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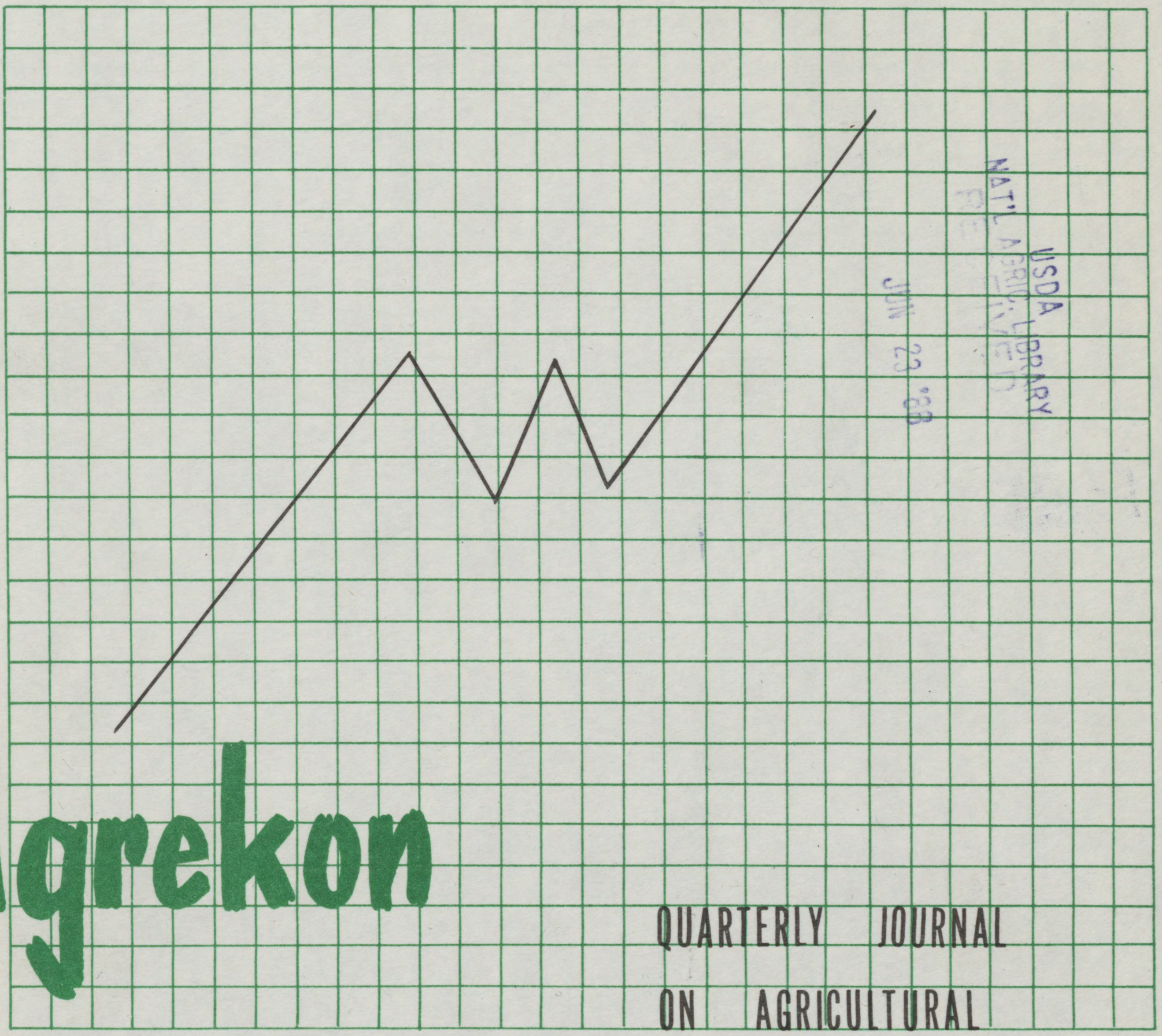

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THE DEVELOPMENT OF A DAIRY FEED PLANNING MODEL

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1. INTRODUCTION

Building computer models for agricultural research and extension can be a long and costly process involving a number of different fields in agriculture. It is therefore important to consider only those factors relevant to the ultimate objective of the model.

