Animal Feed Formulation

Economics and Computer Applications

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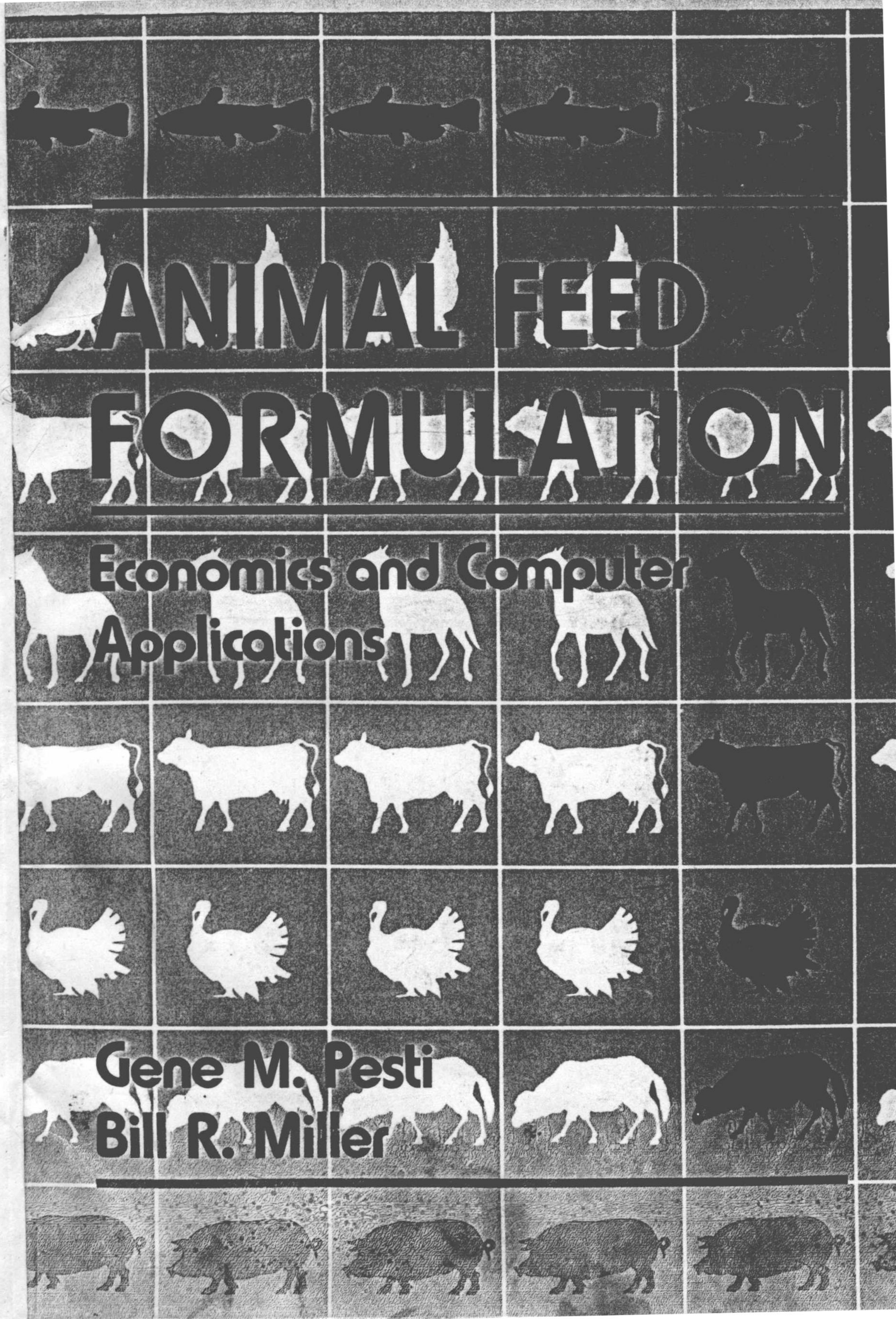

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动物营养

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Preface

This text is an introduction to the computerized formulation of animal feed using a new feed-formulation program. Special emphasis is placed on the techniques that are commonly used by the animal feed industry and on the nutritional and economic consequences of these techniques. The book should be particularly useful to students in all phases of animal agriculture, since it provides the basic information important for understanding, interpreting, and applying their nutrition knowledge to practical problems. Its detailed coverage of animal nutrition and its presentation of many clear examples simplify the application of economic concepts to feed formulation. It should also be of interest to the general reader, student, extension agent, or feed formulator who wants to learn about the concepts and microcomputer applications of linear programming to feed formulation. The examples and principles illustrated may be applied to feeds for many animal species. Moreover, where linear programming is not the complete solution, concepts of nonlinear programming are provided for the interested student.

