



Animal diet formulation: optimization and simulation techniques

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Outline

1. Mathematical Models
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Mathematical Models

- Mathematical models have been extensively used for animal feed formulation since the origin of linear programming technique. Objective of feed formulation model is, to identify the set and quantity of nutrient ingredients to maximize the animal weight gain and animal yields. Feed mixes are formulated to provide a palatable ration at minimum cost to fulfil energy and nutritional requirements of animal.

Important Factors for Animal Diet

- Feed composition, requirement of specific nutrient ingredients and financial goals are important aspects of animal feed formulation. An optimized feed mix is formulated for livestock development as well as for commercial purposes. Different nutrient ingredients are combined in such a way that the feed will provide energy and required nutrition at different stages of production

Need for mathematical programming techniques

- Development of dairy industry directly depends on the quality of feed supplied to the ruminants. Experience based judgment cannot be used to feed animals for consistent results. Before the development of mathematical programming techniques, feed to the animals was given on the basis of experience based judgement

Purpose of the work

- The aim of this work is to provide an introduction to the problems involved in the formulation of feed mix and nutritional management. Using the mathematical programming techniques balanced feed mix can be formulated at minimum cost and many more objectives can be achieved. To derive the maximum yield from animal and maximum animal weight gain at optimum cost, feed mix formulation models are developed using mathematical programming techniques for more than a century.

Division of work

- **Feed Formulation Models with Linear Programming technique**
- **Feed Formulation Models with Stochastic programming**
- **Feed Formulation Models with Weighted Goal Programming**
- **Feed Formulation Models with Dynamic Programming**
- **Feed Formulation Models with Fuzzy Programming technique**
- **Feed Formulation Models with Nonlinear Programming**
- **Computer programming models and simulators**

Feed Formulation Models with Linear Programming technique

- Animals cannot perform in terms of reproduction and high yields when fed with the feed ingredients which are easily available on low cost irrespective of the quality of the feed. The linear Programming (LP) technique is a scientific approach to animal feed mix problem which has been introduced to obtain the least cost quality feed mix which can provide the adequate nutrition to the animals. For ruminant feed mix formulation, Linear Programming technique has been extensively used as basic tool

Feed Formulation Models with Stochastic programming

- Variation is inherent in the nutrient composition of the feed ingredients which can have a negative impact on the growth of the animals as well as on the cost. Therefore to reduce the risk of over and under nutrition, it is essential to consider this variation while developing the models for animal feed mix formulation. Stochastic programming model is an appropriate tool to deal with the nutrient variability. These models have been developed to incorporate nutrient variability.

Feed Formulation Models with Weighted Goal Programming

- Though linear programming technique is widely used for formulating animal feed mix problems, it has the drawbacks such as optimization of a single objective function only, rigidity of the constraints, linearity, deterministic approach etc. These drawbacks of linear programming are overcome by use of advanced programming techniques. Practically feed mix formulation is a complex process which cannot be confined to the achievement of one objective only.

- It involves satisfaction of multiple conflicting objectives on priority basis. Also the rigidity of the constraints may lead to infeasible solution while a small relaxation in the RHS will not affect the results. These drawbacks can be reduced by introducing multi criteria decision making. Goal programming is used with weights and penalties to include and exclude particular nutrient ingredients in the feed mix.

- Goal programming is combined with linear programming to get the better results in terms of feed and nutrition. A number of models were developed using goal programming. Goal programming (GP) can be used to select feed to meet specific nutritional requirements. It is designed to overcome an oversupply of certain nutrients. It is difficult to achieve the nutritional balance in feed selected by LP, owing to the complex inter-relationships of the constraints. GP is presented as a method of achieving nutritional balance in selected feed mixes.

