simulated time. The model is intended to be general with respect to major input- output relations; by changing the input parameters, the same model may be used in principle to simulate production under widely different sets of conditions.

In the TAMU model animals are treated in classes with distinct characteristics which can be subject to different management. Classification is based

primarily on age. For breeding females month of lactation and month of pregnancy are additional criteria for subdivision of age classes.
Application of the TAMU model in Botswana (ILCA, 1978) pointed to the need to have an integer model formulation, where fractional classes of stock are not simulated. Such a model allows for a continuous monitoring of individual animals throughout their lifecycle, which is of particular advantage when dealing with small herds. A further advantage is the computational efficiency of the integer approach as formulated in the ILCA model (Konandreas and Anderson, 1982). The authors also tried to account for the variability in feed resources resulting from differences in growth conditions (rainfall) between years. For this purpose, use is made of the concept of different year-types which occur each with a certain probability. Forage conditions for each year-type are specified in a digestibility, crude protein and availability vector. Each vector is composed of twelve values corresponding to the months of the year. A month is the time step of both the TAMU and ILCA models. For a particular simulation run a series of year-types are selected at random according to the probability of occurrence of the different types. This is one of the main stochastic elements of the model. Stochastic features are also introduced to model cow conception rates and mortality due to other than nutritional causes. As a result of including these stochastic elements, simulation runs with the same set of general operating conditions may yield different results from the same initial condition.

The structure of both models is very similar. For every time step Δt, the biological status of animals is recalculated starting from the situation at time t and the change taking place over Δt according to estimated intake of energy and the utilization of this energy. Individual aspects which affect changes in the biological status are represented in separate components for growth, reproduction and mortality. With regard to reproduction and mortality the model tries to distinguish between the effects of nutrition and those of other environmental factors like climate, disease load and their complex interactions. For instance, death rates have a deterministic component depending on nutritional status and a stochastic component related to all other possible causes (pests, diseases, accidents).

The first time the TAMU model was applied to African livestock production systems was in a study of the traditional cattle production system and an improved ranching system in Botswana (ILCA, 1978). The objective was to investigate the effect of interventions in both systems on biological and economic efficiency. For this aim a baseline situation was established using existing information about input and output of the two systems. Forage clipping and oesophageal sampling procedures provided data to allow estimates of the feed input parameters to be made. Animal input parameters like potential mature cow size and potential milk production in mature females, mortality due to non-nutritional causes etc., were estimated from field data on herd productivity. Validation of the model consisted of a comparison of simulated production traits like calving rate, calf mortality, weaning weight, 18-month weight and simulated growth curves with recorded data. Several production alternatives (interventions) were examined: alternative weaning ages, controlled breeding, the use of reserved pastures for specific stock classes, introduction of dry season forage plants, introduction of hand milking. Alternatives were tested alone and in different combinations. Production alternatives obviously ranged from small scale innovations to complete new technology.

The merits of the Botswana study are probably best represented by a greater awareness of the total impact of well defined interventions on herd structure and productivity. This impact becomes visible only, if herd development can be monitored on a sufficiently long term. For this purpose a time-dynamic model provides an excellent tool. For instance, reducing weaning age creates an immediate advantage for the condition and reproductive performance of the cow, but at the same time a disadvantage for the calf expressed as initially retarded growth. Whether the balance in terms of change in total herd productivity will be positive or negative can only be appreciated after a number of years. The same conclusion applies to the introduction of milking. Milking may appear attractive from an economic point of view if only accounting is done for short-term gains. However, in the longer term negative effects on reproductive performance and calf survival may affect seriously the viability of the enterprise.

The ILCA model has been applied to a practical research problem in Botswana and to a comparison of four pastural production systems in West-Africa. The Botswana study (Konandreas et al., 1983) comprised an appraisal of the comparative merits of indigenous and cross bred stock for joint production of meat and milk. The complex of tradeoffs which occur at the herd level when both meat and milk are produced by a herd, was adequately modeled, and researchers as well as policy makers considered the study to be both useful and instructive. In the West-African application De Leeuw and Konandreas (1982) compared the simulated results of herd productivity with actual productions of cattle herds in two Nigerian and two Malian regions. Reasonable agreement between model results and actual production data could only be obtained by manipulating the forage intake component of the model, beyond acceptable limits, indicating a likely problem in the specification of the intake function used in the model.