The program used here to illustrate the principles of least-cost feed formulation was originally called User-Friendly Feed Formulation or UFFF (pronounced *oof*). The new effort, version 2.0, is named UFFDA, or User-Friendly Feed Formulation, Done Again. This program should be useful where specialized commercial software would not be warranted. UFFDA is menu-driven software with the editing capabilities of a spreadsheet program, for altering the ingredient and nutrient composition matrix. Special features include the ability to specify ratios between nutrients, input–

output editing screens, and the printing of custom feed mixing sheets. Changes in the problem matrix (i.e., in the ingredient cost, ingredient minimums or maximums, or nutrient minimums or maximums) can be made from the input–output screens, and solutions recalculated immediately. The entire matrix is given for each of the example feeds, so that the principles discussed can be illustrated with any linear programming algorithm.

UFFDA will run on IBM PC and 100% compatible microcomputers with 640k of memory. Problems with approximately 100 ingredients and 50 nutrients have been solved, and much larger problems should be possible. This capability exceeds most known feed formulation problems.

The authors are grateful to the administration of The University of Georgia, the College of Agricultural and Environmental Sciences, and to their respective departments for their encouragement during the preparation of this book. Grateful acknowledgment is also due James Hargrave for his programming skill and patience as the microcomputer program evolved, and Scott VanderVeen for collecting data and for many helpful discussions. To Jane Blount, Wilma Alewine, Vivian Patten, and Jo Anne Norris, grateful appreciation is expressed for the typing and secretarial assistance that was so essential to the preparation of the book.

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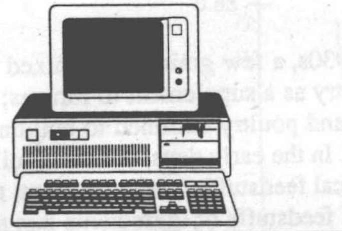
Chapter 1



Economic Analysis

ANIMAL FEEDING

The analysis of animal growth as a response to feeding has a long history in both animal science and agricultural economics. No book on the economics of animal response would be complete without calling attention to the pioneer and still relevant work of writers such as Heady et al. (1964) on milk production, Heady et al. (1963) on beef cattle production, and the fundamental general work of Heady and Dillon (1961) on animal production functions. More modern approaches to growth response, such as shrimp production and scheduling by Hochman et al. (1990), are still dependent on estimating a growth coefficient, feed intake, and feed cost. Without these data, more general analysis is not possible.

The more general economic approaches to livestock response are characterized by increased emphasis on the intensity of labor and capital use associated with the feeding process. Thus, no matter how complex and general the economic analysis becomes, its starting point must be the use of a least-cost feed that provides technically efficient growth. Least-cost, efficient feed is the topic of this book, and providing the best possible solution to creating such feed is its goal. Its importance is accentuated by the fact that the question of least-cost, efficient feed has become the source of income for consulting firms that operate in a worldwide market. Linear programming is the basic tool of the world's feed industry, and all of the topics in this book have had important commercial applications.

The mixing of animal feeds has progressed in the past sixty years from a very simple operation to a very complicated one. In the 1930s, a few grains were mixed on the floor and given to pastured livestock and poultry as a supplement to forages; in the 1990s, computerized feed mills for livestock and poultry confined to buildings routinely mix thousands of tons of feed each week. In the early days, the meat, milk, wool, or egg producer had a limited number of local feedstuffs to choose from; today, the producer is faced with a wide selection of feedstuffs or ingredients that are produced hundreds or even thousands of miles from where they are fed. Constant changes in their prices complicate the appropriate choice of ingredients to be included in a feed.

Linear programming (LP) was the principal tool developed to help nutritionists choose among feedstuffs when formulating rations. In order to use LP in ration formulation, the question "What feedstuffs should be fed?" is reduced to purely mathematical terms that obey the principles of nutrition and economics. The amounts of each essential nutrient and other considerations (e.g., the ability of the diet to develop pigment in egg yolks) are then expressed mathematically.