Dairy farming is possibly among the most complex of farming enterprises, since it not only involves the production of feed, but also requires the balancing of feed rations on a daily basis 365 days a year. Animals cannot be neglected for short periods of time, or even fed a lower than average quality ration for a few critical months (from a feed promotion point of view) since this will affect not only animal production (milk) during the period of poor feed, but also for the rest of the cows' current lactation and even future lactations.

Planning a dairy ration involves, directly and indirectly, up to eighty per cent of variable costs associated with milk production. Farm study groups show that purchased feed makes up a substantial portion of total feed costs (Berry and Whitehead). Farm-produced feed is cheaper than purchased feed but of lower quality. Surveys indicate that fertiliser, labour and machinery are the most important of the costs associated with the production of feed on a farm. Ideally, therefore, a computer model aimed at planning dairy feed rations should take almost all aspects of dairy farming, including purchased feeds, into account.

The purpose of this paper is to develop a feed planning model for dairy farms in Natal with a view to establishing guidelines as to which factors/options are more relevant with regard to dairy feed planning and should be included in future models and which factors could be left out with minimal effect on the results obtained. The model is aimed at providing data for individual farms and is based largely on data already stored in the computer. The matrix demonstrating the interdisciplinary nature of farm decision-making contained 3 200 rows and 16 000 columns, which is large by any standard.

* Paper is based on M.Sc. Agric. thesis of first author entitled "A Linear Programmed Feed Model for Dairy Farms in Natal", 1981

2. STRUCTURE AND COMPONENTS OF THE LINEAR PROGRAMMED FEED MODEL

The model was built on the premise that planning an optimum dairy ration and planning a dairy farm could not be regarded as two separate steps, but rather that both were interrelated parts of a single planning process. This required that as many different factors be built into the model as might have a significant effect on the composition of the dairy ration.

2.1 Diagrammatic representation of the model

Figures 1 and 2 are diagrammatic representations of the complete model, consisting of 15 submatrices which can be grouped into five groups of decision processes. The model has a planning period of one year and within the model use is made of both annual and monthly time periods to increase flexibility and accuracy of prediction.

Because of the size of the complete model, a matrix format of the model is shown in Fig. 1.

(i) Submatrix 14 contains purchasing activities for all farm inputs as well as all costs included in the model. These inputs are converted where feasible into physical units for transfer to those enterprises using the inputs. There are 33 separate cost and input items in the model, restricted by either the capital investment restriction or the operating cost restriction.

(ii) Submatrix 15 contains selling activities for farm produce, this being milk and maize grain. Both milk and maize grain are transported from one place to another in physical units, litres and tons respectively.

(iii) Submatrix 13 contains mechanisation planning activities. This submatrix makes allowance for the purchasing of tractors, implements, combines etc., their link-up and resultant work rates for each tractor/implement combination on a monthly basis. Inputs to this submatrix are: fixed and variable machinery costs, fuel and labour requirements. Output is the available working time for each mechanised operation on a 200 hour monthly basis (e.g. ploughing for each month from January to December).

(iv) For many farm operations involving machinery there is a certain flexibility in the timing of the operation. For example, on a