As currently specified, the model uses functions which may prove inadequate when forage on offer to grazing animals in subject to extreme seasonal variation with extended periods with feeding values below that required for maintenance.

III.2 Critical evaluation of the state-of-the-art

In a certain way we may compare the TAMU and ILCA models for secondary production with the basic model for primary production BACROS which simulates plant growth as a function of input of solar energy. These models have in common that they explain the behaviour of a system from one major driving variable. Model predictions will be satisfactory as long as the system under study is indeed governed mainly by this variable. The secondary production models were developed for environments where energy availability was considered to be the major driving force for animal performance. The question is how appropriate such a model will be for analysing many African livestock systems in which often other factors are probably of equal or perhaps even greater importance as driving variables or in other words as constraints to actual herd production. Apart from energy, available water, proteins and minerals, the occurrence of pests and diseases and climatic factors may have a large influence on final output. Pests and diseases do not only affect death rates but are also causes of reduced feed intake, retarded growth, diminished fertility etc. These interactive effects are at present not included in the secondary production model. The modular form of the ILCA model would allow their specification if data were available on these interactions and their effect on productivity. Experience with plant growth models shows increasing difficulties in modelling crop production when the number of possible constraints (radiation, water, nitrogen, phosphorus) increases and when simulation tries to approach more the real-life conditions of arid and semi-arid ecosystems. These considerations may make expectations from model predictions of herd productivity under such conditions perhaps more realistic. However, the fact itself that careful application of a model reveals deviations from expected values, makes it a valuable tool for a better understanding of the system.

Until now, application of the secondary production model seems to be hampered by several other factors viz. lack of information about input parameters, lack of validation and lack of interaction between animal performance and forage production. The structure of the secondary production model requires estimates of expected growth and milk yield based on genetic potential of breed and estimates of expected reproduction and mortality rates under a normal nutritional regime. All this information is usually derived from field data of the the system under study, as independent data for the relevant type of animals are lacking. As a consequence one may expect that the genetic potential is nearly always underestimated as the conditions for real optimum growth and milk production are seldom met under these circumstances. With regard to mortality, death rates have to be partitioned between two sources: firstly, due to nutritional stress as a result of inadequate feed supplies and secondly due to all other factors, i.e. diseases, accidents, predation etc. The result is that model parametrization, calibration and validation tend to get confounded by lack of independent data. Collecting data for the feed input parameters poses another problem. A considerable amount of sampling seems necessary. Unless the same parameters could be derived from a primary production model, there is a clear need for standardized sampling procedures to obtain reliable and comparable information about the diet composition of grazing animals.

Assumptions about the variability in forage conditions between years are extremely important for the herd dynamics. In the ILCA model, the occurrence of different year-types was introduced with their respective vectors of digestibility, crude protein and feed availability. The basis for the assumed magnitude of variations in these parameters seems at present fairly narrow and establishing vectors to any particular situation is heavily dependent on first hand experience with the system under study as seldom time series of sufficient duration are available to allow statistical estimation of the vectors. In an example data set used in the model for poor years, i.e. years with low rainfall, forage production is supposed to be low in availability and of low quality in term of digestibility. However, indications exist that with respect to quality the reverse could be true.

Model validation for African conditions has been restricted to the behaviour of the entire system. In order to find causes of discrepancies between simulated and observed output and to gain more confidence in model predictions, individual modules should be tested thoroughly. Sensitivity analyses are useful to identify critical processes in the total system. For instance, in analysing the meat-milk trade-off in production systems where milking is not as yet practiced, sensitivity analyses are helpful to trace the effect of different assumptions about uncertain parameter values such as the forage intake of calves when partially deprived of mother milk. Validation should also include the concepts of liveweight and body condition, as simulation runs showed an inadequate response of derived parameters as for example conception rate.

Finally, the lack of interaction between herd and environment, the absence of short and long term effects of grazing on feed resources limits the scope of model application. More information about this interface will certainly extend the usefulness of both primary and secondary production models.