LP can be used to find the combination of feedstuffs that meets certain specifications (mainly nutrient requirements) at the lowest cost. This is called the *least-cost feed formulation*, and it is least-cost *only* for the specifications given. It is important to note that it does *not* automatically follow that these specifications will lead to the best or most economical production.

Least-cost feed formulation is an important subproblem of the more general problem of profit maximization. Profits in animal feeding must consider product prices and all inputs to production and marketing, not just feed. Production of animals requires the conversion of nutrients into animal growth that takes place over space and time; hence capital, labor, feed, and management inputs are required in the process and must be used at minimum cost for a specified level of output produced in any specified unit of space and time.

ASSUMPTIONS OF LEAST-COST ANALYSIS

When a nutritionist specifies the nutrient requirements of a feed, assumptions about profit maximization are usually not specified. An example of the role of economics in the specification process can be provided by broiler production.

First, assume that the ration specified will produce the weight of broiler that will maximize profit. Within this framework an important problem of substitution, or trade-off, between the constraints of the least-cost ration can be solved.

Conditions may be analyzed under which the same (profit-maximizing) size broiler can be produced in approximately the same time period by substituting dietary metabolizable energy E for dietary protein P. This substitution may produce significant cost savings in periods when feeds that are high in energy, such as corn, are available at relatively low market prices. In such periods, rations relatively high in energy and low in protein may be formulated that produce the least feed cost per pound of broiler per unit of time, and will thus maximize profits for a given broiler price. Vice versa, a change in relative prices may favor rations containing an increased level of protein, perhaps from soybean meal, and less energy. Economists refer to the curve defined

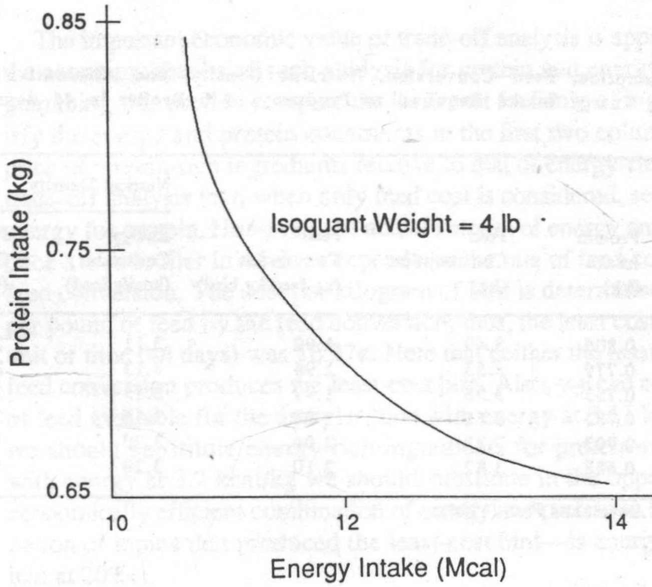


Figure 1-1. An isoquant for broiler production (Georgia, 1988). *After:* Miller, Arraes, and Pesti (1986).

by the highest-efficiency substitution possibilities as an *isoquant* (also known as an *iso-product curve* or *producers' indifference curve*).

For example: The relevant data for input (energy and protein) substitution analysis have been shown by Miller, Arraes, and Pesti (1986) to be the growth of broilers in response to energy *E* and protein *P* and the relative prices of these two variables. An isoquant describing all levels of protein and energy intake that produce a 4-lb bird was computed by Miller et al. and is shown in Figure 1-1; isoquant values of protein and energy intake are shown in Table 1-1. For a 4-lb broiler, energy intake may increase by about 13%, from 10.86 to 12.24 Mcal over the range of substitution with protein, but the energy level increase is only 3% (from 3.11 to 3.20). These percentage changes take into account increased feed consumption associated with increased energy and decreased protein (Table 1-1). The energy and protein levels of feed consumed are not fixed for a given size bird: In fact, to produce the same bird weight, the roughly 13% increase in energy intake shown in the table can be associated with an approximately 17% decrease in protein intake (from 0.805 to 0.688 kg).

Relatively high prices of protein-rich feedstuffs might dictate using low levels of protein in feed formulation because the same size bird can be achieved with either low or high protein levels. Many technically efficient combinations will produce the same size bird (Table 1-2), but only one of these will be economically efficient, because of the varying cost/unit of feed and the amount of feed consumed. An important and appropriate economic trade-off is apparent in Table 1-2, where protein and energy are quantified as substitutes in the production of broiler weight gain.