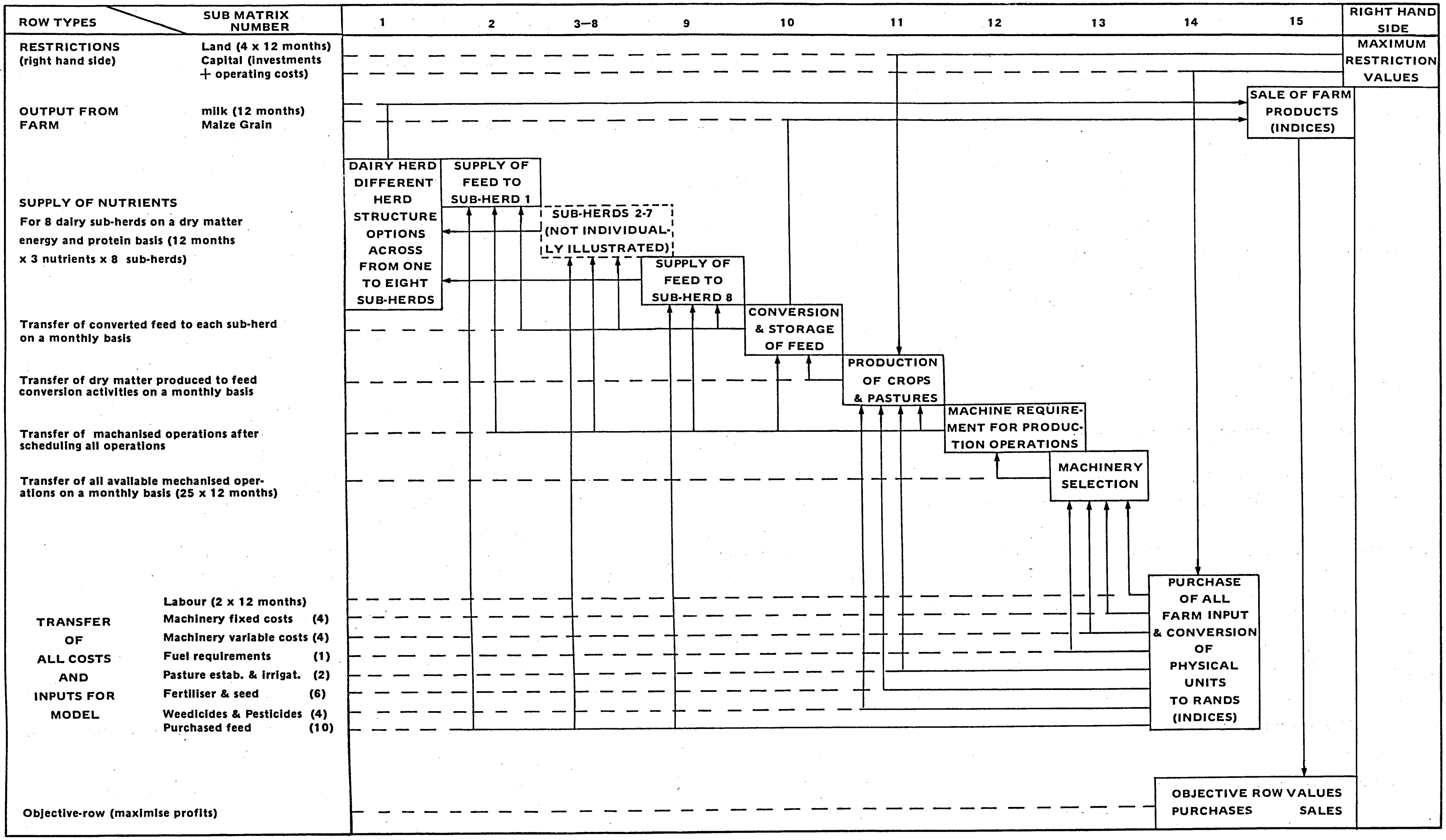

FIGURE 1 - DIAGRAMMATIC REPRESENTATION OF THE COMPLETE FEED PLANNING MODEL IN MATRIX FORMAT
(Bracketed figures refer to number of rows in matrix)