IV. COMBINING PRIMARY AND SECONDARY PRODUCTION MODELS

IV.1 Introduction

In the workshop there seemed to be a consensus that it would be useful to aim at an integration of the primary and secondary production models. For those modelling primary production in (semi-)arid regions, the prediction of primary production as such is of little use, because arable farming cannot be practiced to any extent because of the low and erratic precipitation. Economic benefit from primary production in these areas can only be achieved through exploitation by animals and any evaluation of production systems should therefore include animal performance. For those engaged in research on livestock performance and especially modelling secondary production, an essential input to the system is the availability of forage. Since the mandate area of ILCA contains a large number of primary production sites, differing in soil properties, species composition and annual rainfall, it seems virtually impossible to obtain experimental data covering all these systems. Moreover, there is a high year-to-year variability, especially in amount and distribution of rainfall, which also leads to wide variations in forage availability. The measurement of this would require long-term costly and laborious experimentation. Use of a simulation model, able to predict primary production on the basis of existing information, notably on weather data, which more are generally available, would minimize the need for such experimentation.

A joint effort of the CABO/TPE/ARO group and ILCA aimed at the development of such an integration was therefore considered worthwhile.

IV.2. Objectives

Development of models applicable to the analysis of agro-pastoral and pastoral systems with a special view to the case of the grazing bovine in tropical Africa. The analysis should in first instance concentrate on the following topics:

- determining the actual constraints of various systems.
- evaluating the impact of prospective interventions on the biological and economic performance of these systems.
- developing alternative agro-pastoral or pastoral systems.

IV.3. Strategies

- Definition of the relevant modules of the system.
- Establishing functional relations between the various modules.
- Establishing the variables necessary to quantify the functional relations.
- Improving and extending the structure and internal relations of the individual models to arrive at more explanatory formulations.

With respect to the latter point specific recommendations were made:

Primary production model

1. To develop models to predict the biomass production of perennial as well as annual pasture plants.
2. To account for the effects of defoliation on future growth and composition of the vegetation.
3. To incorporate the above to predict the accretion of biomass in a grazed mixed vegetation system.
4. To influence estimates of biomass quality as for example nitrogen content, digestibility, cell wall content.

Secondary production model

5. To further refine the formulations with particular reference to factors determining energy and protein intake, reproduction and mortality.

Integrated model

6. To evaluate the extent of interactions of the grazing animal on the primary production through, e.g. defoliation, trampling, application of dung and urine, etc.
7. To validate the model using biological data sets.
8. To determine the degree of complexity required to give adequate predictions of overall herd and pasture productivity.

IV.4. Priorities and responsibilities

In the final sessions of the workshop, those subjects requiring the highest priorities for a useful integration of models of primary and secondary production were identified and institutional responsibilities, either stemming from the joint project or otherwise acquired, were discussed.

IV.4.1. Primary production (CABO/TPE)

Phosphorus: For quite a number of production systems, availability of phosphorus to the vegetation is one of the determinants for primary production. It is necessary therefore to include that in primary production models. For annual vegetations it may be possible to introduce the influence of phosphorus content on primary production based on the P/N ratio concept developed in the project Primary Production in the Sahel (PPS). In first instance, phosphorus availability in the soil should be incorporated as a descriptive function without going into the dynamics of the element in the soil. The latter is subject of a special study carried out in the framework of the Centre for World Food Studies (CWFS), but it is unlikely that that will produce useful results within the period envisaged for the present project.

Perennial species: The contribution of a complex variety of perennial species to the forage on offer is substantial for a large number of animal production systems in the ILCA mandate area. A prediction of the quantity and quality of this component is therefore necessary for the description of the integrated system. Within the CABO/TPE group attention should therefore be paid to the modelling of such species with special emphasis on the internal cycling of nitrogen and carbon. It may be worthwhile to check up on existing models of perennial species.

Effects of grazing on primary production: The interaction between primary production and secondary production must deal with the effects of the latter on the former. Two phenomena may be distinguished in this respect: the direct effect of removal of part of the green material during the growing season on primary production. That seems for most of the African grazing systems only of minor importance; stocking density is generally so low in relation to the amount of growth and the growing season so short, that the effect of the amount removed maybe negligible. The indirect effect of grazing through exhaustion of the nutrient store in the soil and the risk of physical soil degradation, when insufficient biomass is left at the end of the dry season, seem much more important. However, modelling work on the long-term dynamics of these variables is difficult to envisage at this moment. It seems within the present framework necessary therefore to resort to some ad-hoc decisions on the treatment of these phenomena.

Burning: In many animal production systems burning is an indispensable management practice to assure availability of high quality forage during a critical part of the year. Two main effects can be distinguished; the first one relating to the loss of part of the plant nutrients present in the vegetation from the system; the second relates to the regrowth of perennial species after burning. The first process is related to the previous subject and will not be treated separately here. The second one is related to the waterbalance in the soil, since regrowth can only take place, if residual moisture is available to the plant and to the growth characteristics of perennials notably the remobilization of carbon and nitrogen from their root system. That process should thus be treated in this context.

IV.4.2 Primary/secondary production (ILCA/CABO/ARO)

Intake mechanisms: This seems to be a key issue in the linkage of primary and secondary production models, since it translates the amount of material present at a particular point and its composition, into intake by the animal. In first instance, it is necessary to further develop animal behaviour sub-model(s) to improve the relation between availability of forage and intake by the animal for different types of forage. It is not clear at this stage whether sufficient experimental data can be found (or collected) to actually validate such a model.

High priority must be given to the definition of parameters, characterizing forage quality in addition to crude protein content. At this stage, cell wall constituents (Van Soest, 1982) as wel as other plant components such as tannins seem to be promising. Some experimental work is needed to determine such new parameters as a function of the development stage of the vegetation (could probably be done in CABO controlled environment), as well as existing ones such as digestibility and protein content. In ILCA, work is being carried out to determine these characteristics for species important in the Ethiopean situation. It was emphasized that under certain conditions animal intake may not meet maintenance requirements even though sufficient material of acceptable quality is available. A point that needs attention is the influence of selectivity of the animal. Quality distribution in a given vegetation should be described quantitatively and a relation with animal intake established. A plea was made for the execution of a comprehensive experiment in which intake of different "classes" of animals (calves, barren females, lactating females, etc.) grazing under the same conditions can be compared. However, this would be difficult to realize.

IV 4.3 Secondary production (ILCA/ARO)

Reproductive performance: The test runs executed with the ILCA model (De Leeuw and Konandreas, 1982) seem to indicate an unsatisfactory description of animal reproductive performance. However, only a limited data base is available. Present experiments in ARO may provide a wider base. There may also be a possibility for a larger body of reproduction data collected in Zimbabwe as well as in other ILCA studies, to shed some light on this problem.

Mortality: The description of mortality from causes other than malnutrition is completely descriptive in the present model and can therefore hardly be used to predict the effects of changes in management. It is likely that data coming available in the near future from ILCA's country programs may provide a basis for an improved description of this process.

It was further suggested to carry out a sensitivity analysis with the secondary production model to establish the relative importance of mortality on model output.

Water: The present model lacks any effect of water availability on animal intake and performance, except indirectly through the walking distance specified. There is no doubt as to the importance of water availability in the various production systems under the ILCA mandate. It seems therefore worthwhile, to analyse existing data both on the effects of water on animal performance and on the role of water in production systems.

Diseases: No explicit description of the influence of pests and diseases is incorporated in the model at present. Nevertheless, disease load seems to be one of the most important parameters determining herd productivity in the sub-Saharan animal production systems. The topic is complex and would require substantial effort to model satisfactorily even though the integer and modular form of the ILCA model lends itself to inclusion of a disease module.

Multi-species: It is recognized that for overall productivity in many animal production systems the contribution of small ruminants (and possibly camels) is of great importance. However, there is no possibility of working directly on models pertaining to other animals than cattle at the moment. Contacts with CRSP in Nairobi and/or Texas A & M have been established for this purpose.

V. PRACTICAL IMPLICATIONS

In order to maintain a viable cooperation between the various parties in the joint effort, a number of conditions should be met:

- it is necessary that in each of the participating institutions one person is responsible for maintaining the contacts, and some personal involvement of these scientists in the end product is indispensable;
- the linkage between the primary and secondary production models should be effectuated, so that more time is not lost for this purpose;
- in all participating institutions parallel work must effectively continue to improve the concepts and the structure of the models involved. Models that reach a static state in a situation where still doubt exists about the conceptualization tend to become obsolete in a very short term;
- it would be desirable to specify at short notice what actually the first system(s) will be that will be analyzed with the integrated model, so that data collection, both for input and for validation can be carried out concurrently;
- it seems necessary to decide shortly on a follow up meeting and on a tentative agenda for such a meeting, especially in view of the many obligations that interested parties have.

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APPENDIX: LIST OF PARTICIPANTS

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