TABLE 1-1
Feed Consumption, Feed Conversion, Nutrient Density, and Alternative Levels of Protein and Energy Intake Required to Produce a 4-lb Broiler in 44 days (Georgia, 1988)

				Nutrient Density	
Energy Intake (Mcal)	Protein Intake (kg)	Feed Consumption (kg)	Feed Conversion (kg feed/kg bird)	Energy Constraint (kcal/g feed)	Protein Constraint (% [g/100 g feed])
10.86	0.805	3.49	1.92	3.11	23
11.01	0.779	3.53	1.94	3.13	22
11.27	0.753	3.58	1.97	3.15	21
11.40	0.733	3.61	1.98	3.16	20
11.90	0.703	3.72	2.04	3.20	19
12.24	0.688	3.82	2.10	3.20	18

After: Miller, Arraes, and Pesti (1986).

TABLE 1-2
Technically Efficient Levels of Protein and Energy, Associated Feed Costs and Feed Conversion on the Isoquant for Producing a 4-lb Broiler in 44 days (Georgia, 1988)

Nutrient Density				
Energy Constraint (kcal/g)	Protein Constraint (% [g/100 g feed])	Least Feed Cost per cwt Feed ($)	Feed Conversion (kg feed/kg bird)	Cost per kg Bird (¢)
3.11	23	8.62	1.92	16.55
3.13	22	8.55	1.94	16.59
3.15	21	8.38	1.97	16.51
3.16	20	8.27	1.98	16.37
3.20	19	8.09	2.04	16.50
3.20	18	7.94	2.10	16.67

After: Miller, Arraes, and Pesti (1986).

As shown in this table, differences in feed conversion data contribute to the difficulty of determining the trade-off between *P* and *E* because broilers require a larger amount of a low-cost ration to reach the same weight as a smaller amount of a high-cost ration. The most economically efficient point of energy–protein intake occurs because of a possible trade-off between energy and protein. For example, if protein is increased, there is an additional cost for it; however, if energy can be decreased—traded for the protein without losing broiler weight—then it will be a good trade so long as the increase in protein cost is smaller than the decrease in energy cost. This trade-off should be continued for as long as it yields net savings in cost. Of course, depending on prices of the feedstuff, the trade-off could also work in the opposite direction, decreasing protein in favor of using more energy.

The important economic value of trade-off analysis is apparent in Table 1-2, where the economic results of such analysis for protein and energy are shown. Linear programming was used to compute the least-cost feed mix of ingredients available to satisfy the energy and protein constraints in the first two columns. Notice that the high price of protein-rich ingredients relative to that of energy-rich ingredients results in a trade-off analysis that, when only feed cost is considered, seems to favor substituting energy for protein. However, the actual amount of energy and protein required to produce a 4-lb broiler in 44 days depends on the rate of feed consumption and resulting feed conversion. The cost per kilogram of bird is determined by multiplying the cost per pound of feed by the feed conversion; thus, the least cost per kilogram of bird per unit of time (44 days) was 16.37¢. Note that neither the least-cost feed nor the lowest feed conversion produces the least-cost bird. Also, we can conclude, given the prices of feed available for the analysis, that with energy at 3.11 kcal/g and protein at 23% we should substitute energy-rich ingredients for protein-rich ingredients, whereas with energy at 3.2 kcal/kg we should substitute in the opposite direction. The most economically efficient combination of energy and protein in this example—the combination of inputs that produced the least-cost bird—is energy at 3.16 kcal/g and protein at 20%.

Does the least-cost bird produce the maximum profit? This question must be answered by a different kind of trade-off analysis, one between level of nutrient use and production. We call this *input–output analysis*.

Notice that the energy–protein trade-off analysis did not consider what would happen if both energy and protein were increased at the same time. Would feed conversion be lower or higher? What would happen to feed consumption, or cost per kilogram of feed? If the energy and protein levels are both increased by 1% (Table 1-2, cols. 1 and 2), the least cost of feed (col. 3) can readily be computed via linear programming. Assuming no changes in the price of any feedstuff, the cost of all the least-cost feeds will increase. Will feed conversion (col. 4) drop at the new input levels? Most broiler nutritionists would say that the conversions in Table 1-2 are fairly good, so let us assume they remain constant; cost per kilogram of bird must then increase. Trade-off analysis of nutrients to product indicates that the added cost of feed is higher than the added value of bird produced (none). Therefore, profits would decrease if we were to increase input levels by 1%. Obviously, many other scenarios are possible.