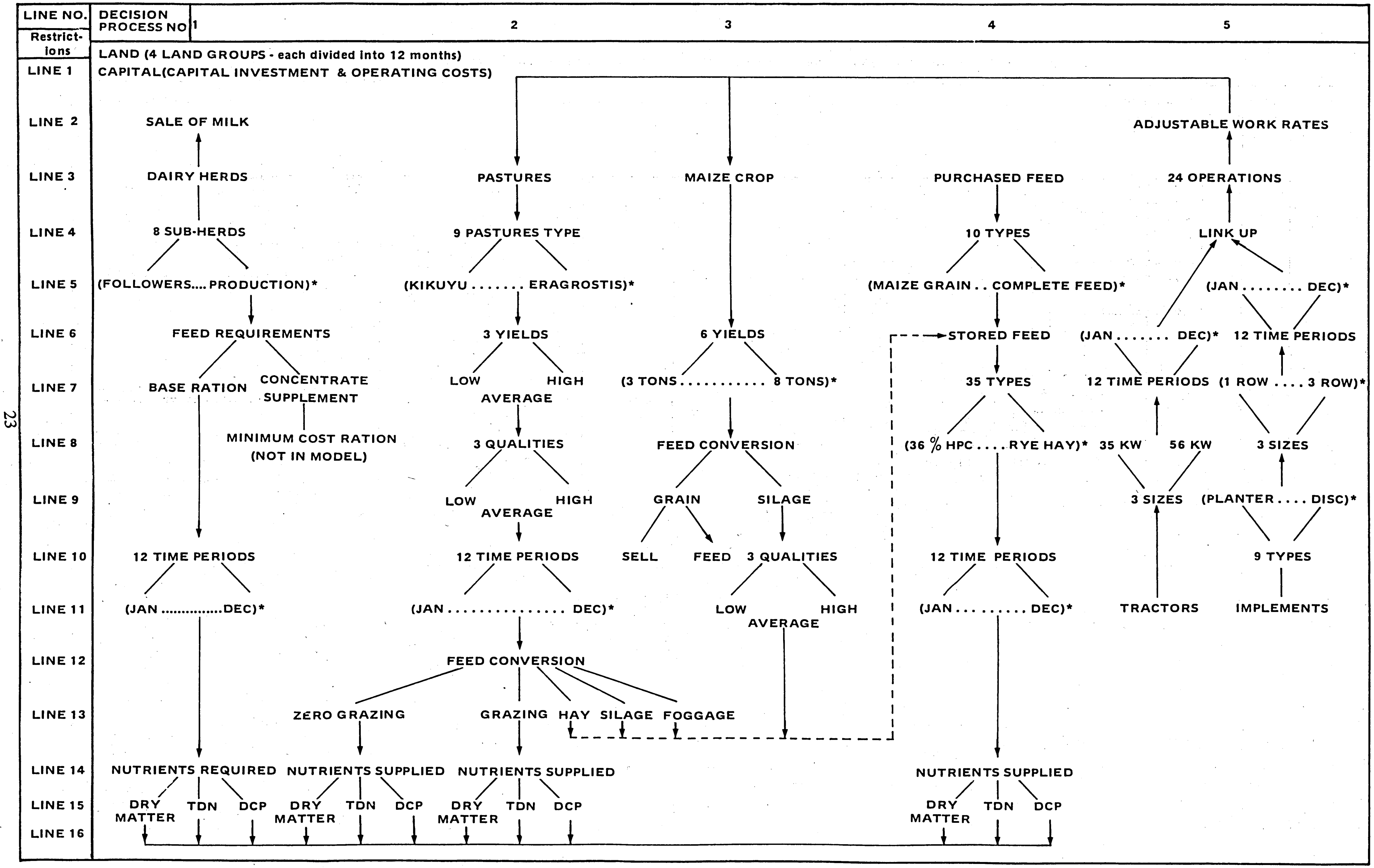

FIGURE 2 – DIAGRAMMATIC REPRESENTATION OF THE POINTS OF DECISION-MAKING IN THE MODEL

***Those subherds, time period etc. specified are only examples of the full range available in the model**

given farm it may be that a hectare of maize could be planted any time between late September and early December. Submatrix 12 provides all the links and transfers required to allow for this type of flexibility in the model.

(v) Submatrix 11 contains activities for maize and pasture production. These activities are restricted by area of land available. The model provides for up to four different land groups, each restricted on a monthly basis in the right-hand side of the model. Production inputs are fertiliser, weedicide, pesticide, seed, irrigation and pasture establishment costs (from the 'cost rows') and machinery (from submatrix 12). Output is a monthly dry matter yield for each pasture and an annual dry matter yield for the maize crop.

