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.

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).

For many farm operations involving machinery there is a certain flexibility in the timing of the operation. For example, on a
**Row Types**

<table>
<thead>
<tr>
<th>Sub Matrix Number</th>
<th>1</th>
<th>2</th>
<th>3-8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
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<th>15</th>
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<tbody>
<tr>
<td><strong>Restrictions</strong> (right hand side)</td>
<td>Land (4 x 12 months)</td>
<td>Capital (investments + operating costs)</td>
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<td><strong>Output From Farm</strong></td>
<td>Milk (12 months)</td>
<td>Maize Grain</td>
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<td><strong>Supply of Nutrients</strong></td>
<td>For 8 dairy sub-herds on a dry matter energy and protein basis (12 months x 3 nutrients x 8 sub-herds)</td>
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<td>Transfer of converted feed to each sub-herd on a monthly basis</td>
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<td>Transfer of dry matter produced to feed conversion activities on a monthly basis</td>
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<td>Transfer of mechanised operations after scheduling all operations</td>
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<td>Transfer of all available mechanised operations on a monthly basis (25 x 12 months)</td>
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<td><strong>Transfer of</strong></td>
<td>Labour (2 x 12 months)</td>
<td>Machinery fixed costs (4)</td>
<td>Machinery variable costs (4)</td>
<td>Fuel requirements (1)</td>
<td>Pasture estab. &amp; irrigat. (2)</td>
<td>Fertiliser &amp; seed (6)</td>
<td>Weedicides &amp; Pesticides (4)</td>
<td>Purchased feed (10)</td>
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<td><strong>All costs and inputs for model</strong></td>
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<td>Objective-row (maximise profits)</td>
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**Right Hand Side**

<table>
<thead>
<tr>
<th>MAXIMUM RESTRICTION VALUES</th>
<th>SALE OF FARM PRODUCTS (INDICES)</th>
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**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 inputted, 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. Individuality 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 could play a dual role in determining the optimum feed plan.

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
cocksfoot 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
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.

REFERENCES

BERRY, C.G. and E.N.C. WHITEHEAD (1979). Average Business Summary of Mail-in Record Study Groups in the Natal Region. Former Department of Agricultural Economics and Marketing, Division of Agricultural Production Economics, Natal Region