Feed Formulation Models with Dynamic Programming

- Linear programming has been integrated with dynamic programming to optimise the economic performance of a dairy cow over its entire lactation. Linear programming provides solutions for each potential live weight during four week periods over the lactation. Then dynamic programming has been used to select the optimal sequence of live weight changes during the lactation and the specifications of rations associated with this optimal path

Feed Formulation Models with Fuzzy Programming technique

- One of the basic assumptions of linear programming is deterministic coefficient for objective function and constraints. Use of fuzzy models for feed models overcomes this deterministic approach of formulation. Fuzzy models link measurable information to linguistic interpretation using membership functions. Fuzzy models have been developed for animal feed mix formulation and results have been compared to linear programming models which show that fuzzy models are giving better results.

Computer programming models and simulators

- Many large scale complex problems can be solved very easily using computer programs and software. Computer software and simulators are able to solve complex models in minimum time and are easy to use. Without going much into the theoretical concepts and lengthy calculations, the optimal feed mix can be calculated for animals using simulators. These simulators provide more flexibility in terms of changes in the objective function, feed ingredients and nutrients required by the animals. Changes can be incorporated in the input data and results can be seen very easily.

Table 1 Feed formulation models (based on mathematical programming)

References	Objective of study	Programming method	Remarks
Yates and Rehman [65]	To determine realistic optimal replacement strategy for a dairy herd over a 10-year planning horizon	LP model	Overcome the inadequacy of the replacement policy done by Markovian decision process
Al-Deseit B. [66]	To determine Least-cost broiler ration formulation	Linear programming technique.	
Brokken [67]	To find model for the use of Lofgreen–Garrett net energy system for ration formulation	Four alternate simple models	Overcome linear difficulties given by Garrett
Munford [68]	Formulate two non-linear optimization problems as an iterative sequence of LP problems	Iterative LP	Overcome linear difficulties and a better solution is obtained
May et al. [69]	To find optimal monthly feeding strategies and costs for March and May calving alternatives	Integer programming	Sensitivity analysis is conducted to estimate the yield ratio
Amir et al. [70]	To find optimal dry hay system by constructing mathematical framework and compares six hay packing methods	Mixed integer programming	Includes interdependence and interaction of components of hay and results for various quantities of dry hay ranging of 100–1500 tonnes

St. Pierre NR, Harvey WR. [71]	Incorporation of uncertainty in composition of feeds into least-cost ration models. 1.	Single-chance constrained programming.	Certainty constrain of LP is overcome.
St. Pierre NR, Harvey WR [72].	Incorporation of uncertainty in composition of feeds into least-cost ration models. 2.	Joint-chance constrained programming.	
Bruce [73]	To use net energy to balance cattle feed mixs	Quadratic equation	Seven variables are used for two feedstuffs and coefficients of equation are calculated by percentage calculation and subtraction for two feedstuffs, respectively
Chen [74]	To find least-cost feed formulation model under a probabilistic protein constraint	Iterative quadratic programming	
Ferguson EL, Darmon N, Fahmida U, Fitriyanti SIM [75].	Design of optimal food-based complementary feeding recommendations and identification of key	goal programming	Deal with non-linear functions.

Kennedy [76]	To determine optimal marketing and feeding policies for beef cattle	Dynamic programming	Deal with non-linear and discontinuous functions involved
Grossmann IE. [77]	For the synthesis of engineering systems. Research in Engineering Design	Mixed-integer nonlinear programming Techniques	Overcome linearity constraint.
VandeHaar and Black [78]	To develop a ration formulation program	Combination spreadsheet	Can be reworked to meet the needs of individual farm on the basis of biological and management considerations
Ryan [79]	To find simulation model for development and planning of feedlots	Simulation model	Evaluates alternative management practices

Conclusion

- Optimization methods are effective tools to determine balanced feed and effective use of resources. This paper discusses animal feed formulation models formulated with the help of optimization techniques. It reviews assumptions, constraints, methodology and outcomes of different mathematical models. It also considers applications and comparison of different optimization techniques with input feed ingredients and output in terms of yield and least cost ration. Major emphasis is given on model formulation on the basis of computer based tools. Spread sheets, excel solvers, software and simulators are discussed. An effort has been made to give a new dimension to the already existing multi dimensional models based on different mathematical programming and computer based programs. Conceptually, it moves from deterministic to stochastic and dynamic modelling sense.

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