The data in Table 1-2 are experimental, but similar decisions must be made regularly by the manager-nutritionist, and calculating the least-cost feed is frequently just one step in the decision process. The UFFDA program is a user-friendly tool for performing these calculations; however, as useful as computers are, they cannot replace the manager-nutritionist, who must specify the important constraints that must be satisfied for profit maximization. Moreover, there is probably no substitute for the experience and skill of a good manager-nutritionist in sensing when a trade-off is possible. If he (or she) believes that alternative specifications of energy and protein (or amino acids or fats, etc.) will produce a similar yield of meat, milk, eggs, or wool, then least-cost feed formulation can guarantee that he will know the exact value of the potential trade. Similarly, least-cost formulation can determine the trade-off between alternative grain sources and protein supplements: The manager would simply test his decisions by computing the least-cost feed for alternative decisions. Each alternative least-cost feed would then be multiplied by the weight of feed that would be consumed for each kilogram of broiler produced. The alternative with the least total cost of feed consumed per weight of output or product would also be profit maximizing for the amount of output produced.

This book includes examples of nutritional decision making in several types of animal agriculture. Studying these models, and using the program and data provided, will give the student of nutrition practice in problem solving that would otherwise require years of experience. Also given are examples of the use of linear programming to specify profit-maximization models directly (in the chapters on beef and dairy cattle, broilers, and turkeys).

WHAT TO EXPECT FROM APPLYING LINEAR PROGRAMMING

Animal nutritionists and economists have worked together to develop and refine ways in which linear programming can be used to simplify ingredient purchasing. The LP algorithm (i.e., the basic mathematics) must be designed so that one particular kind of mathematical problem—the so-called *primal problem*—is solved. In the UFFDA program, the primal problem is the minimization of cost, but interpretations are provided for results other than least cost. Many of these variants, outlined below, involve the use of imputed valuations known as *shadow prices*.

1. Information can be derived from a least-cost ration that indicates how much the cost of an ingredient will have to fall before it is included in the formula. Subtracting this cost change, called the *marginal price change for use*, from the current ingredient cost results in the *shadow price of the ingredient*. An ingredient that is included in the ration has a shadow price of zero.
2. The change in formula cost with a change in a nutrient constraint is called the *shadow price of the nutrient*. For a least-cost feed formulation, the shadow price of a constraint is zero if the level of nutrient use is not equal to the constraint level. If the level of nutrient use is equal to the constraint, the change in least cost is logically related to the type of constraint. Since the goal of the least-cost mix is to minimize cost, a *minimum* constraint (e.g., "protein must be greater than or equal to a minimum level") will be less costly the lower the constraint. UFFDA will display positive shadow prices when a minimum constraint has been reached. The objective function value will increase by the amount of the shadow price if the minimum constraint is forced to be one unit higher. (If a constraint is of the *maximum* type [e.g., "protein must be less than or equal to a maximum level"], then the least cost will increase if the constraint is made one unit lower—but again, only if the constraint equals the level of use in the ration. Similar logic applies to these constraints in a maximization problem.)

   Shadow prices of a constraint may be very stable, not changing over a wide range of feed requirements; alternatively, they may be unreliable as an economic measure. For example, the shadow price may only exist for a one-unit change; if a two-unit change is made, the level of use may not equal the constraint, and the shadow price will vanish (i.e., the shadow exists only when the constraint is in the spotlight). If the constraint, or feed requirement, is of the minimum variety, it is likely to apply over a wide range. The user may want to systematically vary the constraint to observe the economic cost of a one-unit change.

Note that although many constraints in feed-formulation problems are expressed as decimal amounts, the shadow price is always for one unit. Changing the unit of measure of a constraint (say, from tons to pounds) will also affect its shadow price (reducing it to a per-pound rather than a per-ton basis).