(vi) All farm-produced feed may be fed in one or more different forms (e.g. pasture, hay, silage, etc.). Submatrix 10 contains the necessary conversion activities with their respective loss factors. Output is the dry matter of each type of feed on a monthly basis. Input is the machinery requirements (from submatrix 12) and dry matter produced (from submatrix 11).

(vii) There are eight subherds in the model and each of submatrices 2 - 9 contains feeding activities for a particular herd. In these submatrices converted dry matter from submatrix 10 is given energy and protein values. Actual values depend on the source, quality and time period of the dry matter. Input includes machinery requirements, in addition to the dry matter already mentioned. Output from each submatrix is a monthly supply of dry matter, energy and protein for a particular subherd.

(viii) Dairy herd structure and size selection is contained in submatrix 1. Input is the output from submatrices 2 - 9 and output is the supply of milk.

Fig. 2 shows, in a flow type diagram, different points at which decisions are made in the model. Five separate decision-making processes are illustrated, showing, on separate lines, the range of options open to be selected either by the user or by the computer. Arrows indicate the direction of decision-making, from the more general decisions in the direction of increasing detail. In the feed flow, the point at which demand for feed and supply of feed must be equalised is reached in line 16. The supply of feed from production and purchases measured in kilograms of dry matter, total digestible nutrients (TDN) and digestible crude protein (DCP) must equal the demand of the dairy enterprise for feed.

(i) In decision process 1, all the decisions are user inputed, the computer deciding only which herd to select and its overall size, i.e. all detail from lines 2 - 15 must be specified for as many different herd structures as are required for purposes of comparison.

(ii) For decision processes 2 - 5 the decision points may be decided either by the user or by the computer. Following the direction of the arrows, once a particular choice has been made by the user, all others are eliminated from computer optimisation. Thus in the pasture decision process (2) there are nine different pastures to select from (lines 4 and 5). The user may eliminate as many of the pastures as are not suitable for the farm in question, leaving the computer to optimise feed production from those remaining. For each pasture remaining in the model, there are three possible yields (line 7). Again, the desired yield may be specified, so eliminating others. In each case selection may be qualified by use of an upper and/or lower bound or a fix in the bounds section of the matrix.

Using this select and eliminate approach, combined with the setting of bounds and restrictions, the model is set to simulate as closely as possible the farm to be planned. By changing restrictions and selected options opportunity, the cost of different decisions can be estimated, and a final plan decided on.

2.2 Mechanisation Planning

High capital investment in farm machinery and high annual costs, particularly in respect of feed production costs (Berry and Whitehead), require that particular attention be paid to the inclusion of farm machinery in a model. Individibility and high capital costs mean machinery could play a dual role in determining the optimum feed plan.

2.2.1 Machinery as a Restricting Factor in Production Planning

The number and range of machines on a farm vary according to area cultivated, farming pattern, farmer preferences, etc. The farming pattern is also adjusted to a certain extent to suit the available machinery. This is likely to be particularly true of high capital cost items such as tractors and combine harvesters. Machinery is not, however, a 'strict' restriction in that extra capacity can be purchased. The inclusion of machinery in the model allows for the cost of not being able to do an operation when it is required to be done, to be weighted against the cost of relaxing the restriction through increased machinery capacity by the inclusion of machinery purchasing activities for each machine, each actively reflecting only capital investment costs.

2.2.2 Machinery as a Cost of Production

(i) Fixed costs. When it is decided to use extra machine capacity in a peak period for that machine the additional costs of acquiring the extra capacity as well as the variable costs of using the machinery must be taken into account. Because machinery is indivisible, a small increase in capacity may well require a large capital investment. Therefore the costs of relaxing a machine restriction even marginally may well be very high, particularly if the machine in question happens to be a high capital cost item.

(ii) Variable costs. During non-peak periods for machinery, it is the variable costs which must be considered when costing a particular operation. Farm surveys in the Natal Midlands and Ixopo areas indicate that variable costs represent 59 % of total machinery costs.

2.2.3 Cost Estimates

Machinery fixed and variable cost estimates used in the model are based on guidelines provided by Kassier and Ortmann, and on estimates from the Division of Agricultural Engineering, Pretoria.

2.3 Labour

The labour costs of feed production are included in the machinery costs. This decision is based on the assumption that almost all labour costs can be linked to machinery on the basis of skilled labour (drivers and machine operators) and unskilled labour (loading etc.). Labour is treated as a 'fixed' cost in the model in the sense that if a man is required in one month, he becomes available for work in the remaining eleven months.

2.4 Feed Production

2.4.1 Land

Land is allocated to crops and pastures on a monthly basis so that the timing of tillage, planting and reaping as well as the option of double cropping can be considered. Soil fertility and type are made adjustable for each farm by the use of a combination of four land groups, soil tests (N,P,K and soil acidity) and yield variations.

2.4.2 Pastures

Seven pastures, namely kikuyu, rye grass, eragrostis, fescue, fescue clover, cocksfoot and cooksfoot clover, each with three different fertilisation rates, corresponding yields and five quality options, were included. Where possible experimental data were used (former Department of Agricultural Technical Services, Jones and Arnott, Bredon and Steward) and where not available, data are based on estimates from pasture scientists from the University of Natal (Pietermaritzburg) and Cedara Agricultural Research Institute. Dry matter production from each pasture was considered on a monthly basis.

2.4.3 Veld

Sweetveld, sourveld and mixed veld types were included in the model. No allowance was made for veld improvement and veld production costs were taken as zero.

2.4.4 Maize

Maize was the only crop considered in the model for which five different rates were included (4 - 8 tons of grain/hectare). Fertiliser recommendations were based on experiments done on Msinga clay loam (Farina *et al.*,) and low, average and high yield options were included for each fertilisation rate.

2.4.5 Costs

Production costs and input requirements were based on estimates of both the former Department of Agricultural Economics and Marketing and the former Department of Agricultural Technical Services, adjusted where necessary to fit in with the model structure (e.g. machinery costs were not individually estimated for each production activity, only machinery input requirements, since machinery costs are included in the machinery submatrix of the model).

2.5 Purchased Feed

Nine purchased feeds, ranging from maize meal to a complete feed, were included in the model to allow for the possibility that it might be more economical to balance a ration using purchased feed in months of shortage rather than to produce the feed.

2.6 Dairy Herd

2.6.1 Herd Structure

A complete dairy herd comprises a number of subherds which can broadly be divided into three groups, viz production cows, dry cows and followers. The model allows comparison between dairy herds of different structures, each with between one and eight subherds. The ration for each subherd is balanced for energy, protein and dry matter on a monthly basis in such a way that at least the minimum energy and protein requirements are met within the maximum dry matter limits for each subherd.

2.6.2 Feed sources for each subherd are selected from the same set of options, which include grazing, zero-grazing, hay and silage for pastures, grazing and hay for veld, maize grain and silage and ten purchased concentrates. (Refer to figure 1).

2.6.3 Loss Factors

Four different groups of loss factors are built into the model to take into account the difference between experimentally determined dry matter yields and that quantity of dry matter actually ingested by the animals. These are: *feed conversion* loss factors (e.g. grazing, hay or silage), *feed source* loss factors (e.g. kikuyu or veld), *climate* loss factors (loss variations as a result of the time period in which the dry matter is produced, fed, etc.) and a *management* loss factor adjustable to reflect individual managerial abilities. All loss factors, except for management, were estimated for each feed source by pasture scientists of the University of Natal and Cedara Agricultural Research Institute, since very few experimental data are available. The estimates used are an average of the estimates from each pasture scientist, which varied by as much as 50 per cent for the same grass in the same month, utilised in the same way. Individual estimates were usually within 15 per cent of each other.

3. RESULTS

Discussion of feed plans is based on 48 dairy feed plans generated by the complete feed planning model.

Because of the vast amount of data generated in the study an overall review and an evaluation of the main findings will be presented.

Feed selection was based on providing a minimum energy and protein level in the rations of each subherd, given a maximum dry matter intake. The six subherds included in the model can broadly be divided into production cows, dry cows and followers. The result of this is to ensure a minimum quality of ration at any particular time for each subherd, this quality being determined by the estimated requirements of animals in each subherd.

Results show that most rations should be based on maize silage to the extent to which it is possible to grow maize. Even where maize is produced under conditions requiring higher than average fertiliser and/or with low yields, maize silage still forms the basis of the rations, particularly among cows in production. Basically, maize silage provides the energy balance in a ration and efficiency of maize production determines the energy costs of a ration.

Pastures are used to provide the protein requirements of the rations, and as protein requirements are increased, so the proportion of pasture dry matter in a ration increases. Pastures are most efficiently utilised by zero-grazing and ensiling, except for rye grass, which is mostly grazed or made into hay. Efficient pasture utilisation requires that the cheaper summer pastures be ensiled to provide part of the winter protein requirements.

It is unfortunate that the model does not include any farm-produced protein sources other than pastures, since it could well be more profitable to provide at least some of the protein in the form of beans or nuts, especially since the quality of pastures varies from month to month. Purchased high protein concentrates are only used to balance rations where production of pastures is limited, and then usually during the winter months.

Results from the model indicate that feed planning models should take energy and protein requirements as well as dry matter into account when determining production of feed. Of the three, energy was the most important determinant of ration content. The availability of maize silage throughout the year makes it possible to provide only the minimum energy requirements and the inclusion in the model of a similar source of protein could have the same effect on the protein content of rations. With quality feed production, dry matter is seldom a limiting factor, although for higher production levels it is important. For maintenance rations, a lower limit on the dry matter content of a ration should be considered. If hay is required in the ration, results suggest that it would have to be forced into the plan at the required level, especially with respect to cows in production.

Although farm machinery is an integral part of feed production, and machinery costs are high, mechanisation planning does not appear to be important in terms of the decision as to what feed should be produced. Initial results indicate that feed rations can be planned without considering machinery fixed costs, since these have little effect on the planning of farm-produced feeds, unless capital is a restricting factor or certain items of machinery are not available. Machinery fixed costs are, however, important and profits can be maximised by efficient mechanisation planning to meet the required production needs. In other needs, mechanisation planning can be done after feed production with very little effect on overall planning efficiency. Dividing the model into its two major components, feed planning and mechanisation planning, and using each as separate but related models would appear to be more useful than using the complete model. Initial tests using both the full model and its two 'component' models suggest that the following advantages could be gained by using the component models.

(i) Saving in overall computer time, especially during initial feed planning
(ii) Use of integer programming to arrive at the required mechanisation plan.

Little loss in accuracy is expected if 'component' models are used instead of the full model, although more thorough testing on farms is required before a definite statement can be made in this regard.

One of the most important points brought to light during the development of the model, is the importance of close liaison between the different branches of research in agriculture, if computer models are to reach anything near their potential both in agricultural extension and research. A model is only as good as the data on which it is based and since data are interlinked, it is the quality of the poorest data in the model which often determines the accuracy or otherwise of the model. *There is very little to be gained from having accurate estimates of the protein requirements of a cow if little is known about protein production in pastures at different periods, let alone about how digestible the produced protein is.* Models, such as the one developed in this study, can be used both as extension aids and to provide guidelines for future research, particularly in order that the development of certain important aspects of farm management should not be allowed to fall behind. Some of the more important *areas which require* *further research in order to improve current data are*:

(i) Expected quality of each pasture in terms of at least energy and protein at different periods and for different fertiliser applications

(ii) Expected dry matter production of each pasture at different periods and for different fertiliser applications

(iii) Harvesting and feeding loss factors. These factors determine how much of the feed produced the animal actually takes in and as such are very significant determinants of the cost of each nutrient source, especially since estimated losses range from ten to eighty per cent of available dry matter. Since there is very little experimental data available on the required loss factors, estimates were obtained from pasture scientists at the University of Natal and at Cedara College of Agriculture. For the same grass in the same month and utilised in the same way, estimates varied by as much as fifty per cent but were usually within fifteen per cent of each other. This illustrates the need for research on loss factors in farm-produced feed, especially considering that the estimates made presupposed optimum management. The same problem applies to maize silage in the model and to any other feed source that might be included in such a model.

It would be possible to use the existing model to establish the critical upper and lower limits for quality, dry matter production and each of the four fixed loss factors considered in the model. This would establish bounds outside of which estimates could substantially affect feed planning. For quality and dry matter production, a range of estimates is already included in the model and provides simple basis on which to establish critical limits. It would be more difficult to do this for the loss factors, since no alternatives are built into the model. However, substituting new estimates for existing estimates and establishing which loss factors have a small range between upper and lower critical limits with the aid of a model is likely to be both less time-consuming and less costly than trials in the field. Quality, production and loss factors with unacceptable critical limits could then be investigated using field trials. Other areas in which the model could be used for further investigation are: mechanisation planning, fixed and working capital restrictions and the effect of changes in prices of farm inputs relative to each other.

In today's economic climate of rapidly changing relative and overall prices of all inputs and products, an important feature of the model is the ease with which the prices of all inputs can be updated to allow for changes of prices in the economy as a whole or simply between different farms. This is an essential feature of any model which is not to become rapidly out-dated. By generalising from results obtained from testing the model on two different farms* (59 feed plans), the following broad conclusions may be drawn:

Dairy farming has a higher rate of return per hectare than maize farming, and the relative advantage increases as higher fuel prices are simulated in the model relative to other costs. Results clearly indicate that reasonably high levels of production can be obtained without having to resort to purchased concentrates. In particular, a high quality base ration for production cows should not rely on purchased concentrates.

Maize - Maize silage is the most profitable source of energy in a dairy ration, even at very low grain yields. If maize production is restricted below optimum levels, then grain sales rather than silage production should be reduced, the latter being the more profitable way to utilise maize on a dairy farm.

Pastures - Where possible mixed clover pastures are preferable to plain pastures. Winter pasture production is a more economical source of protein than purchased feeds, but pastures could possibly be replaced by a higher protein crop such as soya-beans (not considered in the model).

Purchased feeds are used as a protein balancer to rations and are only used in small quantities, particularly where good quality pastures are available all year round.

Ration formulation - Energy was found to be the most important determinant of the ration formulation, with protein being the next most important, particularly during winter. Dry matter capacity of animals is not found to be a major determinant of ration formulation for milk yields used to test the model. Energy measured in kilograms of total digestible energy (TDN) had an average shadow price of approximately six cents per kilogram and protein (kilograms of digestible crude protein) an average of approximately 17 cents per kilogram for cows in production. Shadow prices for protein varied more on a monthly and farm basis than did those for energy.

Fuel price increases are not expected to bring about major changes in dairy farm feeding practices since the rations currently being used are those predicted by the model after a trebling of fuel prices relative to prices of other farm inputs.

4. DISCUSSION AND CONCLUSIONS

Results indicate that most rations should include maize to the extent that it is possible to grow maize. Pastures are, however, the cheapest source of feed and should be fully utilised. Maize should not be grown on the steeper slopes because of erosion problems. Natal soils are highly leached, virgin soils are acid, low in nitrogen and available phosphate. With proper fertilising maize results have been spectacular in many areas in Natal. A pasture scientist, Mr John Klug, with whom the results were discussed, warned that soils must be properly fertilised for maize production otherwise

*These generalisations are made subject to two provisos:
1. The model is designed to provide guidelines for individual farms and not farms in general
2. Most of the 59 feed plans come from submodels of one farm

the switch from pastures to crops leads to a loss in soil protection and soil erosion. Excellent results were obtained by a prominent farmer, Mr Jan Pretorius, at Impendle by utilising the whole maize plant in beef production. On the same farm the previous owner's best year was a loss of R17 000 while in his first year Mr Pretorius made a profit of over R100 000.

Fuel price increases are thought to influence optimum cropping patterns. If fuel prices treble from the 1980 levels then it is estimated that the optimum cropping mix according to the model will change from 5 % grazing, 23 % pasture silage and zero grazing, 5 % maize grain and 66 % maize silage to 50 % grazing, 17 % pasture silage, 2 % hay, 3 % maize grain and 28 % maize silage. With increases in fuel prices, grazing becomes more important and maize silage less so.

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