3. An important analytical use of LP is to observe the impact of changing prices of ingredients in a least-cost solution. How much of an ingredient would be used if it were available at various costs? This question is answered by changing the *price parameter* of the ingredient and re-solving the problem as many times as necessary to cover the possible changes in ingredient price. If the results are plotted, the summary graph is commonly referred to as a *price map*. In a similar manner, any coefficient (parameter) in the data base can be examined in this way if information is needed on sensitivity of least costs caused by the effect of variance in model coefficients. Examples of such *parametric linear programming* are provided in this chapter and in Chapter 5.
4. Other modifications of LP allow nutrient use to be specified in terms of the energy content of the diet (i.e., *optimum density*). The optimum density problem is closely related to the value of the shadow price on an equality constraint. A principal constraint in the least-cost ration problem is that the weight of the feed mixed is one unit (say, a kilogram). If the energy level (or some other requirement level) cannot be fulfilled by 1 kg, but can be included in, say, 1.05 kg, then there will be a positive *shadow price of the weight constraint*. Ration costs will decrease if the equality can be increased to a higher level. Of course, there is also a possibility that the requirements of a ration can be satisfied by less than 1 kg; in this case, costs will be lower if the equality can be decreased to a lower level. However, changing the equality constraint will affect all of the constraints the user has specified for the ration, and the weight constraint cannot be arbitrarily changed without wide-ranging consequences. The optimum density problem is explored in an example given later in this chapter (p. 23).
5. Ingredient composition may be altered, with several nutrients changed in relation to another nutrient (a process known as *nutrient factoring*). UFFDA includes a utility, unique among available LP algorithms, that allows the user easily to specify that nutrients must exist proportionately in the ration. This utility, called the Nutrient Ratio screen, is explained by several examples (e.g., p. 26).
6. More than one diet may also be formulated at the same time, which is particularly useful when one ingredient is available in limited quantities. This technique is called *multiblending*.
7. Normal use of UFFDA or any other LP program assumes that the ration meets its requirements only 50% of the time that it is formulated. Logically, this result is related to the assumption that all of the data used in the analysis are averages. A higher probability of success can be achieved, but the ration will be more costly to formulate. In order to ensure that each unit of livestock gets its needed nutrients each day, *safety margins* may also be added to rations. The safety margin concept is closely related to stochastic programming.

The techniques outlined above are shown in application to various species of farm animal throughout Chapters 2–10.

LEAST-COST FORMULATION: THE BASIC LINEAR-PROGRAMMING PROBLEM

Least-cost feed formulation may be accomplished by three approaches: graphing, equation solving, and computerized linear programming. Below, all three of these are brought into play regarding the following problem:

> Given corn that contains 8.8% protein, has 3.43 kcal of metabolizable energy (ME) per kilogram, and costs 6.97 cents per pound (¢/lb), and soybean meal that contains 48.5% protein, has 2.44 kcal ME/kg, and costs 10.50 ¢/lb, what is the least expensive combination of corn and soybean meal that can be mixed to give a ton of feed containing 23% protein and at least 2.97 kcal ME/kg?

To use any mathematical technique (including linear programming) to solve this problem, the information must be transformed into a series of equations or inequalities. If X and Y stand for the quantities of corn and soybean meal, respectively, then mathematical expressions can be developed for each of the specifications (restraints) on the solution as follows:

	Corn			Soybean Meal			Constraint
Cost	6.79	$\times X$	+	10.50	$\times Y$	=	Minimum
Weight	1	$\times X$	+	1	$\times Y$	=	2,000 lb
Energy	3.43	$\times X$	+	2.44	$\times Y$	>	2.97 × 2,000 lb
Protein	8.8%	$\times X$	+	48.5%	$\times Y$	=	23% × 2,000 lb

Solving the problem

The relationships of these equations can be depicted graphically as shown in Figure 1-2. Each of the equations is drawn with respect to the corn (X) and soybean (Y) axes. For the expression where "at least" was specified, any point on or to the right of the solid line is in the acceptable or feasible area for metabolizable energy (i.e., yields ≥ 2.97 kcal ME/g). However, since there is only one combination of corn and soybeans that contains 23% protein and weighs 2,000 lb—shown by the intersection of the dashed and dotted lines, respectively—this is the only feasible solution to the problem. Fortunately, this combination of 1,285 lb of corn and 715 lb of soybean meal contains greater than 2.97 × 2,000 kcal of energy; otherwise, there would have been no feasible solution. The student should verify the amounts of corn and soybean by solving the weight and protein equations assuming that protein equals 460 lb/ton.

Note that this solution is to the right of the solid line in Figure 1-2 and contains the minimum amount of protein (23%) but an excess of metabolizable energy. The student should verify the amount of excess ME by putting the solution of 1,285 lb of corn and 715 lb of soybean meal into the energy equation and solving for ME: