To the Graduate Council:

I am submitting herewith a thesis written by Daniel M. Sevcik entitled " Development of Methodology for Evaluating Agro-Industrial Byproducts as Potential Feed Ingredients for Ruminant Diets." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Animal Science.

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DEVELOPMENT OF METHODOLOGY FOR EVALUATING AGRO-INDUSTRIAL BYPRODUCTS AS POTENTIAL FEED INGREDIENTS FOR RUMINANT DIETS

A Thesis

Presented for the

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Degree

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ASTRACT

A methodology for the evaluation of byproducts as a potential feedstuffs for ruminant diets was developed. The development process involved 1) development of methodology for the preliminary evaluation of a byproduct as a potential livestock feed. The methodology was tested using wet corn gluten feed (WCGF) as a model byproduct; 2) the construction of a least-cost linear program model to evaluate the value of a feedstuff on the basis of nutritional properties exhibited; 3) the application of the byproduct (WCGF) to specific feeding systems

The methodology for preliminary evaluation of a byproduct indicate that WCGF appears to be free of any physical or chemical characteristics which would hinder or inhibit the use of WCGF as a feedstuff for growing and finishing beef cattle diets. The protocol did not address all issues necessary for dealing with wet materials. Additional suggestions were made to increase the thoroughness of the methodology for evaluating wet materials.

Least-cost linear program models, the crude protein (CP) and rumen degradable protein (RDP) models, were evaluated as to their effectiveness in describing the economic value of nutrient constituents within a feedstuff. The RDP model was determined superior over the CP model in describing the economic value of feedstuff considered for inclusion in

growing steer diets. The RDP model gave economic advantage to feeds containing unique protein qualities which are required by growing (215 kg) steers for maximum growth and development. The RDP and CP models were found to formulate identical rations for finishing (318 kg) steers. The CP system is recommended for evaluating diets of heavy weight class of steers due to the greater availability of CP values over RDP values.

Application of the RDP model to WCGF determined WCGF to be of negative economic value in growing steer diets. WCGF demonstrated value as an energy source for finishing steer diets, when included up to 15% of ration dry matter. The high variability of the nutrient content of WCGF resulted in a considerable discount in the nutrient value credited to WCGF, and may have caused a reduction in the dietary levels of WCGF included in finishing diets.

This study provides a combination of methodology and technical procedures by which a byproduct can be thoroughly evaluated for factors effecting the manageability, nutrient quality, economic value and safe application of the material considered for inclusion in beef cattle diets.

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CHAPTER I

INTRODUCTION

The United States produces billions of tons of garbage and industrial wastes each year. Public concern for proper disposal of these materials is growing as health and environmental decay, resulting from improper management of wastes, becomes more evident to the public eye. Industry is trapped in a vicious cycle. Production levels of goods are increased to meet increased demands of a growing population, but disposal of waste materials yielded during processing is becoming more and more difficult as populations enlarge. Industry, as well as the public, is forced to find creative solutions to the ever growing problem of byproduct disposal.

Development of livestock feeds from byproduct materials is one such option which, amid present circumstances, is gaining popularity. Some byproducts, such as soybean meal, dried distillers grains, dried brewers grains, etc.., have been extensively used in the livestock feeding industry. The majority of byproducts available to feeders, however, have not been properly evaluated in areas of management requirements or nutritional and economic value. The absence of methodology for thorough examination of byproduct materials as potential livestock feeds has resulted in uncertain application of these byproducts.

The proposal of this study was to develop a methodology for evaluation of newly available byproducts as potential feedstuffs for ruminant diets.

CHAPTER II

REVIEW OF LITERATURE

Basis for Byproduct Utilization

Utilization of byproducts as feedstuffs for livestock is not a new concept, but is one which is now being seen with renewed importance. World shortages in animal feeds, primarily in developing countries, and buildup of byproducts of processing, primarily in developed countries, are two reasons for this renewed interest (Iwema, 1984). Presently the United States, with existing surpluses of grains for both animal and human consumption, does not feel the resource limitation constraints which are known by the majority of the world. Survey figures from 1975 estimate that 90% of cereal protein produced by the United States was fed to livestock. This is compared to a world wide figure of 40% (Gillies, 1978). Intense production of livestock requires the use of excellent quality feeds. As long as economically advantageous, high quality feeds will be utilized regardless of opportunity costs which exist in other locations. However, with a world population predicted of approximately seven billion by the year 2000 (Romoser,1977), the luxury of inefficient utilization of resources may no longer be acknowledged as a practical convenience. The urgency of the world food situation is felt in the following statement by Kotter (1986) at an international seminar on rural development and careful utilization of resources:

> Inspite of some progress made in the increase of agriculture production in different countries of the Third World, the overall per capita food availability did not keep pace with population growth. Hence, stronger efforts have to be made to raise food production within developing countries. On the other hand, it becomes more and more evident that natural resources are put under considerable pressure. In some parts of the world overutilization and a mismanagement of resources have already caused serious ecological damage. Other eco-systems are in danger to deteriorate rapidly if not methods of more careful utilization of non-renewable natural resources are developed and applied.

Efficiency, in this discussion, is defined as maximization of quantity of output per unit input. Therefore, efficient utilization of limited resources dictates that ruminants be treated as true ruminants. The ruminant animal has the ability to utilize materials which are generally high in fiber, poor in protein quality or high in non protein nitrogen content, and are thus unacceptable for monogastric species. The advantage of the ruminant lies in the ability of the ruminant to convert material of poor nutritional quality to a product for human consumption which is high in quality protein and other important nutrients. The mechanism for this transformation is a microbial fermentation process conducted in the rumen of the animal. This process yields products which sustain metabolic processes within the animal. Cattle are not very efficient in converting feed to gain, averaging 8-10:1. This ratio is compared to approximate feed conversion factors of 1.9:1 for poultry (Veltmann et al., 1986), 3.5:1 for swine (Chahuna, 1980), 1.1:1 for catfish (Henken et al., 1987). These latter groups, in exchange for their superior feed conversion capabilities, require feeds higher in nutrient quality. Thus, with increased limitation in feed resources, economic distribution of quality feeds will be directed toward more efficient monogastric and avian species.

As stated earlier utilization of byproducts as feedstuffs for livestock is not a new concept, but has been in practice as long as food and grain processing have been in existence. The "old school philosophy" of making do with what is available, was and is to some extent today the basis for byproduct feed use. Often it was more profitable for a farmer to sell his grain than to use it as animal feed. In this case forages and agro-industrial byproducts became the economic alternative. Very little if any prefeeding evaluation of a byproduct was conducted. The value of a byproduct as a feedstuff was determined primarily by monitoring of the performance of a group of animals fed the material. Formal evaluations, which were performed to determine the nutritional worth of a potential feedstuff, consisted of rough chemical analysis and very basic digestion trials to estimate digestible nutrients in a feedstuff. Microscopic examination was also used to determine the portion of the seed grain constituting the byproduct. A nutrient value for the byproduct was assigned according to the composition of the byproduct. When formal techniques of evaluation were not employed, the nutrient value for a byproduct was considered to be similar to the pre-processed grain or compared to another feed with similar characteristics and processing methods (Armsby, 1898). Prior to the late 1800's, biological and physiological factors of the animal were not addressed in consideration of the nutrient value of a feedstuff (Woll, 1916). At this time byproduct feeds were utilized primarily as protein supplements or as a compliment feed, improving the acceptability and nutritive value of a less acceptable feed (i.e. wet distillers grains mixed with coarse fodder) with very little emphasis on energy worth of a feed (Armsby, 1898). Today, advancing technology and understanding of physiological processes allow more accurate means of byproduct evaluation.

As industry output strives to keep up with ever-growing public demand, large quantities of wastes requiring disposal are produced. A number of problems arise from this buildup of wastes. From the industrial standpoint, waste buildup hampers production process and often restricts product output. Disposing of wastes has become increasingly difficult as government health and environmental regulations tighten. Landmass available for dumping industrial wastes, both toxic and non-toxic, lessens as human populations grow.

Waste removal and treatment is an expensive process, but as dumping of wastes becomes more difficult the search for practical bases for reclamation of renewable wastes becomes more attractive. The result is an increasing supply of industrial byproducts made available as potential feedstuffs for livestock.

For an average livestock production system, feed costs comprise approximately 80% of the total variable costs (Thompson and O'Mary, 1983). Incorporation of newly available byproducts into existing feeding systems may offer an economically attractive alternative to other more commonly used , higher priced feedstuffs. There are some inherent risks associated with the feeding of unconventional materials. This fact often reduces their attractiveness. One of the major problems of byproduct feed use is the lack of nutritional information available for specific byproducts for specific species and classes of animals. Even for those byproducts evaluated, nutrient estimates provided are of limited value due the extreme variability which often exists. This variation in product and lack of information concerning the nutrient worth of a byproduct makes prediction of animal response and assessment of economic worth extremely difficult. The challenge of industry today and in the future is to reduce variation in the material provided to livestock producers. Safety risks for the user and consumer must be dealt with by industry and livestock producer, respectively. Increased intensity in livestock production increases the risk involved for the producer. Thus, incorporation of byproducts into feeding systems is not always practical. Questions concerning special requirements for handling, preservation and further processing of the material must be answered also. A methodology which addresses these issues for the use of byproducts as feedstuffs for livestock does not presently exist. The application of such a methodology which thoroughly evaluates byproducts for this use could possibly result in an increased utilization of available byproducts as feedstuffs.

With any evaluation, it is important to have an understanding of the character and history surrounding the subject of interest. Possessing a knowledge of the industry yielding the byproduct often provides insight into a materials nature. The National Research Council (1983) provides generalized descriptions of byproduct materials produced by specific types of industries. These are as follows: food processing wastes , industrial non-food processing wastes, forest residues, animal wastes, crop residues and aquatic plants. Food processing wastes are described as being generally high in moisture content and thus require immediate processing. Special requirements for treatment, handling and storage may at times render some byproducts economically infeasible. Ensiling of byproducts low enough in moisture content may provide an economic alternative. Application of high moisture wastes to dry, poor quality roughage is another possible alternative. Fruit and vegetable wastes are described as generally being high in carbohydrates, low in protein and seasonal in availability. Fuel production is considered a viable alternative use for these wastes due to the high levels of fermentable carbohydrates present. As a potential feed, pesticide residues present concerns for this group of wastes along with inherent drugs which may be contained in the material (i.e. caffeine and theobromine in cocoa wastes). Care must be taken in combining substances from this group with non-protein nitrogen (NPN) sources (i.e. apple pomace treated with NPN source has been shown to cause reproductive problems when fed to pregnant cows). Animal processing wastes are high in protein, low in carbohydrates and consistent in supply. Heavy metals may be a problem in some tannery byproducts.

Industrial nonfood wastes fall into three categories- chemicals, fermentation byproducts and municipal wastes. Most of the wastes in this group, with the exception of fermentation byproducts, require further processing before their value to the feed industry is realized. Such processing includes 1) synthesis of microbial protein, 2) hydrolysis of large molecular weight compounds to enhance nutrient availability, 3) modification of physical form, 4) synthesis of carbohydrates, fats and fatty acids from nonnutritionally valued organic compounds, and 5) detoxification. These methods are, however, extremely expensive. Chemical substances are used as medium for growth cultures of bacteria, yeasts, molds and fungi providing as an end product single cell protein. The potential for the contamination of toxic chemicals and heavy metals are serious concerns for this group. The fermentation industry yields an estimated one million tons/year of brewery byproducts and 360,000 tons/year of distillers and ethanol byproducts, the majority of which are currently being used as livestock feedstuffs. However, the high costs of drying waste slurry has prompted interest in market development for alcohol byproducts in their wet form. Municipal wastes, through separation of constituents, may also provide a useful product for ruminant production systems. Cost again is the restraining factor.

Forest residues provide heavily lignified cellulolytic compounds which typically are resistant to microbial attack in the rumen. Physical and chemical treatment can potentially raise the energy value of some species of trees to that of medium quality hay, providing an alternative feed for wintering animals. Pulp and paper industry residues are potentially good feed sources for ruminants due to a partial delignification which occurs during processing. Care must be taken, however, to insure that toxic materials are not present. With all byproducts of this group, supplementation of protein, minerals and vitamins is essential.

Animal wastes are high in fiber and NPN levels and are as a result particularly suited for inclusion in ruminant diets. Mixture with other ingredients for ensiling is a practical application of this byproduct.

Crop residues, usually low in protein and low to moderate in energy value, can be enhanced in nutritive value by alkali or ammonia treatment. This group is a good candidate for mixing with high moisture byproduct feeds for improved quality.

Aquatic plants have yielded satisfactory responses when fed to ruminants. Members of this group are high to moderate in protein and energy. Location and moisture content present difficulties in the harvesting and processing of these products.

These descriptions portray the diversity of byproducts available for livestock feeding and the versatility of their potential application. The difficulty in discernment of a materials feeding potential is apparent. A thorough description of the material is the first step toward discovering the value of a byproduct.

Several sources have proposed general guidelines in assessment of byproducts for use in livestock diets. Haendler (1980) proposed some general principles for describing specific feeds. These included: 1) origin; 2) substrate compositional make-up; 3) processing or treatment methods having been applied to the material; and 4) nutrient composition of the material. The effects of outside influences, such as storage, production location and possible changes during shipment, soil type and possible pesticide and fertilizer contamination, were also included in the description. In a recent publication, the National Research Council (1983) included the following topics in their description of several byproduct feedstuffs: quantity available, physical characteristics, chemical composition, nutritive value (nutrient content and availability, and animal performance), handling (processing methods, storage and preservation), alternative uses, animal and human health problems and regulatory aspects (pesticides, heavy metals, drugs and residues), utilization systems, and processing technology and collectability of the material. Wilson (1980) proposed a few other factors to consider in evaluating new raw materials as livestock feeds; these are "drying requirements (cost of removing water), acceptability to farmer and ultimate consumer - aesthetic considerations, proximity of the byproduct to livestock populations, competition with human foods, availability of information concerning nutrient value, animal acceptability, uniformity of analysis (ease by which raw materials can be incorporated into a compound diet by the nutritionist)."

These issues can be condensed into 7 categories: 1) origin of the material; 2) description of the material; 3) special requirements associated with handling, storage and preservation of the material; 4) variability and factors affecting; 5) health and safety of the material; 6) application of the material to production systems; 7) economic valuation. The specific issues within the categories will vary among different geographic locations around the world.

Origin

A thorough knowledge of the origin of a material is essential for a correct evaluation. Information concerning feedstock history, processing methods invoked on the feedstock, recovery methods utilized and products yielded from the process is of great value in determining the nature and composition of the byproduct being considered (Waller and Black, 1981). The end-products can be altered by variation in type or quality of feedstock ingredients. Determination of the likelihood of contamination from pesticides, herbicides, molds, mycotoxins, heavy metals, etc.., present in a feedstock or processing ingredient aides in assessing health and safety risks associated with a material. Physical and/or chemical treatments imposed upon an ingredient during processing or recovery also have an effect on the physical, chemical and nutritive characteristics of a material. Seed meal byproducts, for example, vary in nutrient content depending on method of oil extrusion utilized, solvent or mechanical. Heat treatment of corn or soybeans can increase or decrease the nutrient value of a feed depending on the level and duration of the heating process. Proteins are denatured and starches are geletinized by heating (Sunde,1973).

Description of Byproduct

Physical characteristics such as color, texture, odor and forms available determine the acceptability by both animal and feeder. A materials physical form and characteristics determine requirements for special management in areas of handling, preservation and storage, as well as possibly restricting the materials use.

Measurement of the nutritional value of a byproduct is a much more difficult process. This is primarily because nutrition is a function of biological, physiological and environmental factors which cannot be simulated in a reproducible process. The vehicles attempting to convey nutrient worth of feeds are known as feed standards. The development of the first feed standard for livestock is credited to Albrecht Daniel von Thaer in the early 1800's (Flatt,1970). Values of feedstuffs in von Thaer's system were determined on a comparative basis using "good quality hay" as a point of reference. Performance data of animals fed different diets was used to determine nutrient values for the respective diets. In an effort to reduce the time and cost involved in this method of nutrient value determination, von Thaer and a German chemist, Einhof, developed a crude method of chemical analysis to replace costly feeding trials. Values provided from this process were extremely rough and were not very representative of the actual nutritional worth of a feed. Feeling the need to provide more accurate means for evaluating feedstuffs, Henneberg and Wolff developed techniques for conducting digestion trials. Wolff later combined efforts with Lehmann in 1896 and purposed the Wolff-Lehmann feed standard. This standard was based on digestible protein, digestible carbohydrates and digestible fat (Morrison, 1940). In 1915, Morrison simplified the Wolff-Lehmann standards by combining the energy fraction of a feedstuff in terms of total digestible nutrients (TDN). TDN values represent the amount of digestible organic nutrients in a feed which possess potential to serve as a heat and energy source. These nutrients are digestible protein, fiber, nitrogen-free extract and fat (Morrison,1940). Definition of commonly used energy standards is as follows:

Digestible energy(DE)= feed energy intake(IE) - fecal energy(FE)

(NRC,1984)

Metabolizable energy(ME) = DE - methane loss(GE) - urinary energy loss(UE)

(NRC,1984)

Total digestible nutrients(TDN) = digestible protein(DP) + digestible nitrogen free extract(DNFE) + digestible crude fiber(DCF) + 2.25 x digestible ether extract(DEE)

(Tyrrell,1985)

Net energy maintenance (NE_m) = $1.37ME - 0.138ME^2 + 0.0105ME^3 - 1.12$ = " The amount of thermal energy produced by a fasted animal."

(NRC,1984)

Net energy gain (NE_g) = $1.42ME - 0.174ME^2 + 0.0122ME^3 - 1.65$ = " The amount of energy deposited as non fat organic matter (mostly protein) plus that deposited as fat."

(NRC,1984)

TDN and DE requirements are determined by the conversion of 1 kg TDN = 3.62 Mcal of ME and DE = ME/0.82

(NRC,1984).

With DE, TDN and NE values being derived from ME values, Tyrrell (1985) suggested the ME value of a feedstuff to be the most critical measurement for predicting animal performance. This statement is true in that it is the starting point for basically all feed evaluation systems based on NE concepts (NRC,1984).

There are specific advantages and disadvantages to each energy system. These are as follows:

1) Digestible energy: DE is the easiest analysis to perform, but is the least accurate. The error of this standard lies in the inability to discern variances in digestiblity resulting from feed and animal variation (Tyrrell, 1985). DE also overestimates availability of energy contained in high fiber diets to that of lower fiber, more highly digestible materials (NRC,1984). High fiber content of many agro-industrial byproducts makes DE undesirable as a basis for a feed standard; however, economic constraints may dictate the use of this system in lesser advantaged countries.

2) Metabolizable energy: ME accounts for loss during digestive process by subtracting combustible gas production and urinary energy loss from the estimated DE. UE, however, is not an estimate of feed energy unavailable for tissue utilization, but rather represents metabolic end products (Tyrrell, 1985). Both urinary and combustible gas energy losses are relatively predictable and thus DE and ME are highly correlated (NRC, 1984).

3) Total digestible nutrients: TDN values are calculated using estimates derived from the proximate analysis system. The proximate analysis system is comprised of a series of analytical techniques used to determine a) lipid and fat

content via ether extract; b) crude protein content as determined by nitrogen content (all nitrogen is considered to be in the form of protein, containing 16% nitrogen); c) the poorly digestible fibrous and structural portion of the feed by crude fiber analysis; and d) levels of highly digestible carbohydrate in terms of nitrogen free extract (NFE). The assumptions used in these procedures are not valid, but all result in error to varying degrees (Van Soest, 1983).

There is much debate concerning the worth of chemical analysis systems. This type of system offers no prediction of the feeds effect on rumen function, microbial fermentation and available response of nutrients to post ruminal digestion. Feed analysis systems fail in the following: a) No form of feed analysis characterizes the efficiencies of the rumen ecosystem. b) The response of digestibility due to differing levels of feed intake is unpredictable in many cases and may be affected to a greater extent by supplementation. c) Crude protein content does not express amino acid availability of a diet. d) Balances among long chain fatty acids, glucogenic energy and essential amino acids taken up by the animal largely dictate the energy value and energy utilization efficiency of a diet (Preston, 1985).

The ease by which nutrient values for feeds can be obtained by chemical analysis is a strong point of the system. Alterations in the proximate analysis system to a more accurate method of feed fraction extraction and determination (i.e. utilization of detergent fiber analysis in lieu of crude fiber (Van Soest,1983)) might provide a more accurate means of nutrient value description of a feed.

4) Net energy: NE measures the quantity of energy in a feed which is converted to energy in animal product form. It surpasses ME in accuracy of evaluation by accounting for variation in the levels at which the nutrients are efficiently utilized. Physiological groupings of NE (maintenance, growth, lactation) allows for distinctions in nutrient utilization efficiencies (NRC,1984). NRC (1984) lists two major advantages of the NE system: a) animal diet does not effect stated NE requirements of the animal; and b) feed requirements for maintenance and productive functions are estimated separately.

The energy system selected to be used to describe a feed should convey the level of technical information and facilities available for its determination and use.

Protein, like energy, has a multitude of systems which describe its value in a feedstuff. The ruminant has a unique ability of utilizing nonprotein nitrogen (NPN) to synthesize essential amino acids in the form of microbial protein. The simplistic expression of animal protein requirements and feedstuff protein content in terms of crude or digestible protein (nitrogen content x 6.25) is not sufficient for describing animal needs for feed protein quality (Chalupa, 1980). Assumptions made in the crude protein system have been found to be invalid. For example, true protein accounts for approximately 70% of the nitrogen present in forages, not 100% as assumed. Also, the nitrogen content of plant proteins fluctuates slightly from the assumed nitrogen content of 16% (Van Soest, 1983). These variances challenge the constant, 6.25, utilized in crude protein determination. Van Soest (1983) denounced the accuracy of the crude protein system in fecal protein analysis. True protein usually accounts for only a small portion of nitrogenous substances contained in fecal material. The bulk are made up of microbial substances or Maillard products which contain 7-11% nitrogen.

An increased understanding of the ruminants duodigestive process necessitates a more complete description of the proteinacious portion of feed stuffs. Recent attempts to accommodate this new knowledge are discussed at length by NRC (1985). These systems express protein in terms of net protein (NP) are defined as follows:

$$NP = \frac{\text{grams nitrogen retained} \times 6.25}{\text{grams nitrogen intake} \times 6.25}$$

(Waller et al., 1980).

The following factors influencing protein metabolism in the ruminant are considered under the NP system:

1.Feed protein intake

2.Rumen degradability of the protein fraction

3.Bypass protein- protein which is not degraded in the rumen

4.Microbial protein synthesized in rumen limited by:

A) Energy available for microbial growth and production- fermentable organic matter, digestible organic matter, DE, ME

B) Microbial protein conversion of available nitrogen given energy restraints

5.Recycled nitrogen- efflux and influx of ammonia through the rumen wall or urea present in saliva

6.Quality and digestibility of bypass protein

7.Undigestible dietary protein

8.Absorbed or metabolizable protein from microbial and dietary protein

9.Endogenous protein- metabolic waste and nitrogenous secretions of the digestive tract

10.Rumen turnover- digestiblity rates which can affect production of microbial crude protein and intake levels of dietary protein.

Microbial conversion of ruminal ammonia to microbial protein causes protein quality in terms of amino acid balance, not to be as significant as in monogastric species. The important issue regarding protein in ruminants is availability and extent of digestion in different locations along the digestive tract of the animal. Nitrogenous compounds consumed by the animal can be in the form of proteins, peptides, amino acids, nucleic acids, water soluble nitrogen and acid detergent fiber bound nitrogen (Sniffen, 1980). These compounds are either degraded in the rumen and utilized for synthesis of microbial protein or exit the rumen to be digested in the small intestine or excreted in the feçes. Protein supplied by microbial protein appears to be sufficient for maintenance, slow growth and early pregnancy, but is not sufficient for rapid growth, late pregnancy or lactation (Chalupa, 1980). When animal protein requirements exceed that provided by microbial protein, the protein source utilized in the ration must contain a sufficient level of ruminally non-degradable protein (bypass protein) in order to obtain desired production level. To determine the quantity of ruminally degradable protein (RDP) and bypass protein required by an animal consuming a given amount of energy, Chalupa (1980) proposed the following equations:

1) $$RDCP = ME \times \frac{1}{0.8 \times 0.0045} \times (0.65) \times (0.15)$$

or = (Mcal of ME) x 26

where

RDCP = Rumen degradable crude protein (grams)

ME = Metabolizable energy required by the animal (Mcal)

0.82 = 18% of apparent digested energy lost as methane

.0045 = digestible (Mcal) in digestible organic matter

0.65 = fermented organic matter in digestible organic matter

0.15 = microbial crude protein from fermented organic matter

2) $$RUCP = \frac{MP - (RDCP \times 0.80 \times 0.75)}{0.75}$$

where

RUCP = rumen undegradable crude protein (grams)

MP = metabolizable protein by animal (grams)

RDCP = rumen degraded crude protein

0.80 = microbial true protein

0.75 = digestibility of crude protein or MCP.

The advantages of more accurately assessing the nature and value of nitrogenous compounds in feedstuffs for uniquely capable ruminants are obvious. The disadvantages exist in the form of increased difficulty and complexity in feed protein valuation. NP values for specific feeds are difficult to locate and vary depending on the NP system utilized. These disadvantages significantly reduce the value of net protein systems for evaluation of byproduct feeds. Some parameters addressed in these systems such as bypass or rumen degradable proteins, may be of more significant value individually due to the greater availability of their values. Estimated rumen degradability of proteins with various forage and grain based diets are provided by Agriculture Research Council (1980) and Chalupa (1980). Preston (1987) provides bypass protein values for specific feeds.

An alternative method of describing energy and protein was proposed by Orskov (1980). His approach was to categorize feedstuffs according to levels of digestible energy and nitrogen. For feeds to be categorized in such a manner, the form and source of the nutrient must be determined. Nitrogen can exist in protein or NPN form and can be evaluated via analytical techniques. Energy sources exist in carbohydrate and fat form. The quality and availability of the nutrients to the rumen microbial population must be evaluated. This approach allows direct discernment in application and further processing required (i.e. If the energy source is fat, intake must be limited to no greater than 5% of the diet to promote a desirable rumen environment.). The materials are described in the following categories:

1) Low in digestible carbohydrates, high in nitrogen -- These materials may be treated with alkali to increase compounds available for fermentation or by supplementation of fermentable substrate for maximum utilization of nitrogen (i.e. excreta).

2) Low in digestible carbohydrates, low in nitrogen -- These materials have a slow rate of passage resulting in decreased intake. Reduction in particle size and alkali treatment are methods of increasing passage rate and digestibility (i.e. cereal straw, husks, legume hulls, wood/paper byproducts).

3) High in digestible carbohydrates, high in nitrogen-- These materials pose few if any problems. Possible problems may exist in the area of handling, moisture content, seasonality of production and storage problems (i.e. vegetable processing byproducts).

4) High in digestible carbohydrates, low in nitrogen -- These materials are best supplemented by rapidly degradable nitrogen sources to meet rapid fermentation needs (i.e. sugar processing wastes, fruit and cereal processing).

It is important to define type of feed to obtain optimum utilization of the product. Combining energy yielding feeds is more complex than combining materials to obtain optimum NPN usage. Incorporation of rapidly fermentable substances (groups 3 and 4) often reduce digestion of cellulose/hemicellulose in fibrous feeds. Therefore, it is not advisable to combine groups 1 and 2 with groups 3 and 4 or with high concentrate diets. The desired use and function must be determined prior to this generalization because exceptions do exist (i.e. combination of excreta with group 4 to meet nitrogen deficiency).

This method of expressing the nutrient value is easy in its application and is valuable for predicting feed interactions. However, the lack of specific nutrient values make this system impractical for tightly regulated feed formulation.

Other nutrients, such as vitamins and minerals, are straight forward in their descriptions. Dietary requirements and metabolic function of these nutrients have been reviewed by NRC (1984). Vitamin and mineral content (with the exception of macrominerals such as calcium, phosphorous and potassium) are not generally emphasized in ration formulation for ruminants. Supplementation of cattle diets with trace mineral salts is an economical and effective method of assuring adequate levels of trace minerals. Vitamins present naturally in feedstuffs and those synthesized by microbes or intrastitially are sufficient to meet requirements in most cases (NRC, 1984).

Variation

Variation is a problem which plagues the byproduct industry, and is a major source of risk to the feeder. The two primary areas of variation are in composition and availability (Waller, 1985).

High variability in nutrient and substrate composition is an inherent problem in byproduct feeds as a whole. Variations in input, processing technology, recovery methods, handling and storage and transportation of a material from industry to producer, all affect product consistency. Utilization of a single source, rather than multiple sources, can help reduce this variation but will not eliminate it. The level of variation within a product is generally accounted for in market price (McLemore, personal reference, 1988). Price histories, however, are not available for most byproducts. Determination of acceptable price adjustment factors for known variation is a problem which will be addressed in a later section.

Variation in supply and demand of a material incorporates factors of seasonality, amount available, competition for that supply, stability and outlook of the industry yielding the byproduct, proximity to livestock populations, restrictions on shipment size made available, and price. These factors are situation specific and must be evaluated by individual producers.

Health and Safety

Safety of a byproduct being considered as a livestock feed is extremely important to both the producer and consumer. The producers primary concerns are in the areas of handler and animal safety and carcass acceptability. Understanding potential sources of toxic substances is the first step to detecting their presence. Shillam and Worden (1967) list three sources of toxic materials: 1) elements and contaminants which occur naturally in the feedstock; 2) contaminants occurring unintentionally and 3) added chemicals.

Molds and toxins produced by molds (mycotoxins) are examples of contaminants which may naturally occur in certain feedstocks. Mycotoxins are of serious concern to both animal and human welfare. For livestock, ingestion of low levels of these substances may result in reductions in feed intake and animal performance. Ingestion of higher concentrations may result in hemorrhaging of the small intestine or other organs, eventually resulting in death. Human symptoms of low to medium infection levels are sluggishness and reduction in strength of the body's immune system. High levels of mycotoxin ingestion produce a multitude of organ and tissue disorders, malfunctions and cancers (Lillehoj, 1978; Pettit and Taber, 1976). In an effort to eliminate development possibilities of mycotoxicosis, the Federal Food and Drug Administration imposed regulations setting maximum allowable levels of mycotoxin contamination of grains and fruits processed for human consumption or fed to livestock at 20 ppb (Lillehoj, 1978). The wet nature of many byproduct feeds, which do not fall under such regulation, make them extremely susceptible to contamination. Improper handling and storage of these materials can be expected to result in considerable loss for the producer. Even with seemingly proper storage and handling mycotoxins may develop. The likelihood of their presence in stored feeds is determined by feed factors, primarily moisture content greater than 13%, and environmental factors, moderate to high temperature and relative humidity greater than 65% (Mirocha and Christensen, 1976). For specific information on types of fungi, toxins produced by fungi, environmental conditions under which they proliferate, and specific symptoms on infection, see Pettit and Taber (1976), Mirocha and Christensen (1976), Diener (1976) and Carlton (1976).

Often mycotoxins are the culprit for unexplained illness or reduction of performance of livestock. Detection of mycotoxins can be performed by the following tests proposed by Pettit and Taber (1976):

"1) A veterinary problem agent in which no obvious cause can be immediately determined.

2) A causal agent cannot be transmitted from one animal to another. It is neither infectious nor contagious.

3) Treatment with antibiotics or drugs has little effect on recovery from typical symptoms.

4) Outbreaks are of seasonal nature following climatic conditions which favored fungal growth on the consumed feed.

5) An examination of suspected grasses, hay or feeds reveals the signs of fungal growth. Mycotoxin-producing fungi can be isolated.

6) Chemical analysis for toxic mold metabolites (mycotoxins) characteristics of the isolated fungi reveals their presence within a feed."

If feeds have been determined to be contaminated, application of anhydrous ammonia is proven effective for detoxification (Lillehoj, 1978).

Other examples of substances occurring naturally in certain feed materials are high levels of polyunsaturated fats and products of fat oxidation (meat processing wastes), toxic florine levels (some sources of rock phosphate), trypsin inhibitor (unheated soybean meal), and gossypol (cottonseed). Inorganic element contaminants such as mercury, selinium, lead, aluminum, cadmium, etc.. present potential problems for utilization of solid waste material as a feed. Certain levels of these elements are tolerated by the ruminant (Gillies, 1978).

Exogenous contaminants often arise from improper handling, storage or recovery. Bacterial contamination, i.e. salmonella or anthrax, cause serious concern for both human and livestock welfare. Lubricating oils used on processing machinery can easily contaminate materials, especially byproduct materials which are not handled as attentively as primary products. These lubricants contain chlorinated napthalenes which upon ingestion result in hyperkeratosis, ending in death from kidney and liver failure. Pesticide and herbicide residues are other good examples of exogenous contaminants which pose concerns.

The third category, intentionally added chemicals, applies to chemicals used during processing or those substances commonly added to a diet (i.e. urea or a non nutritive feed additive).

Safe and healthful byproduct feed utilization is a function of feedstock quality, industrial processing, storage and handling, and appropriate application. Failure to investigate and apply the necessary management required in any one of these areas for potential risks may result in serious loss.

Special Requirements

The most significant factor affecting special requirements in areas of handling, preservation and storage is moisture content. As already stated, high moisture content may limit the use of some byproducts (National research Council, 1983). Often wet byproducts are dried (i.e. distillers grains, brewers grains, corn gluten feed) to improve handling and storage qualities. The high cost of energy required for drying of these materials is prompting attempts to market the material as a wet feed. Preservation of these feeds is the task.

There are a number of additives which enhance ensiling or extend keeping quality and bunklife. These additives act in the following manner: 1) inhibition of bacterial or fungal activity by lowering pH or partially sterilizing the substrate , or 2) stimulate lactic acid production by providing fermentable substrate or inoculum of lactic acid bacteria culture (Wilkinson, 1986).

Inhibitors of fungal growth or certain bacterial activity are comprised of acids (i.e. propionic, formic, sulfuric) and salts (i.e. sodium nitrate, calcium formate, ammonia complexes). Formaldehyde is also known to protect protein compounds from microbial breakdown during ensiling and in the rumen; thus, increasing the amount of bypass protein. This chemical, however, has been banned in this country as a carcinogenic agent. Stimulants of desirable fermentation are energy substrates (i.e. sugars-sucrose, molasses) and inoculum of lactic producing bacteria (biologicals), both of which accelerate the ensiling process (Wilkinson, 1986). Byproducts to wet too ensile must be fed immediately, chemically preserved for short periods or combined with drier materials to obtain desirable dry matter content for ensiling. Discretion must be applied in selecting the type of silo to be used. Particle size and bulk densities may prompt utilization of bunker or trench silos in lieu of upright silos.

Some byproducts are limited in value due to high levels of indigestible fiber, and thus, require special treatment before their value can be realized. A number of physical and chemical treatments have been developed to increase the nutrient availability of fibrous feedstuffs. Specific information pertaining to alteration of physical from to improve nutritive value can be found in the following sources: Pearce (1982), Jayasuriya (1985), and Greenhalgh (1986).

Application to Production Systems

The application of byproducts to specific production systems should be based on information gathered from the other sections discussed in this report. Wilson (1980), using feed categorization methods proposed by Orskov (1980), provided a valuable tool for anticipating possible areas of concern for managing different types of byproducts. The five energy-nitrogen groups were ranked from 1 (best or least) to 5 (worst or greatest) for specific management areas. These figures are presented in Table 1. From this chart a producer can anticipate possible problems or difficulties surrounding application of a certain type of byproduct for his/her operation.

TABLE 1. Evaluation of Management Issues for Specific Feed Types Categorized By Levels of Nitrogen and Digestible Energy[a]

	HIGH N LOW DE (ANIMAL EXCRETA)	HIGH N HIGH DE (FISH AND SLAUGHTER	HIGH N HIGH DE (VEGETABLE WASTES)	LOW N LOW DE (CEREAL STRAWS)	LOW N HIGH DE (SUGAR BYPRODUCTS)
Safety	5	4	2	3	1
Acceptability	5	4	1=	3	1=
Quantity available	2	5	3	1	4
Drying requirement	3	4	5	1	2
Proximation to livestock	1	5	3=	2	3=
Competition with human food	1=	3=	3=	1=	3=
Information about nutrient value	5	4	3	2	1
Uniformity of availability	4=	4=	3	2	1

[a] Wilson, 1985

Risk associated with byproduct use is often a strong deterrent for the prospective feeder; occasionally it is not strong enough. Extreme care must be taken to insure successful utilization of byproduct as livestock feeds. "Byproducts are used more successfully in feeding programs where the producer has the managerial expertise to fully capture these potential savings in feed costs. If producers are ranked by their managerial skills on a scale of one to ten with five as an average, byproducts should be a considered in feeding programs only for those ranking seven or higher" (Waller, 1985).

High levels of product variation are major contributors to increased management required. The ability to access and quantify risk associated with incorporation of byproducts into livestock diets is required for safe, effective, economical use. A method which allows the producer to adjust dietary formulation to accommodate nutrient variation which exists in a material was presented by Black et al. (1978). the following equation was purposed:

$$Aij^{*} = E(Aij) - f\ (Vij)^{-1}$$

where:

Aij* = corrected nutrient value of the ith nutrient of the jth feed to be used in formulation

E(Aij) = tabular or mean value of a nutrient

f = adjustment factor

Vij = variance of the nutrient value

The adjustment factor (*f*) allows specification of the confidence level required for specific situations. Assuming a normal distribution of variation exists, adjustment factors can be selected from values presented in Table 2.

TABLE 2. Adjustment Factors Needed To Achieve Alternative Confidence Levels

Odds of violating requirements, %	Adjustment factor, Standard deviation
50	.00
40	.26
30	.53
20	.83
10	1.29
5	1.65
1	2.33

Selection of adjustment factors is a management decision based upon subjective determination of the level of risk acceptable to the individual producer. Black et al. suggest minimal adjustment factors of 0, 0.8, 1.1 and 1.2 for steers weighing < 500 lbs., 500 lbs., 700 lbs. and 900 lbs., respectively. These values were considered to be economically optimal as determined from studies monitoring the cost of gain for animals consuming diets formulated with nutrient values adjusted to different levels of risk.

Although this method of nutrient value adjustment is a helpful tool in managing risk, sound judgment is not replaced. The assumption is made in this procedure, for instance, that upward variation in nutrient levels are not considered threatening. Accidosis may occur if energy values for ingredients in energy dense rations are underestimated. Where margins in meeting specific nutrient requirements are narrow, feeding of byproducts as a whole should be avoided.

Investigation, evaluation, assessment of risk and management of that risk are all essential elements for successful application of a byproduct to specific systems.

Economic Valuation

Recent articles appearing in the popular press (Weigel and Hutjens, 1986; Charolais Commercial Newsletter, 1985) that deal with the pricing of specific byproducts are limited in scope. These approaches have over simplified the issues involved in price determination for a feed. Addressing of single nutrients in a comparison between byproducts (i.e.corn gluten feed) and conventional feedstuffs (i.e.corn, soybean meal(SBM)) are not complete in describing nutritional potential of a feed material. For example, Weigel and Hutjens (1985) proposed the value of dry corn gluten feed(DCGF) to equal 75% the price of corn plus 25% the price of SBM, where corn and SBM are contributors of energy and protein, respectively. This procedure does not address the energy value and other nutrients in SBM, nor the protein contributed by corn. The Charolais Commercial Newsletter (1985) compared performance of steers fed a corn silage diet supplemented at two different levels of pelleted CGF (33% and 66%). The economic value for CGF at their respective dietary levels was determined solely as a function of the cost of feed per pound of gain. Neither method of evaluation utilizes existing information concerning the duodigestive process of the ruminant and its ability to utilize different types of nutritional components to differing efficiencies.

Black et al. (1983) proposed a method of determining the economic worth of each nutrient component within a feed. This approach utilized a least cost linear program model and a procedure termed "value mapping". The flexible structure of the LP model allowed for the incorporation of multiple nutrients to be considered in ration formulation and economic valuation. It also allowed for the determination of multiple right hand side values, or animal requirements, to be specified for different classes of livestock. The result was a versatile model which would consider more than one or two nutrients when determining economic value, as they are applied to unique requirements of different livestock classes.

A factor which is not addressed in any of these examples is that of variability of byproduct composition and the resultant effect on economic value. A complete economic model should give the economic advantage to those products displaying consistency in composition, and discount those which do not. Black and Peterson (1978) proposed a method of adjustment of a nutrient value of a feed prior to its incorporation into an economic model; allowing that adjustment to apply an economic advantage/disadvantage in accordance with the variation which exists. This particular system is linked with management, as discussed in the previous section. The determination of adjustment factors that will be applied to a nutrient value should reflect the level of risk a producer is willing to accommodate. The results of this study indicate that as a beef animal approaches market weight, the economically optimal adjustment factor will increase, thus lowering the nutrient values utilized in diet formulation. This in effect indicates a reduction in the economic value of a variable feed material.

Although economic value is important in determining the use of byproducts in animal diets, other important factors discussed in this literature review are of equal, if not greater, importance than economic value. The incorporation of byproducts into animal diets has historically occurred without a thorough, organized approach that covers the issues discussed in this review. Therefore, the objective of this research is to develop a methodology for establishing the merits of a byproduct or new feed ingredient proposed for ruminant diets.

CHAPTER III

MATERIALS AND METHODS

Section I

East Tennessee is a grain deficit region of the state. Thus, the cattle feeding industry in this region is very limited. The region produces about one third of the 700,000 head of feeder cattle produced in the states each year. Also, this region has the third, fourth and fifth largest population centers located within the states. Therefore, with a readily available supply of feeder cattle and a population base to consume the end product, the region exhibits potential for growth in cattle feeding. Such growth would require a reduction in the grain deficit, training of management personnel and an increase in meat packer capacity.

Corn gluten feed (CGF) has recently become available to the region in as a wet byproduct feed (approximately 40-50% moisture). The high moisture content limits the distance the product can be transported economically from the A.E. Staley plant in Loudon, Tennessee. Full incorporation of a feedstuff into livestock feeding systems in any region of the U.S. requires the same basic information, such as nutrient content and general behavior of the feedstuff in a number of diets. WCGF appears to show promise as a valuable protein-energy source, thus possibly altering the grain deficit in this area, reducing one aspect which hinders growth of a feeding industry. However, a number of factors associated with WCGF must be evaluated prior to recommendation for the materials application. The absence of methodology for assessment of such newly available feed materials often results in limited or inappropriate use of the material.

This section was designed to provide a method of byproduct feed evaluation which thoroughly investigates aspects of a material directly affecting the materials application and economic value for specific livestock systems. Issues to be addressed in this section were determined from literature reported in the review and combined in outline form. The initial outline for the methodology used is as follows (recommendation for a final outline was developed and provided in the discussion section of this report):

I. Description of byproduct

A. Physical description

1.Form-

2.Color-

3.Texture-

4.Odor/ Taste-

5.Composition-

B. Background Description

1.Source-

2.Location-

3.Primary products-

4.Byproducts yielded-

5.Feedstocks-

6.Feedstock source-

7.Processing/Recovery methods-

C. Chemical Description

1.Nutrient Profile-

2.Characteristics-

a) Fiber- dry matter and ADF digestibilities

b) Protein- RDP and ADFN

II. Availability

A. Quantity (amount and time basis)-

B. Seasonality (yes/no;specify if yes)-

C. Restrictions on shipment size made available-

D. Supply outlook (stability)-

III. Health and Safety

A. Potential contaminants from section IB.-

B. Observable symptoms to contaminants listed in part(A)-

C. Potential residuals-

D. Potential storage risk-

E. Physical/Chemical treatments to be avoided-

IV. Special Requirements

A. Storage

1.Short term-

2.Long term-

B. Handling

C. Feeding

The availability of information for addressing the elements of the methodology will vary depending on the byproduct being considered. Often byproduct information concerning these areas may be obtained from different types of publications. Information for WCGF was obtained from the following sources:

1) Professional Journals
    - Journal of Animal Science
    - Journal of Dairy Science
    - Canadian Journal of Animal Science
    - American Feed Science and Technology
2) Agricultural Extension and Government Publications
    - Missouri Beef Cattle Report
    - Nebraska Beef Cattle Report
    - National Research Council publications
3) Conference Proceedings and Industry Publications
    - Cornell Nutrition Conference
    - Feed Dealers Seminars
    - Distillers Feed Research Council
    - Feedlot Management
    - Beef magazine
    - Feedstuffs magazine

Section II

The objective of this section was to develop a least-cost linear program model which would allow economic valuation of feeds according to unique nutrient qualities, including certain protein parameters. Lindo (Lindo Systems,Inc., 1985), a linear programming package, was utilized for this process. An IBM, Model-AT (512 KB), personal computer was used to drive the program. Twenty-two feeds commonly used in ruminant diets were incorporated into the model to provide flexibility in diet types and combinations. A list of these feeds and their respective nutrient values are presented in Table 3. The objective function (minimizing cost) and a list of subsequent constraints is provided in Appendix A and B. Two approaches were used to test the sensitivity of the model constrained to different protein descriptions, crude protein (CP) and rumen degraded protein (RDP). Diets under both approaches were balanced specifically for 1.17 Mcal NEg and constrained by protein parameters described in Table 4. Diets were formulated for growing (215 kg) and finishing (318 kg) weight steers. Upper limits of RDP for growing and finishing diets were established according to RDP contained in SBM and urea supplemented diets, respectively. The level of RDP in the SBM and urea supplemented corn silage diets were found to be within diet

TABLE 3. Nutrient Values of Feeds Incorporated into Least-Cost Diet Formulation Model [a]

Feed	DM	CP	BP	ADF	NDF	CF	Ca	P	K	TDN	NEm	NEg	NEl
	% of dry matter										---Mcal/kg---		
CS	34	8	3.2	28	51	24	0.24	0.22	1.00	75	1.65	1.06	1.67
CG	89	10	1.0	3	10	3	0.03	0.13	0.35	89	2.16	1.48	2.05
DCGF	90	26	5.2	--	41	9	0.36	0.78	0.60	82	1.96	1.30	1.91
SBM	89	51	13	10	14	6	0.33	0.70	2.20	84	2.02	1.34	1.91
Urea	99	288	0	0	0	0	0	0	0	0	0	0	0
DDGS	92	16	16	18	42	18	0.30	0.82	0.70	85	2.05	1.36	1.94
CSM	91	46	17	13	22	13	0.19	1.15	1.40	76	1.78	1.14	1.72
WCS	91	10	0	51	0	34	1.70	0.25	1.20	45	0.99	0.07	0.97
AHF	89	16	4.5	41	56	34	1.30	0.22	1.70	53	1.17	0.40	1.17
AHM	89	77	3.7	38	50	30	1.40	0.23	1.90	58	1.28	0.57	1.28
AHE	90	18	3.2	35	47	29	1.41	0.24	2.40	61	1.36	0.68	1.34
FH	89	12	4.2	41	75	30	0.40	0.24	1.70	56	1.23	0.51	1.23
OGH	88	11	3.3	40	67	34	0.34	0.33	2.70	59	1.30	0.62	1.30
SMF	90	15	---	47	65	36	0.49	0.18	1.70	51	2.24	1.12	1.10
CSH	90	4	1.6	71	89	48	0.15	0.09	0.90	46	1.02	0.51	0.99
MOL	56	5	---	0	0	0	1.10	0.10	3.40	75	1.74	1.10	1.69
OATS	89	13	5.2	17	31	12	0.07	0.38	0.50	74	1.72	1.08	1.67
BDG	92	28	16.8	24	52	15	0.33	0.60	0.10	84	2.02	1.34	1.91
LS	98	0	0	0	0	0	34.0	0.02	0	0	0	0	0
DICAL	96	0	0	0	0	0	22.0	18.65	0.01	0	0	0	0
KCL	100	0	0	0	0	0	0.05	0	50.54	0	0	0	0

a Preston, 1987

b Key: CS, corn silage; CG, corn grain; DCGF, dry corn gluten feed; SBM, soybean meal; DDGS, dried distillers grains with solubles; CSM, cottonseed meal; WCS, whole cottonseed; AHF, alfalfa hay(full bloom); AHM, alfalfa hay(mid bloom); AHE, alfalfa hay(early bloom); FH, fescue hay; OGH, orchardgrass hay; SMF, soy mill feed; CSH, cottonseed hulls; MOL, molasses; BDG, brewers dried grains; LS, limestone; DICAL, dicalcium phosphate; KCL, potassium chloride.

TABLE 4. Protein Constraints of Diets Formulated for Growing (215 kg) and Finishing (318 kg) Steers

Steer Weight	CP	RDP max	RDP min
-kgs-		% dietary dry matter	
215	13.75	8.11	7.61
318	11.75	7.24	---

specific RDP ranges provided by Agricultural.Research Council (1980) and Chalupa (1980). Additional nutrient constraints applied are presented in Table 5.

This linear program was used to determine the economic value of dried distillers grains with solubles (DDGS) under each protein system. DDGS was used so that comparison could be made between protein system models in this section and the protein system model (Michigan Net Protein System) used by Black et al. (1983). Feedstuffs serving as potential diet ingredients were corn grain, corn silage, SBM, urea, limestone and dicalcium phosphate. Nutrient values and prices for these feeds are presented in Tables 6 and 7, respectively. Exclusion of feeds in diet formulation was performed by pricing out individual feeds not desired in the formulation. A value mapping procedure used by Black et al.(1983) was utilized to determine changes in dietary

TABLE 5. Nutrient Constraints Used for Formulating Diets for Growing(215 kg) and Finishing (318 kg) Steers[a]

Weight	NEg	CP	Ca	P	K	Suppl. NPN[b]
	- Mcal/kg-	------------	% dry matter	-------------		
215 kg	1.166	13.75	.46<c>.5	.34<p>.41	>.6	<=.014
318 kg	1.166	11.75	.34<c>.5	.26<p>.30	>.6	<=.012

[a]Fox and Black, 1976
[b]Urea $\leq$ 30% of crude protein

percentage of DDGS in accordance with changes in price. Value mapping is a method of determining the value of a feed in relation to the value of other feeds included in the diet at specified prices. This procedure allows monitoring of intradietary reactions to altering levels of a feed ingredient. These reactions, demonstrated in terms of change in dietary percentage of ingredients, are mathematically quantified to allow assessment of the value of one feed ingredient compared to another Shadow prices (incoming price - $1) were used as the representative values of DDGS in consecutive computer runs until the byproduct could no longer be increased in the diet by lowering price.

TABLE 6. Nutrient Values for Feeds Used for Formulating Diets Including DDGS[ab].

Feed	Nutrients (% dry matter)						
	DM	CP	Ca	P	K	RDP[c]	NEg[d]
corn silage	34	8	0.24	0.22	1.0	50	1.06
corn grain	89	10	0.03	0.13	0.35	40	1.48
SBM, 44	89	50.8	0.33	0.70	2.20	72	1.34
DDGS	92	28	0.30	0.82	0.70	38	1.36
Urea	99	288	--	--	--	100	--
Limestone	98	--	34.0	0.02	--	--	--
Dical. Phos.	96	--	22.0	18.7	0.10	--	--

[a]Preston, 1987
[b]Supplemental NPN<= 30% of CP requirement
[c]NRC, 1985 (expressed as percent of crude protein)
[d]expressed as Mcal/kg

TABLE 7. Prices for Ingredients Used in Formulating Diets Containing DDGS or WCGF.[a]

Feed	Price[b]
Corn Silage	6.70[c]
Corn grain	10.45
Soybean meal	20.24
Urea	24.75
Limestone	5.61
Dicalcium phosphate	32.12

[a]Feedstuffs, 1984-1986
[b]cents/dry kg
[c]5.4 bu corn/ton silage x Price of corn + $3.00 (Fox and Black, 1977)

The results of value mapping sequences were used to calculate specific price values for DDGS as prices of corn and SBM were fluctuated independently. Altered price values of corn were determined by inflating and deflating the price of corn (Table 7) by $1/ dry bu. SBM prices were inflated and deflated by $60/ dry ton. This was performed to provide information for determining the role of the byproduct in the diet, and the price relationship between the byproduct and these industry standards, corn and SBM.

Section III

Information from the preliminary evaluation (Section I) and validation of the least cost linear programming model (Section II) was utilized to determine potential application of the byproduct, wet corn gluten feed (WCGF), for a specific diet. The model, validated in Section II was applied to WCGF. Diets were formulated using corn silage as the diet base, and corn, SBM, limestone and dicalcium phosphate as energy, protein and mineral supplements, respectively. Nutrient and price values for these feeds are presented in Table 8 and 7, respectively. All other feeds were excluded from diet formulation by inflating price. Diets were formulated for medium frame, British breed, growing (215 kg) and finishing (318 kg) weight steers. Nutrient requirements for these groups of cattle are presented in Table 5. Protein systems used for formulating specific diets were selected according to recommendations made from Section II. Protein parameters used in formulating their growing and finishing diets are presented in Table 4. Nutrient values for WCGF were taken from nutrient profile information obtained during the preliminary evaluation conducted in Section I.

Average nutrient values for WCGF were adjusted for variation existing in the nutrient composition according to risk management procedures proposed by Black et al. (1978). These adjusted values were inserted into the linear

TABLE 8. Nutrient Values for Feeds Used for Formulating Diets Including WCGF.

Feed	Nutrients (% dry matter)[a]						
	DM	CP	Ca	P	K	RDP[b]	NEg[c]
corn silage	34	8	0.24	0.22	1.0	50	1.06
corn grain	89	10	0.03	0.13	0.35	40	1.48
SBM, 44	89	50.8	0.33	0.70	2.20	72	1.34
Urea	99	288	-	-	-	100	-
Limestone	98	-	34.0	0.02	-	-	-
Dical. Phos.	96	-	22.0	18.65	0.10	-	-

[a]Preston, 1987
[b]NRC, 1985 (expressed as percent of crude protein)
[c]expressed as Mcal/kg

utilizing the linear program model validated in Section II, and economic values were given to WCGF by the value mapping procedure used by Black et al. (1980).

As in Section II, the results of value mapping sequences were applied to calculate specific price values for WCGF as prices of corn and SBM were fluctuated independently. Altered price values of WCGF were determined by inflating and deflating the price of corn (Table 7) by $1/ dry bu. SBM prices were inflated and deflated by $60/ dry ton. Monitoring the response on WCGF to changing prices of corn and SBM allows determination of the role of the byproduct in the diet, and the price relationship between the byproduct and these industry standards.

CHAPTER IV

RESULTS

Section I

Wet corn gluten feed (WCGF) was evaluated utilizing the proposed methodology for byproduct feed evaluation. Results of the preliminary evaluation (Section I) are provided below. In some cases questions in the evaluation were not relevant or applicable, since they addressed a specific location/situation. Questions considered to be unique to given situations were answered NA (not applicable).

I. Description of byproduct

A. Physical description

1.Form- wet (40% dry matter)

(Miracle Bulletin, 1983)

2.Color- golden brown

3.Texture- fine flakes and particles

4.Odor/ Taste- sweet molasses odor

5.Composition- "fermented condensed corn extractives (steep), the corn kernel hulls and fibrous particles"

(Miracle Bulletin, 1980)

B. Background Description

1.Source- Corn wet-milling industry

2.Location/Proximity- NA

3.Primary products- high fructose syrup, corn oil, starch, ethanol

4.Byproducts yielded- corn gluten feed, corn gluten meal, corn bran, steep liquor

(Paterson et al.,1985)

5.Feedstocks- whole shell corn

6.Feedstock source- NA

7.Processing/Recovery methods- see Figure 1

C. Chemical Description -

1. Nutrient values for WCGF are presented in Tables 9 and 10. Values not available from their respective sources are indicated (--).

2.Characteristics-

a)Fiber

(1).Dry matter digestibility- 76.6% ; 75.2%

(Jaster et al., 1984 ; Green and Stock, 1986)

(2).ADF digestibility- 49.9 ; 66.5

(Jaster et al., 1984 ; Green and Stock, 1986)

b)Protein

(1).Rumenally degraded protein- 84.4%

(Firkins et al, 1984)

(2).ADF bound nitrogen- 15.6%

(Firkins et al, 1984)

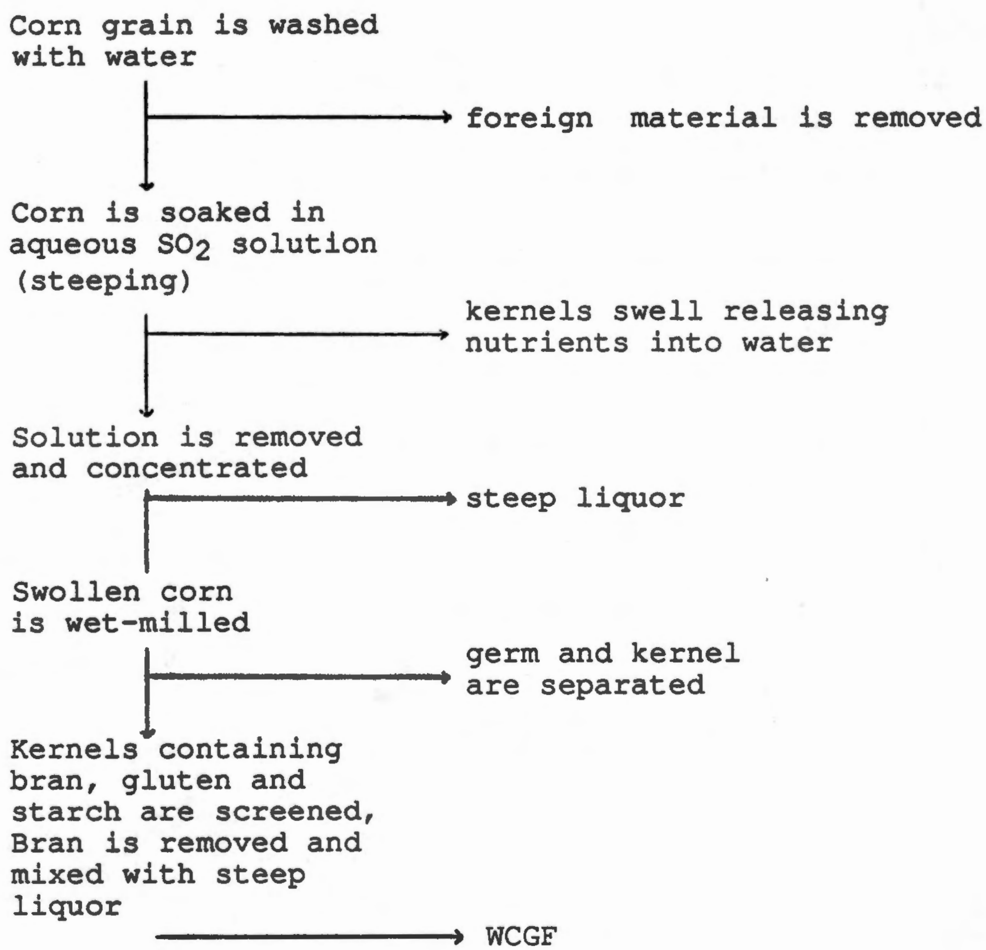

Figure 1. Processing and Recovery Methods Yielding WCGF

TABLE 9. Nutrient Profile of WCGF

DM	CP	NDF	ADF	TDN	CA	P	K	NE_m	NE_g
% dry matter								- Mcal/kg -	
[a]49.6	23	--	10.3	--	--	--	--	--	--
[b]43.8	22.5	--	7.4	--	0.03	1.31	2.24	--	--
[c]43.0	21.0	--	--	87.0	0.10	1.0	1.6	--	--
[d]43.9	19.2	51.2	16.5	--	0.21	0.98	--	--	--
[e]45.4	16.4	56.8	12.5	--	--	--	--	--	--
[f]45	17	51	12	--	--	--	--	--	--
[g]--	--	--	--	--	--	--	--	1.96	1.30
[h]46.8	19.9	53.0	11.7	87	0.11	1.10	1.92	1.96	1.30
[i]6.3	2.7	3.3	3.3	--	0.09	0.19	0.50	---	---

[a] Waller, unpublished
[b] Droppo et al., 1985
[c] Weigel and Hutjens, 1986
[d] Staples et al., 1984
[e] Bowman et al., 1985
[f] Paterson et al., 1985
[g] Miracle Bulletin, 1980
[h] Mean values
[i] Standard deviations

TABLE 10. Nutrient profile of WCGF produced by A.E. Staley Co, Loudon, Tennessee[a]

Sample	DM	CP	ADF
	---- % dry matter ----		
1	50.31	23.11	10.59
2	48.15	23.00	10.31
3	50.95	22.80	10.45
4	50.49	23.69	9.93
5	50.70	23.88	9.99
6	48.43	23.48	11.03
7	48.73	22.78	10.79
8	48.98	23.09	11.06
9	49.25	23.00	11.18
10	49.61	22.80	11.58
11	48.26	23.15	11.30
12	48.17	23.31	10.81
13	47.92	23.35	10.76
14	48.48	22.63	10.22
15	50.04	21.71	9.78
16	49.55	21.68	9.30
17	49.81	22.34	9.79
18	50.39	22.56	9.55
19	50.85	22.32	9.31
20	50.99	22.72	9.68
21	50.48	23.50	9.78
22	50.77	23.16	10.07
23	50.66	23.24	10.12
24	49.89	23.83	10.19
Mean	49.66	22.96	10.32
Stnd dev.	1.034	0.574	0.639

[a] Waller, unpublished data, 1985

II. Availability

A. Quantity (amount and time basis)- NA

B. Seasonality (yes/no; specify if yes)- no

C. Restrictions on shipment size made available- NA

D. Supply outlook (stability)- excellent, anticipated growth of high fructose syrup demand as a natural sweetener

(Hodgkin, 1987)

III. Health and Safety

A. Potential contaminants from section IB.-

Source	Potential contaminant	Determination
feedstock/source	mycotoxin	NA
processing/ recovery	chlorinated napthalenes	NA

B. Observable signs to contaminants listed in II(A)-

Mycotoxins: reduced performance

Chlorinated Napthalenes: Hyperkeratosis

C. Potential residuals- none

D. Potential storage risk- none

E. Physical/Chemical treatments to be avoided- none

IV. Special Requirements

A. Storage: Environmental temperatures above freezing require special treatment

Short term- May be placed on concrete slab (preferably covered) and fed within 1-2 days. Extended preservation obtained via treatment with an application of propionic acid, formic acid or diacetate-sorbate and fed within 10-28 days depending on level of treatment.

(Droppo et al.,1985; Larson et al.,1983)

Long term- Exhibits excellent ensiling qualities. May be stored in upright or bunker silo. Surface must be well packed or sealed. May mix with other ingredients (i.e. corn silage).

(Miracle, 1980)

B. Handling- can use traditional automated feeding systems, or front-end loader mixer wagon combination

C. Feeding- No special feeding requirements were determined.

Section II

Diets were formulated using the proposed least-cost linear program model for separate runs under both CP and RDP systems. The byproduct, DDGS, was used to determine the sensitivity of the model to price changes of that byproduct. Results of the impact of price of DDGS on proportion of each dietary ingredients formulated under the RDP system for growing (215 kg) and finishing (318 kg) steers are presented in Tables 11 and 13, respectively. Results for dietary comparisons of DDGS for growing (215 kg) and finishing (318 kg) steers under the CP system are presented in Tables 12 and 14, respectively. Value mapping results determining the economic value of DDGS at varying dietary levels for growing and finishing steers under the RDP and CP systems, are presented in Tables 15 and 16, respectively. The relationship of the price of DDGS to changing prices of corn and SBM are presented in Table 17.

TABLE 11. Impact of the Price of DDGS on the Proportion of Each Ingredient in the Diet Dry Matter When the Diet is Formulated Using the RDP System (215 kg Growing Steer)

		Price of DDGS/Price of SBM			
	DDGS exc.	1.009	.605	.548	.494
	------Proportion of Dietary Dry Matter------				
Corn silage	.665	.634	.623	.623	.602
Corn grain	.197	.249	.209	.134	.041
SBM	.126	---	---	---	---
DDGS	---	.093	.135	.226	.344
Urea	---	.012	.010	.008	.005
Limestone	.005	.005	.006	.007	.006
Dical	.005	.005	.003	---	---

TABLE 12. Impact of the Price of DDGS on the Proportion of Each Ingredient in the Diet Dry Matter When the Diet is Formulated Using the CP System (215 kg Growing Steer)

	Price of DDGS/Price of SBM				
	DDGS exc.	.738	.605	.550	.462
	------Proportion of Dietary Dry Matter-------				
Corn silage	.640	.633	.637	.635	.620
Corn grain	.301	.270	.126	.072	.031
SBM	.031	---	---	---	---
DDGS	---	.070	.224	.284	.341
Urea	.014	.014	.004	---	---
Limestone	.004	.004	.007	.006	.006
Dical	.007	.006	---	---	---

TABLE 13. Impact of the Price of DDGS on the Proportion of Each Ingredient in the Diet Dry Matter When the Diet is Formulated Using the RDP System (318 kg Finishing Steer)

	Price of DDGS/Price of SBM		
	DDGS exc.	.605	.550
	------Proportion of Dietary Dry Matter-------		
Corn silage	.676	.678	.677
Corn grain	.304	.208	.157
SBM	---	---	---
DDGS	---	.102	.159
Urea	.011	.005	.001
Limestone	.002	.004	.004
Dical	.004	---	---

TABLE 14. Impact of the Price of DDGS on the Proportion of Each Ingredient in the Diet Dry Matter When the Diet is Formulated Using the CP System (318 kg Finishing Steer)

	Price of DDGS/Price of SBM		
	DDGS exc.	.605	.550
	------Proportion of Dietary Dry Matter-------		
Corn silage	.676	.678	.677
Corn grain	.304	.208	.157
SBM	---	---	---
DDGS	---	.102	.159
Urea	.011	.005	.001
Limestone	.002	.004	.004
Dical	.004	---	---

TABLE 15. Economic Value of DDGS Given Prices of Alternative Feedstuffs (All values are on a dry basis)[a]

Steer weight (kg)	Percent DDGS in the diet	Value of DDGS (cents/kg)[b]
215	9.3	$P_{DDGS} = -.382P_c + 1.355P_{sbm} - .129P_u$
	13.5	$= -.029P_c + .933P_{sbm} - .074P_u - .007P_l + .015P_{dc}$
	22.6	$= .337P_c + .558P_{sbm} - .035P_u - .009P_l + .022P_{dc}$
	34.4	$= .551P_c + .366P_{sbm} - .015P_u - .003P_l + .015P_{dc}$
318	10.2	$P_{DDGS} = .930P_c + .059P_u - .020P_l + .039P_{dc}$
	15.6	$= .921P_c + .063P_u - .013P_l + .025P_{dc}$

[a] Diets formulated using the RDP system

[b] Key (all values in cents/kg, dry matter basis).

- P_c price of corn
- P_{sbm} price of soybean meal, 44
- P_u price of urea
- P_l price of limestone
- P_{dc} price of dicalcium phosphate

TABLE 16. Economic Value of DDGS Given Prices of Alternative Feedstuffs (All values are on a dry basis)[a]

Steer weight (kg)	Percent DDGS in the diet	Value of DDGS (cents/kg)[b]
215	7.0	$P_{DDGS} = .493P_c + .443P_{sbm} + .014_{dc}$
	22.4	$= .807P_c + .138P_{sbm} + .045P_u - .013P_l + .031P_{dc}$
	28.6	$= .816P_c + .109P_{sbm} + .049P_u - .007P_l + .025P_{dc}$
	34.1	$= .823P_c + .091P_{sbm} + .041P_u - .006P_l + .021P_{dc}$
318	10.2	$P_{DDGS} = .930P_c + .059P_u - .020P_l + .039P_{dc}$
	15.9	$= .921P_c + .063P_u - .013P_l + .025P_{dc}$

[a] Diets formulated using the CP system

[b] Key (all values in cents/kg, dry matter basis).

P_c price of corn

P_{sbm} price of soybean meal, 44

P_u price of urea

P_l price of limestone

P_{dc} price of dicalcium phosphate

TABLE 17. The Sensitivity of the Price DDGS to Changes in the Price of Corn and SBM. (All values are on a dry basis)

Steer weight (kg)	Percent DDGS in the diet	Protein System Used	Base Diet[b]	P_{corn} 6.09	P_{corn} 13.28	P_{sbm} 15.84	P_{sbm} 24.64
			--- Prices of Supplements (cents/kg)[a] -----				
			--------- Value of DDGS (cents/kg) --------				
215	9.3	RDP	20.24	21.91	19.16	14.28	26.20
	13.5		17.19	17.32	17.11	13.09	21.30
	22.6		15.02	10.86	14.82	11.65	14.87
	34.4		13.26	10.86	14.82	11.65	14.87
318	10.2	RDP	12.32	8.26	14.95	12.32	12.32
	15.9		11.91	7.90	14.52	11.91	11.91
215	7.0	CP	14.57	12.42	15.96	12.62	16.52
	22.4		13.26	9.74	15.55	12.66	13.87
	28.4		12.71	9.51	15.02	12.23	13.19
	34.1		12.10	8.51	14.43	11.70	12.50
318	10.2	CP	12.32	8.26	14.95	12.32	12.32
	15.9		11.91	7.90	14.52	11.91	11.91

[a] Prices for all other ingredients held constant

[b] Price of corn- 10.45 cents/ dry kg; price of SBM- 20.24 cents/dry kg.

Section III

Risk in cattle feeding associated with variation in the nutrient content of wet corn gluten feed (WCGF) was accommodated by adjusting nutrient values of WCGF prior to their insertion into the diet formulation model. Adjustment factors used for this process were selected according to the recommendations made by Black and Fox (1976). No adjustment of the nutrient values was required for WCGF in diets of the growing(215 kg) steer. Risk involved in feeding a younger animal variable products is relatively low as more time is available to recover lost performance from inadequate nutrient intake. Time constraints placed on feeding heavier steers results in a higher level of risk; therefore, an adjustment factor of 1.1 was applied to the average nutrient values of WCGF to be included in finishing steer diets, altering the values downward to assure that at 87% of the time minimal requirements of the animal would be met. Average nutrient values for WCGF and their respective standard deviations used in diet formulation and adjustment equations are presented in Table 9. Adjusted nutrient alues for WCGF are presented in Table 18. Nutrient values for feeds included in diet formulation are presented in Table 8. Results indicating the impact of the value of WCGF on the dietary combinations for growing and finishing steers are

TABLE 18. Adjusted Nutrient Values for WCGF[a]

	Growing Diet	Finishing Diet
CP	19.85	16.79
Ca	0.11	0.01
P	1.10	0.90
K	1.92	1.37
RDP	16.75	14.18

[a] $Aij^* = E(Aij) - f\ (Vij)^{-1}$ (Chalupa, 1980)

presented in Tables 19 and 20, respectively. Value mapping results from diet formulation runs for both steer groups are presented in Table 21. These value mapping results describe the economic value of WCGF in their respective diets at specific dietary levels. The relationship of the value of WCGF to changing prices of corn and SBM are presented in Table 22.

TABLE 19. Impact of the Price of WCGF on the Proportion of Each Ingredient in the Diet Dry Matter When the Diet is Formulated Using the RDP System (215 kg Growing Steer)

	Price of WCGF/Price of SBM	
	WCGF exc.	.486
	------Proportion of Dietary Dry Matter-------	
Corn silage	.665	.664
Corn grain	.197	.196
SBM	.126	.127
WCGF	---	.002
Urea	---	---
Limestone	.005	.005
Dical	.004	.004

TABLE 20. Impact of the Price of WCGF on the Proportion of Each Ingredient in the Diet Dry Matter When the Diet is Formulated Using the CP System (318kg Finishing Steer)

	Price of WCGF/Price of SBM		
	WCGF exc.	.528	.469
	------Proportion of Dietary Dry Matter-------		
Corn silage	.676	.648	.630
Corn grain	.304	.239	.205
SBM	---	---	---
WCGF	---	.096	.150
Urea	.011	.009	.007
Limestone	.002	.005	.005
Dical	.004	---	---

TABLE 21. Economic Value of WCGF Given Prices of Alternative Feedstuffs (All values are on a dry basis)[a]

Steer weight (kg)	Percent WCGF in the diet	Value of WCGF (cents/kg)[a]
215	0.2	$P_{WCGF} = .765P_c - 0.5P_{sbm}$
318	9.6	$P_{WCGF} = .832P_c + .021P_u - .031P_{ls} + .042P_d$
	15.9	$= .823P_c + .027P_u - .020P_{ls} + .027P_{dc}$

[a] Diets formulated using the RDP system for growing (215 kg) steer diets and the CP finishing (318 kg) steer diets

[b] Key (all values in cents/kg, dry matter basis).

P_c price of corn

P_{sbm} price of soybean meal,44

P_u price of urea

P_l price of limestone

P_{dc} price of dicalcium phosphate

TABLE 22. The Sensitivity of the Price WCGF to Changes in the Price of Corn and SBM. (All values are on a dry basis)

			--- Prices of Supplements (cents/kg)[a] -----				
Steer weight (kg)	Percent DDGS in the diet	Protein System Used	Base Diet[b]	Pcorn 6.09	Pcorn 13.28	Psbm 15.84	Psbm 24.64
			--------- Value of WCGF (cents/kg) --------				
215	0.20	RDP	-2.13	-.546	0.04	0.07	-4.33
318	9.6	CP	10.39	6.76	12.74	10.39	10.39
	15.9		10.02	6.44	12.35	10.02	10.02

[a] Prices for all other ingredients held constant
[b] Price of corn- 10.45 cents/ dry kg; price of SBM- 20.24 cents/dry kg.

CHAPTER V

DISCUSSION

Section I

The application of the methodology for the preliminary evaluation to the byproduct, wet corn gluten feed (WCGF), revealed WCGF to be a high moisture byproduct of the corn wet milling industry which appears to possess no physical or chemical characteristics which would inhibit its use in beef cattle diets. The physical description of the byproduct does not indicate characteristics which would result in poor animal or producer acceptance. The high moisture content of WCGF implies that special preservation, storage and possibly handling is required. The evaluation addressed necessary issues for dry materials but did not require sufficient information to accurately assess the handling and storage qualities of wet materials. A more complete description of the physical properties in terms of 1) state of moisture (extent to which water is bound to the substrate material) or dampness; 2) bulk densities; 3) and clumpinesss or caking, would provide a more accurate assessment of the handling nature and storage restrictions which may exist. Also the generalized description of composition should be more exact by expressing percentage of components, presence of foreign matter, and infestation of insects, molds, etc..(Cooley, 1970).

The background description of WCGF provided a brief explanation of the industry, including: products yielded, feedstocks used and the process of converting those feedstocks into end-products. The purpose behind this step was to provide sufficient information to detect potential health and safety hazards, and to evaluate factors which will impact current and future availability of the byproduct. The evaluation fell short of this goal primarily in specification of the quality of feedstocks used. Recognition of the use of primary products would have revealed that WCGF is a byproduct produced by two types of wet milling industries based on two different qualities of input. The listing of primary products of the corn wet milling industry should be divided into two categories: 1) products produced for human consumption (high fructose syrup, starch, corn oil), and 2) products produced for purposes other than human consumption (ethanol). The intended use of the end-products has a significant impact on the quality of the feedstock to be used for processing. Specifications and regulations controlling feedstocks are considerably different for these two purposes (NRC, 1981). Grain processed for human consumption is tightly monitored by the FDA for mycotoxin levels and other possible contaminants (i.e. pesticides, herbicides); where as, ethanol production grade corn is not. For a byproduct such as WCGF, which accumulates 80 to 90 percent of mycotoxins present in the preprocessed feedstock, determination of feedstock quality is extremely important (Lillehoj, 1978). Another element which should have been considered is post-recovery handling of the material. For high moisture byproducts, failure to address this issue could result in serious loss due to contamination and spoilage from improperly handled and stored industrial wastes. The length of time a wet material is left exposed from the point of recovery to arrival at the feeder will greatly effect the potential for mycotoxin development in the material, regardless of feedstock quality (Diener, 1976). Thus, more specific explanation of feedstock quality grade required for primary product production and post-recovery handling of the byproduct is necessary for assessment of risks which may be present.

The chemical description indicated that WCGF is a high energy, moderate protein source which exhibits high levels of digestible fiber and rumen degradable protein. The description of WCGF by this section provided sufficient nutritional information for evaluating the nutritional aspects of the material. For clarity; however, a section allowing specification of nutrient deficiencies, as determined by inspection of the nutrient profile, should be provided. Average nutrient values for WCGF, from data collected by Waller (unpublished, 1985) prior to these experiments, were included in this section to demonstrate the effect that source of a byproduct has on the nutrient content of that byproduct (see Table 10). Variation of nutrients (CP and ADF), expressed in terms of standard deviations, is much greater between sources (Table 9) than within a single source (Table 10). These results emphasize the importance of analyzing byproduct materials from their specific sources to assure appropriate application.

The availability section of the evaluation provided answers to important questions regarding definition and outlook of supply for the byproduct considered. Several demand factors which directly influence supply; however, were overlooked. Determining the reason for the sudden availability of the material as a livestock feed could expose negative factors or risks associated with feeding the material (Waller, 1985). Determination of existing and potential demands for a material as feeds for other species of livestock, or even food for human consumption, are essential for accurate estimation of future supply. Prices and supply of alternate or competitive feeds and fluctuating markets for ingredients of the byproduct(steep liquor, corn bran) could potentially effect demand of a byproduct, and should thus be included in a description of byproduct availability.

The evaluation of the health and safety issues surrounding WCGF, exposed two potential contaminants from two possible sources. Inclusion of a more specific description of feedstock quality and post-recovery handling of the material may have increased the likelihood of detecting these contaminants. Problems associated with sulfite toxicity in livestock consuming WCGF have been suspected (Waller, personal reference, 1988). Contamination is thought to occur during the steeping process; however, no specific reports stating incidence of sulfite toxicity associated with feeding WCGF could be located. Failure to discern this potential contaminant shows the inadequacy of this section. Therefore, a recommendation should be added that a veterinarian should be consulted regarding the potential presence of toxic contaminants arising from chemicals used in processing of the byproduct. Symptoms and treatments of toxicities should be addressed. Recommended action in response to all toxicities described in Part IIB should be added as a precautionary measure. Management of materials determined to be contaminated should also be addressed. Options for detoxification, reduction in feeding levels, or complete rejection of the contaminated material should be included. For example, anhydrous ammonia has been shown to detoxify mycotoxin contaminated materials (Lillehoj, 1978). Environmental conditions will greatly influence the presence or absence of contaminants such as mycotoxins, and should, thus, be specified in this section (Diener, 1976).

The special requirements section of this report addressed areas in short and long term storage, handling, and feeding of the material. This section was considered to adequately address necessary issues required in each category. WCGF was determined to require special action in preservation and storage. Ensiling appears to be the most practical method for dealing with the wet nature of the byproduct (Larson, 1980). Addition of recommendations made in previous sections of this discussion, dealing with the physical characteristics of the material and specific environmental conditions which exist, would potentially allow a more correct assessment of the special requirements of WCGF. A revised outline for the methodology for preliminary evaluation of a byproduct as a potential feed for ruminants is as follows:

I. Description of byproduct

A. Physical description

1.Form-

a) state of moisture/ dampness-

b) clumpiness/ caking-

3.Bulk density (kgs/cubic meter)-

4.Color-

5.Texture-

6.Odor/ Taste-

7.Composition-

a) percentages-

b) infestation-

c) foreign material-

B. Background Description

1.Source-

2.Location-

3.Primary products-

a) types-

b) uses (i.e. human consumtion or other)-

4.Byproducts yielded-

5.Feedstocks-

6.Feedstock source-

7.Processing/Recovery methods-

8.Post recovery handling-

C. Chemical Description

1.Nutrient profile-

2.Characteristics-

a) Fiber- dry matter and ADF digestibilities

b) Protein- RDP and ADFN

3. Nutrient deficiencies-

II. Availability

A. Quantity (amount and time basis)-

B. Reason for sudden availability-

C. Seasonality (yes/no;specify if yes)-

D. Restrictions on shipment size made available-

E. Supply outlook (stability)-

1) Demands a feed for other species-

2) Prices of alternate or competing feeds-

3) Markets for co-products-

III. Health and Safety

A. Potential contaminants from section IB. (consult veterinarian)-

B. Observable symptoms to contaminants listed in part(A)-

C. Treatment for toxicities resulting from contaminant ingestion-

D. Potential residuals-

E. Recommended action for contaminated materials (i.e. feed at a reduced level, detoxify, dispose)-

D. Potential storage risk-

E. Physical/Chemical treatments to be avoided-

IV. Special Requirements

A. Storage

1. Short term-

2. Long term-

B. Handling-

C. Feeding-

Section II

Specific diets formulated for growing and finishing steers (215 and 318 kg, respectively) under both CP and RDP systems of protein description are displayed in Tables 11, 12, 13 and 14. Table 11, describing the impact of the price of DDGS on diet composition under the RDP system, will be used for explanation purposes. Columns, representing diets for the growing steer, are headed by a ratio expressing the price relationship of DDGS to SBM. The first column describes a diet which excludes DDGS by inflating price above entry level. The second column shows DDGS entering the diet at a level of 9.3%. The column heading expresses the price of DDGS to be slightly greater (.009) than the price of SBM. This relationship between DDGS and SBM demonstrates the cost effectiveness of the DDGS and urea combination over SBM for satisfying protein requirements at specified prices of the ingredients. The high level of bypass protein present in DDGS allowed for introduction of a cheaper crude protein source, urea, to satisfy the ruminal nitrogen requirement without reducing the level of bypass protein made available to the lower gastro-intestinal tract of the growing animal. Supplementation of the diet with a protein source which partially avoids rumen degradation is known to increase performance of growing steers (Van Soest, 1983). Values in the second column also indicated an energy deficit occurring when DDGS replaced SBM. This deficit was corrected by increasing corn. The cost of energy in corn is substantially less than that in SBM, thus corn was used to meet the energy deficit. The third column shows the price ratio of DDGS and SBM declining sharply, with only a relatively small increase in dietary percentage of DDGS (4.2%). This indicates a change in the way the model perceives the nutritive contributions made by increasing levels of DDGS. The economic value of

DDGS diminishes as it moves from being recognized in the model as a high quality protein source to a protein-energy source, leaning more heavily toward the energy side as diet percentage increases. The low cost of energy supplied by corn and corn silage are the basis for reduced economic value of energy in DDGS at these higher levels.

Results of the CP model, used to formulate growing diets presented in Table 12, do not indicate the unique characteristic of the protein fraction of DDGS, as seen in the RDP model. Bypass protein qualities of SBM over urea were not even recognized by the model. Under the CP system, DDGS enters the diet at a much lower price relationship to SBM than DDGS under the RDP system. The base diet (DDGS exc.) entered the maximum allowable level of urea specified [supplemental urea $\leq$ 30% (Taylor, 1984)] as a cheap source of crude protein, thus, lowering the economic value of protein contained in DDGS. SBM was included at a level of 3.1% dietary dry matter to meet protein requirements above those met by urea. The existing level of urea was maintained as DDGS entered the diet demonstrating the economical advantage of urea as a source of crude protein. The third column shows a large increase in the amount of DDGS included in the diet. This increase in DDGS replaces the majority of urea and over half the corn present in the diet. The price ratio of DDGS to SBM heading this column shows a considerable decline in the economic value of DDGS. Value mapping results, presented in Table 15, reveal that DDGS is being valued as a energy-crude protein source. More emphasis is placed on the energy contribution of DDGS under the CP system than the RDP system. Examination of the energy source replaced by DDGS exemplifies the different characters of the models. Under the CP system, DDGS replaces corn grain at higher levels; whereas, DDGS energy replaces corn silage energy under the RDP system. The higher level of bypass protein contained in corn silage, versus that in corn grain (40 vs 10%), results in an exchange of DDGS for corn silage rather than corn grain as an energy source in order to adhere to lower level RDP constraints.

For finishing (318 kg) diets, no preference of DDGS was recognized under either system. This is not surprising since RDP maximum levels were set at the RDP content of a corn silage based diet containing maximum levels of urea. The economical cost of crude protein contained in urea lessens competition with DDGS as a protein source. This price relationship basically forces the model to uses DDGS as an energy feed, or as a combination protein-energy feed, placing emphasis on the energy value of DDGS.

The value mapping results displayed in Tables 15 and 16 express the economical value of DDGS included in growing and finishing diets at different dietary concentrations under the CP and RDP protein systems, respectively. These tables display in economic terms the nutritional issues which have already been discussed. Each equation represents the economic value of DDGS (cents/dry kg) when fed at specified levels in the diet. Values for DDGS for each level of feeding under each system are provided in Table 17. These values emphasize the advantage given to DDGS under the RDP system for growing steer diets. Inflated and deflated prices for corn and SBM were inserted into each equation independently to track the influence that the price of these two commodities has on the value of DDGS. These values show that DDGS, incorporated in growing diets under the RDP system, increases and decreases in price, moving with the price of SBM. This relationship changes as dietary percentages of DDGS increase (see Table 17). Where protein constituents are not emphasized economically, under the CP system, the price of corn plays a more significant role in influencing pricing of DDGS. Under the RDP system, the value of DDGS moves opposite that of corn grain when dietary percentages are lower (9.3 and 13.5%), then shifts positively to corn prices at higher feeding levels (22.6 and 34.6%). Such a relationship does not exist for growing diets formulated under the CP system and finishing diets under either system.

DDGS under RDP system was given an economic advantage over DDGS under the CP system as a feed ingredient for growing steer diets. The distinction is more profound at lower levels of dietary inclusion, but lessens as dietary percentages increase. This portrays the functioning of the

RDP model which economically acknowledges DDGS for bypass protein qualities to saturation of requirements, at which point DDGS begins to be discounted for its inability to maintain required RDP levels. Finishing diets formulated by the RDP model offer no advantage for bypass protein contained in DDGS, and thus, the value of DDGS under both systems is equal. Bypass protein sources, which are not required by heavier weight steers, should be considered of comparable value to rumen degradable protein sources. Because the responses of the models were identical, the CP system is recommended as crude protein values for formulation are more easily obtainable. A model developed by Black et al.(1980) using a more dynamic approach under the Michigan net protein system was found to express similar relationships and interactions of DDGS in diets of growing (215 kg) and finishing (275 kg) steers.

Although the mineral value of DDGS has not been addressed, it does play a role in determining the economic value of the byproduct. The models consider mineral contribution the same manner. As presented in the literature review, descriptions of mineral content of a feedstuff, and balancing for mineral requirements of livestock is fairly straight forward.

The advantages of utilizing value mapping for evaluation and explanation of the various nutrient components of a feed are obvious. Common pricing approaches, such as those taken by Weigel and Hutjens (1986) and Charolais Commercial Newsletter (1985), are not sufficient in thoroughness and effectiveness in describing nutrients contained in feedstuffs, nor do they offer any explanation for inter-dietary relationships between feedstuffs within a diet.

Section III

Section III utilized information obtained in Section I and procedures verified in Section II to determine the nutritional and economic value of WCGF. This process began with an adjustment of the nutrient value of WCGF as a method of managing risk of nutrient variation within a byproduct. Selection of adjustment factors for altering nutrient values to be used in diet formulation were based on recommendations made by Black and Fox (1976). Recommendations made by Black and Fox (1976) were based on feeding trials which evaluated the performance of cattle fed diets formulated with feedstuff nutrient values corrected by various adjustment factors. Economically optimal adjustment factors for different weight classes of steers were determined to minimize cost of gain for these animals. No adjustment of nutrient values of WCGF were made for formulation of growing (215 kg) steer diets. An adjustment factor of 1.1 was used to correct nutrient values of WCGF for finishing (318 kg) steer diets. The adjustment of the nutrient values for the diet of the heavier animal was due to the higher risk involved in feeding a highly variable product to this steer, over the risk involved in feeding the same byproduct to the lighter weight steer. The increase in risk involved with the heavier steer is a function of time. The heavier a steer becomes, the closer that steer gets to market. As the steer approaches market weight, the amount of time available for the animal to recover reduced performance from inadequate feeding practices lessens. Adjustment of nutrient values assures adequate levels of dietary nutrients required by the animal during the critical latter stages of production. Accounting for variation which exists is important, not only for management of risk, but for determination of the economic discount that should be applied to highly variable feeds. This is especially true for byproduct feeds which characteristically possess high levels of variation, compared to conventional feedstuffs (Waller, 1985). Table 18 shows the differences in nutrient values given to WCGF in relation to the level of risk allowed. The reduced levels of risk applied to finishing diets are represented in the reduced nutrient values used in diet formulation. The end result is a decline in the nutritive and economic value given to WCGF as a feed included in finishing diets.

The determined nutrient values of WCGF for their respective diets, were included in the least-cost linear program models developed in Section II. The resultant diets are presented in Tables 19 and 20. The RDP and CP system were used to evaluate the contribution of WCGF in growing and finishing diets, respectively. Results show WCGF to be of little to no value in growing diets, incorporating a maximum 0.2% of the dietary dry matter at a WCGF to SBM price ratio of 0.486. The RDP model did not value the protein contained in WCGF because of the high level of rumen degradability causing WCGF to compete with urea, an economical source of crude protein, rather than SBM, the more expensive protein source. When WCGF was included in the diet, it was used by the model as an energy source, replacing small amounts of corn and corn silage. Value mapping results, presented in Table 21, reveal WCGF to be of negative economic value at specified price levels for dietary ingredients. The response of WCGF to inflating and deflating prices of corn grain and SBM indicates that the model considers WCGF as an energy source (Table 22). The positive and negative correlation existing between WCGF, and corn and SBM, respectively, shows WCGF to act as an energy source, not as a protein source. WCGF was also recognized as a more valuable source of energy in finishing diets under the CP system. This again is verified by value mapping results which indicate a highly sensitive, positive correlation between the price of WCGF and corn grain.

The dietary and economic value of WCGF is considerably different for finishing diets. WCGF was recognized under the CP system as a more valuable energy-protein source. This relationship continued as dietary levels increased. The energy contribution of WCGF was emphasized, but contributions of crude protein were also made, replacing a portion of urea. Price values calculated from value mapping results also display the models focus on the energy contribution of WCGF. These results indicate a highly sensitive, positive correlation between the price of WCGF and corn grain. No response was shown to raising or lowering the price of SBM.

These results of the application of nutrient information for WCGF provided in Section I and the least-cost linear program modeling procedures verified in Section II determined the value of WCGF to be diet specific, based on the unique nutrient needs of the beef cattle types addressed. WCGF was determined to be of no value as a feed ingredient for growing steer diets, under price relationships of feed ingredients specified in the model. A considerable decline in the price of the energy sources utilized (corn and corn silage) may result in an increase in the economic value of WCGF. The likelihood of such a decline in prices of corn and corn silage significant enough to impact the value of WCGF in growing diets is slim. The unique protein requirements of the growing steer are not met by the protein contained in WCGF. In finishing diets, WCGF exhibits energy and crude protein qualities which allow the byproduct to compete with corn and urea combinations at lower levels in the diet.

CHAPTER VI

SUMMARY

A multitude of agro-industrial byproducts are available to producers as feeds for livestock. The types of materials available are as different as the industries yielding them. The application of these materials to specific livestock systems is often uncertain and risk laden. A methodology for thorough evaluation and accurate application of a byproduct to livestock diets has not been reported.

The development of methodology for the evaluation of a byproduct as a potential feedstuff for ruminant diets was conducted in three stages. 1) A methodology for the preliminary evaluation of a byproduct material as a potential livestock feed was developed from research reports dealing with byproduct utilization. The methodology was demonstrated using wet corn gluten feed (WCGF) as a model byproduct. 2) A least-cost linear program model was constructed to estimate the value of a feedstuff on the basis of nutritional properties exhibited and cost of alternate feeds. Price mapping was used to assess and describe the economic value of the byproduct according to nutrients contained. Dried distillers grains with solubles was used as a model byproduct in the verification of the linear programming model. 3) Information obtained in the preliminary evaluation was applied to procedures developed in the second phase of the study to determine the nutritive and economic value of WCGF. Nutrient values of WCGF were adjusted to accommodate acceptable levels of nutrient variation prior to application in the least-cost model. Recommended dietary levels of WCGF inclusion were specified on the basis of economic values determined.

The methodology for preliminary evaluation of a byproduct as a potential feed for growing and finishing steers provided an adequate overall description of the byproduct being considered, WCGF. The evaluation was, however, determined to be lacking in provision of sufficient details required for proper management of wet materials. Additional factors addressed in the discussion section of this report provides a more thorough methodology for describing a byproduct. Results from the preliminary evaluation show that WCGF appears to be free of any physical or chemical characteristics which would hinder or inhibit the use of WCGF as a feedstuff for growing and finishing beef cattle. The presence or development of mycotoxins do, however, pose potential risks which must be managed.

Two least-cost linear program models, the crude protein (CP) and rumen degradable protein (RDP) models, were evaluated as to their effectiveness in describing the economic value of nutrient constituents within a feedstuff. The RDP model was determined superior over the CP model in describing the economic value of feedstuff considered for inclusion in growing steer diets. The RDP model provided economic advantage to feeds containing unique protein qualities which are required by growing (215 kg) steers for maximum growth and development. The RDP and CP models were found to formulate identical diets for finishing (318 kg) steers. The CP system is recommended for evaluating diets of heavy weight class of steers due to the greater availability of CP values over RDP values.

Application of nutrient information, obtained in the preliminary evaluation, to the least-cost linear program models, verified in the second part of this research, determined WCGF to be of negative economic value in growing steer diets. WCGF demonstrated some value as an energy source for finishing steer diets, when included up to 15 percent of diet dry matter. The high variability of the nutrient content of WCGF considerably discounted the nutrient value credited to WCGF, and may have caused a reduction in the dietary levels of WCGF included in finishing diets.

This study provides a combination of methodology and technical procedures by which a byproduct can be thoroughly evaluated for factors effecting the manageability, nutrient quality, economic value and safe application of the material considered for inclusion in beef cattle diets.

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APPENDIX

KEY

ABBREVIATION	FEEDSTUFF
CS	CORN SILAGE
CG	CORN GRAIN
CGF	CORN GLUTEN FEED
SBM	SOYBEAN MEAL
U	UREA
DDGS	DRIED DISTILLERS GRAINS WITH SOLUBLES
CSM	COTTONSEED MEAL
WCS	WHOLE COTTONSEED
AHF	ALFALFA HAY - FULL BLOOM
AHM	ALFALFA HAY- MID BLOOM
AHE	ALFALFA HAY- EARLY BLOOM
FH	FESCUE HAY
OGH	ORCHARDGRASS HAY
CSH	COTTONSEED HULLS
M	MOLASSES
O	OATS
BDG	BREWERS DRIED GRAINS
L	LIMESTONE
DC	DICALCIUM PHOSPHATE
KCL	POTASSIUM CHLORIDE
TMS	TRACE MINERAL SALT
SMF	SOY MILL FEED

KEY

GROWING STEER (215 KG) - RDP SYSTEM

EQUATION	EQUATION DEFINED
1	OBJECTIVE FUNCTION
2	BULK
3	NET ENERGY FOR GAIN
4	TRACE MINERAL SALT
5	NEUTRAL DETERGENT FIBER
6	CRUDE FIBER
7	BYPASS PROTEIN
8	TOTAL DIGESTIBLE NUTRIENTS
9	NET ENERGY FOR MAINTENANCE
10	NET ENERGY FOR LACTATION
11	DRY MATTER
12	POTASSIUM
13	PHOSPHORUS (LOWER LIMIT)
14	CRUDE PROTEIN
15	PHOSPHORUS (UPPER LIMIT)
16	ACID DETERGENT FIBER
17	UREA
18	CALCIUM (UPPER LIMIT)
19	RUMEN DEGRADABLE PROTEIN (UPPER LIMIT)
20	CALCIUM (LOWER LIMIT)
21	RUMEN DEGRADABLE PROTEIN (LOWER LIMIT)

RDP MODEL - GROWING STEER

```
MIN      62 CS + 95 CG + 500 CGF + 184 SBM + 225 U + 500 DDGS + 500 CSM
     + 500 WCS + 500 AHF + 500 AHM + 500 AHE + 500 FH + 500 OGH + 500 CSH
     + 500 M + 500 O + 500 BDG + 51 L + 292 DC + 280 KCL + 153 TMS
     + 500 SMF
SUBJECT TO
       2)    CS + CG + CGF + SBM + U + DDGS + CSM + WCS + AHF + AHM + AHE
     + FH + OGH + CSH + M + O + BDG + L + DC + KCL + TMS + SMF =     1
       3)    1.06 CS + 1.48 CG + 1.3 CGF + 1.34 SBM + 1.36 DDGS + 1.14 CSM
     + 0.07 WCS + 0.4 AHF + 0.57 AHM + 0.68 AHE + 0.51 FH + 0.62 OGH
     + 0.51 CSH + 1.1 M + 1.08 O + 1.34 BDG + 1.12 SMF =     1.166
       4)    100 TMS =    0.25
       5)    51 CS + 10 CG + 53 CGF + 14 SBM + 42 DDGS + 22 CSM + 56 AHF
     + 50 AHM + 47 AHE + 75 FH + 67 OGH + 89 CSH + 31 O + 52 BDG + 65 SMF
     >=   0
       6)    24 CS + 3 CG + 11.7 CGF + 6 SBM + 18 DDGS + 13 CSM + 34 WCS
     + 34 AHF + 30 AHM + 29 AHE + 30 FH + 34 OGH + 48 CSH + 12 O + 15 BDG
     + 36 SMF >=   0
       7)    3.2 CS + CG + 5.2 CGF + 13 SBM + 16 DDGS + 17 CSM + 4.5 AHF
     + 3.7 AHM + 3.2 AHE + 4.2 FH + 3.3 OGH + 1.6 CSH + 5.2 O + 16.8 BDG
     >=   0
       8)    75 CS + 89 CG + 87 CGF + 84 SBM + 85 DDGS + 76 CSM + 45 WCS
     + 53 AHF + 58 AHM + 61 AHE + 56 FH + 59 OGH + 46 CSH + 75 M + 74 O
     + 84 BDG + 51 SMF >=   0
       9)    1.65 CS + 2.16 CG + 1.96 CGF + 2.02 SBM + 2.05 DDGS + 1.78 CSM
     + 0.99 WCS + 1.17 AHF + 1.28 AHM + 1.36 AHE + 1.23 FH + 1.3 OGH
     + 1.02 CSH + 1.74 M + 1.72 O + 2.02 BDG + 2.24 SMF >=   0
      10)    1.67 CS + 2.05 CG + 1.91 CGF + 1.91 SBM + 1.94 DDGS + 1.72 CSM
     + 0.97 WCS + 1.17 AHF + 1.28 AHM + 1.34 AHE + 1.23 FH + 1.3 OGH
     + 0.99 CSH + 1.69 M + 1.67 O + 1.91 BDG + 1.1 SMF >=   0
      11)    34 CS + 89 CG + 90 CGF + 89 SBM + 99 U + 92 DDGS + 91 CSM
     + 91 WCS + 89 AHF + 89 AHM + 90 AHE + 89 FH + 88 OGH + 90 CSH + 56 M
     + 89 O + 92 BDG + 98 L + 96 DC + 100 KCL + 98 TMS + 90 SMF >=   0
      12)    CS + 0.35 CG + 1.92 CGF + 2.2 SBM + 0.7 DDGS + 1.4 CSM + 1.2 WCS
     + 1.7 AHF + 1.9 AHM + 2.4 AHE + 1.7 FH + 2.7 OGH + 0.9 CSH + 3.4 M
     + 0.5 O + 0.1 BDG + 0.1 DC + 50.54 KCL + 1.7 SMF >=   0.6
      13)    0.22 CS + 0.13 CG + 1.1 CGF + 0.7 SBM + 0.82 DDGS + 1.15 CSM
     + 0.25 WCS + 0.22 AHF + 0.23 AHM + 0.24 AHE + 0.24 FH + 0.33 OGH
     + 0.09 CSH + 0.1 M + 0.38 O + 0.6 BDG + 0.02 L + 18.56 DC + 0.18 SMF
     >=   0.34
      14)    8 CS + 10 CG + 19.85 CGF + 50.8 SBM + 288 U + 28 DDGS + 46 CSM
     + 10 WCS + 16 AHF + 17 AHM + 18 AHE + 12 FH + 11 OGH + 4 CSH + 5 M
     + 13 O + 28 BDG + 15 SMF >=   13.75
      15)    0.22 CS + 0.13 CG + 1.1 CGF + 0.7 SBM + 0.82 DDGS + 1.15 CSM
     + 0.25 WCS + 0.22 AHF + 0.23 AHM + 0.24 AHE + 0.24 FH + 0.33 OGH
     + 0.09 CSH + 0.1 M + 0.38 O + 0.6 BDG + 0.02 L + 18.65 DC + 0.18 SMF
     <=   0.42
      16)    28 CS + 3 CG + 10 SBM + 18 DDGS + 13 CSM + 51 WCS + 41 AHF
     + 38 AHM + 41 FH + 40 OGH + 71 CSH + 17 O + 24 BDG + 47 SMF >=   0
      17)    U <=   0.014
      18)    0.24 CS + 0.03 CG + 0.113 CGF + 0.33 SBM + 0.3 DDGS + 0.19 CSM
     + 1.7 WCS + 1.3 AHF + 1.4 AHM + 1.41 AHE + 0.4 FH + 0.34 OGH
     + 0.15 CSH + 1.1 M + 0.07 O + 0.33 BDG + 34 L + 22 DC + 0.05 KCL
     + 0.49 SMF <=   0.5
      19)    4 CS + 4 CG + 16.8 CGF + 36.6 SBM + 288 U + 10.64 DDGS + 30 CSM
     + 11.52 AHF + 13.26 AHM + 14.76 AHE + 7.8 FH + 7.7 OGH + 11.2 BDG
     + 15 SMF <=   8.113
      20)    0.24 CS + 0.03 CG + 0.113 CGF + 0.33 SBM + 0.3 DDGS + 0.19 CSM
     + 1.7 WCS + 1.3 AHF + 1.4 AHM + 1.41 AHE + 0.4 FH + 0.34 OGH
     + 0.15 CSH + 1.1 M + 0.07 O + 0.33 BDG + 34 L + 22 DC + 0.05 KCL
     + 0.49 SMF >=   0.46
      21)    4 CS + 4 CG + 16.8 CGF + 36.6 SBM + 288 U + 10.64 DDGS + 30 CSM
     + 11.52 AHF + 13.26 AHM + 14.76 AHE + 7.8 FH + 7.7 OGH + 11.2 BDG
     + 15 SMF >=   7.61
```

KEY

GROWING STEER (215 KG) - CP SYSTEM

EQUATION	EQUATION DEFINED
1	OBJECTIVE FUNCTION
2	BULK
3	NET ENERGY FOR GAIN
4	TRACE MINERAL SALT
5	NEUTRAL DETERGENT FIBER
6	CRUDE FIBER
7	BYPASS PROTEIN
8	TOTAL DIGESTIBLE NUTRIENTS
9	NET ENERGY FOR MAINTENANCE
10	NET ENERGY FOR LACTATION
11	DRY MATTER
12	POTASSIUM
13	PHOSPHORUS (LOWER LIMIT)
14	CRUDE PROTEIN
15	PHOSPHORUS (UPPER LIMIT)
16	ACID DETERGENT FIBER
17	UREA
18	CALCIUM (UPPER LIMIT)
19	CALCIUM (LOWER LIMIT)

CP MODEL - GROWING STEER

```
MIN      62 CS + 95 CG + 500 CGF + 184 SBM + 225 U + 500 DDGS + 500 CSM
     + 500 WCS + 500 AHF + 500 AHM + 500 AHE + 500 FH + 500 OGH + 500 CSH
     + 500 M + 500 O + 500 BDG + 51 L + 292 DC + 280 KCL + 153 TMS
     + 500 SMF
SUBJECT TO
       2)    CS + CG + CGF + SBM + U + DDGS + CSM + WCS + AHF + AHM + AHE
     + FH + OGH + CSH + M + O + BDG + L + DC + KCL + TMS + SMF =     1
       3)    1.06 CS + 1.48 CG + 1.3 CGF + 1.34 SBM + 1.36 DDGS + 1.14 CSM
     + 0.07 WCS + 0.4 AHF + 0.57 AHM + 0.68 AHE + 0.51 FH + 0.62 OGH
     + 0.51 CSH + 1.1 M + 1.08 O + 1.34 BDG + 1.12 SMF =     1.166
       4)    100 TMS =     0.25
       5)    51 CS + 10 CG + 53 CGF + 14 SBM + 42 DDGS + 22 CSM + 56 AHF
     + 50 AHM + 47 AHE + 75 FH + 67 OGH + 89 CSH + 31 O + 52 BDG + 65 SMF
     >=    0
       6)    24 CS + 3 CG + 11.7 CGF + 6 SBM + 18 DDGS + 13 CSM + 34 WCS
     + 34 AHF + 30 AHM + 29 AHE + 30 FH + 34 OGH + 48 CSH + 12 O + 15 BDG
     + 36 SMF >=    0
       7)    3.2 CS + CG + 5.2 CGF + 13 SBM + 16 DDGS + 17 CSM + 4.5 AHF
     + 3.7 AHM + 3.2 AHE + 4.2 FH + 3.3 OGH + 1.6 CSH + 5.2 O + 16.8 BDG
     >=    0
       8)    75 CS + 89 CG + 87 CGF + 84 SBM + 85 DDGS + 76 CSM + 45 WCS
     + 53 AHF + 58 AHM + 61 AHE + 56 FH + 59 OGH + 46 CSH + 75 M + 74 O
     + 84 BDG + 51 SMF >=    0
       9)    1.65 CS + 2.16 CG + 1.96 CGF + 2.02 SBM + 2.05 DDGS + 1.75 CSM
     + 0.99 WCS + 1.17 AHF + 1.28 AHM + 1.36 AHE + 1.23 FH + 1.3 OGH
     + 1.02 CSH + 1.74 M + 1.72 O + 2.02 BDG + 2.24 SMF >=    0
      10)    1.67 CS + 2.05 CG + 1.91 CGF + 1.91 SBM + 1.94 DDGS + 1.72 CSM
     + 0.97 WCS + 1.17 AHF + 1.28 AHM + 1.34 AHE + 1.23 FH + 1.3 OGH
     + 0.99 CSH + 1.69 M + 1.67 O + 1.91 BDG + 1.1 SMF >=    0
      11)    34 CS + 89 CG + 90 CGF + 89 SBM + 99 U + 92 DDGS + 91 CSM
     + 91 WCS + 89 AHF + 89 AHM + 90 AHE + 89 FH + 88 OGH + 90 CSH + 56 M
     + 89 O + 92 BDG + 98 L + 96 DC + 100 KCL + 98 TMS + 90 SMF >=    0
      12)    CS + 0.35 CG + 1.92 CGF + 2.2 SBM + 0.7 DDGS + 1.4 CSM + 1.2 WCS
     + 1.7 AHF + 1.9 AHM + 2.4 AHE + 1.7 FH + 2.7 OGH + 0.9 CSH + 3.4 M
     + 0.5 O + 0.1 BDG + 0.1 DC + 50.54 KCL + 1.7 SMF >=    0.6
      13)    0.22 CS + 0.13 CG + 1.1 CGF + 0.7 SBM + 0.82 DDGS + 1.15 CSM
     + 0.25 WCS + 0.22 AHF + 0.23 AHM + 0.24 AHE + 0.24 FH + 0.33 OGH
     + 0.09 CSH + 0.1 M + 0.38 O + 0.6 BDG + 0.02 L + 18.56 DC + 0.18 SMF
     >=    0.34
      14)    8 CS + 10 CG + 19.85 CGF + 50.8 SBM + 286 U + 28 DDGS + 46 CSM
     + 10 WCS + 16 AHF + 17 AHM + 18 AHE + 12 FH + 11 OGH + 4 CSH + 5 M
     + 13 O + 28 BDG + 15 SMF >=    13.75
      15)    0.22 CS + 0.13 CG + 1.1 CGF + 0.7 SBM + 0.82 DDGS + 1.15 CSM
     + 0.25 WCS + 0.22 AHF + 0.23 AHM + 0.24 AHE + 0.24 FH + 0.33 OGH
     + 0.09 CSH + 0.1 M + 0.38 O + 0.6 BDG + 0.02 L + 18.65 DC + 0.18 SMF
     <=    0.42
      16)    28 CS + 3 CG + 10 SBM + 18 DDGS + 13 CSM + 51 WCS + 41 AHF
     + 38 AHM + 41 FH + 40 OGH + 71 CSH + 17 O + 24 BDG + 47 SMF >=    0
      17)    U <=    0.014
      18)    0.24 CS + 0.03 CG + 0.113 CGF + 0.33 SBM + 0.3 DDGS + 0.19 CSM
     + 1.7 WCS + 1.3 AHF + 1.4 AHM + 1.41 AHE + 0.4 FH + 0.34 OGH
     + 0.15 CSH + 1.1 M + 0.07 O + 0.33 BDG + 34 L + 22 DC + 0.05 KCL
     + 0.49 SMF <=    0.5
      19)    0.24 CS + 0.03 CG + 0.113 CGF + 0.33 SBM + 0.3 DDGS + 0.19 CSM
     + 1.7 WCS + 1.3 AHF + 1.4 AHM + 1.41 AHE + 0.4 FH + 0.34 OGH
     + 0.15 CSH + 1.1 M + 0.07 O + 0.33 BDG + 34 L + 22 DC + 0.05 KCL
     + 0.49 SMF >=    0.46
```

KEY

FINISHING STEER (318 KG) - RDP SYSTEM

EQUATION	EQUATION DEFINED
1	OBJECTIVE FUNCTION
2	BULK
3	NET ENERGY FOR GAIN
4	TRACE MINERAL SALT
5	NEUTRAL DETERGENT FIBER
6	CRUDE FIBER
7	BYPASS PROTEIN
8	TOTAL DIGESTIBLE NUTRIENTS
9	NET ENERGY FOR MAINTENANCE
10	NET ENERGY FOR LACTATION
11	DRY MATTER
12	POTASSIUM
13	PHOSPHORUS (LOWER LIMIT)
14	CRUDE PROTEIN
15	PHOSPHORUS (UPPER LIMIT)
16	ACID DETERGENT FIBER
17	UREA
18	CALCIUM (UPPER LIMIT)
19	RUMEN DEGRADABLE PROTEIN
20	CALCIUM (LOWER LIMIT)

RDP MODEL - FINISHING STEER

```
MIN      62 CS + 95 CG + 500 CGF + 184 SBM + 225 U + 500 DDGS + 500 CSM
     + 500 WCS + 500 AHF + 500 AHM + 500 AHE + 500 FH + 500 OGH + 500 CSH
     + 500 M + 500 O + 500 BDG + 51 L + 292 DC + 280 KCL + 153 TMS
     + 500 SMF
SUBJECT TO
       2)    CS + CG + CGF + SBM + U + DDGS + CSM + WCS + AHF + AHM + AHE
     + FH + OGH + CSH + M + O + BDG + L + DC + KCL + TMS + SMF =     1
       3)    1.06 CS + 1.48 CG + 1.3 CGF + 1.34 SBM + 1.36 DDGS + 1.14 CSM
     + 0.07 WCS + 0.4 AHF + 0.57 AHM + 0.68 AHE + 0.51 FH + 0.62 OGH
     + 0.51 CSH + 1.1 M + 1.08 O + 1.34 BDG + 1.12 SMF =     1.166
       4)    100 TMS =     0.25
       5)    51 CS + 10 CG + 56.6 CGF + 14 SBM + 42 DDGS + 22 CSM + 56 AHF
     + 50 AHM + 47 AHE + 75 FH + 67 OGH + 89 CSH + 31 O + 52 BDG + 65 SMF
     >=    0
       6)    24 CS + 3 CG + 15.4 CGF + 6 SBM + 18 DDGS + 13 CSM + 34 WCS
     + 34 AHF + 30 AHM + 29 AHE + 30 FH + 34 OGH + 48 CSH + 12 O + 15 BDG
     + 36 SMF >=    0
       7)    3.2 CS + CG + 5.2 CGF + 13 SBM + 16 DDGS + 17 CSM + 4.5 AHF
     + 3.7 AHM + 3.2 AHE + 4.2 FH + 3.3 OGH + 1.6 CSH + 5.2 O + 16.8 BDG
     >=    0
       8)    75 CS + 89 CG + 87 CGF + 84 SBM + 85 DDGS + 76 CSM + 45 WCS
     + 53 AHF + 58 AHM + 61 AHE + 56 FH + 59 OGH + 46 CSH + 75 M + 74 O
     + 84 BDG + 51 SMF >=    0
       9)    1.65 CS + 2.16 CG + 1.96 CGF + 2.02 SBM + 2.05 DDGS + 1.78 CSM
     + 0.99 WCS + 1.17 AHF + 1.[illegible] AHM + 1.36 AHE + 1.23 FH + 1.3 OGH
     + 1.02 CSH + 1.74 M + 1.72 O + 2.02 BDG + 2.24 SMF >=    0
      10)    1.67 CS + 2.05 CG + 1.91 CGF + 1.91 SBM + 1.94 DDGS + 1.72 CSM
     + 0.97 WCS + 1.17 AHF + 1.28 AHM + 1.34 AHE + 1.23 FH + 1.3 OGH
     + 0.99 CSH + 1.69 M + 1.67 O + 1.91 BDG + 1.1 SMF >=    0
      11)    34 CS + 89 CG + 90 CGF + 89 SBM + 99 U + 92 DDGS + 91 CSM
     + 91 WCS + 89 AHF + 89 AHM + 90 AHE + 89 FH + 88 OGH + 90 CSH + 56 M
     + 89 O + 92 BDG + 98 L + 96 DC + 100 KCL + 98 TMS + 90 SMF >=    0
      12)    CS + 0.35 CG + 1.37 CGF + 2.2 SBM + 0.7 DDGS + 1.4 CSM + 1.2 WCS
     + 1.7 AHF + 1.9 AHM + 2.4 AHE + 1.7 FH + 2.7 OGH + 0.9 CSH + 3.4 M
     + 0.5 O + 0.1 BDG + 0.1 DC + 50.54 KCL + 1.7 SMF >=    0.6
      13)    0.22 CS + 0.13 CG + 0.897 CGF + 0.7 SBM + 0.82 DDGS + 1.15 CSM
     + 0.25 WCS + 0.22 AHF + 0.23 AHM + 0.24 AHE + 0.24 FH + 0.33 OGH
     + 0.09 CSH + 0.1 M + 0.38 O + 0.6 BDG + 0.02 L + 18.56 DC + 0.16 SMF
     >=    0.26
      14)    8 CS + 10 CG + 16.79 CGF + 50.8 SBM + 286 U + 28 DDGS + 46 CSM
     + 10 WCS + 16 AHF + 17 AHM + 18 AHE + 12 FH + 11 OGH + 4 CSH + 5 M
     + 13 O + 28 BDG + 15 SMF >=    11.75
      15)    0.22 CS + 0.13 CG + 0.897 CGF + 0.7 SBM + 0.82 DDGS + 1.15 CSM
     + 0.25 WCS + 0.22 AHF + 0.23 AHM + 0.24 AHE + 0.24 FH + 0.33 OGH
     + 0.09 CSH + 0.1 M + 0.38 O + 0.6 BDG + 0.02 L + 18.65 DC + 0.18 SMF
     <=    0.3
      16)    28 CS + 3 CG + 10 SBM + 18 DDGS + 13 CSM + 51 WCS + 41 AHF
     + 38 AHM + 41 FH + 40 OGH + 71 CSH + 17 O + 24 BDG + 47 SMF >=    0
      17)    U <=    0.012
      18)    0.24 CS + 0.03 CG + 0.013 CGF + 0.33 SBM + 0.3 DDGS + 0.19 CSM
     + 1.7 WCS + 1.3 AHF + 1.4 AHM + 1.41 AHE + 0.4 FH + 0.34 OGH
     + 0.15 CSH + 1.1 M + 0.07 O + 0.33 BDG + 34 L + 22 DC + 0.05 KCL
     + 0.49 SMF <=    0.5
      19)    4 CS + 4 CG + 14.18 CGF + 36.6 SBM + 288 U + 10.64 DDGS + 30 CSM
     + 11.52 AHF + 13.26 AHM + 14.76 AHE + 7.8 FH + 7.7 OGH + 11.2 BDG
     + 15 SMF <=    7.237
      20)    0.24 CS + 0.03 CG + 0.031 CGF + 0.33 SBM + 0.3 DDGS + 0.19 CSM
     + 1.7 WCS + 1.3 AHF + 1.4 AHM + 1.41 AHE + 0.4 FH + 0.34 OGH
     + 0.15 CSH + 1.1 M + 0.07 O + 0.33 BDG + 34 L + 22 DC + 0.05 KCL
     + 0.49 SMF >=    0.34
```

KEY

FINISHING STEER (318 KG) - CP SYSTEM

EQUATION	EQUATION DEFINED
1	OBJECTIVE FUNCTION
2	BULK
3	NET ENERGY FOR GAIN
4	TRACE MINERAL SALT
5	NEUTRAL DETERGENT FIBER
6	CRUDE FIBER
7	BYPASS PROTEIN
8	TOTAL DIGESTIBLE NUTRIENTS
9	NET ENERGY FOR MAINTENANCE
10	NET ENERGY FOR LACTATION
11	DRY MATTER
12	POTASSIUM
13	PHOSPHORUS (LOWER LIMIT)
14	CRUDE PROTEIN
15	PHOSPHORUS (UPPER LIMIT)
16	ACID DETERGENT FIBER
17	UREA
18	CALCIUM (UPPER LIMIT)
19	CALCIUM (LOWER LIMIT)

CP MODEL - FINISHING STEER

```
MIN      62 CS + 95 CG + 500 CGF + 164 SBM + 225 U + 500 DDGS + 500 CSM
     + 500 WCS + 500 AHF + 500 AHM + 500 AHE + 500 FH + 500 OGH + 500 CSH
     + 500 M + 500 O + 500 BDG + 51 L + 292 DC + 280 KCL + 153 TMS
     + 500 SMF
SUBJECT TO
        2)    CS + CG + CGF + SBM + U + DDGS + CSM + WCS + AHF + AHM + AHE
     + FH + OGH + CSH + M + O + BDG + L + DC + KCL + TMS + SMF =     1
        3)    1.06 CS + 1.48 CG + 1.3 CGF + 1.34 SBM + 1.36 DDGS + 1.14 CSM
     + 0.07 WCS + 0.4 AHF + 0.57 AHM + 0.68 AHE + 0.51 FH + 0.62 OGH
     + 0.51 CSH + 1.1 M + 1.08 O + 1.34 BDG + 1.12 SMF =     1.166
        4)    100 TMS =     0.25
        5)    51 CS + 10 CG + 56.6 CGF + 14 SBM + 42 DDGS + 22 CSM + 56 AHF
     + 50 AHM + 47 AHE + 75 FH + 67 OGH + 89 CSH + 31 O + 52 BDG + 65 SMF
     >=    0
        6)    24 CS + 3 CG + 15.4 CGF + 6 SBM + 18 DDGS + 13 CSM + 34 WCS
     + 34 AHF + 30 AHM + 29 AHE + 30 FH + 34 OGH + 48 CSH + 12 O + 15 BDG
     + 36 SMF >=    0
        7)    3.2 CS + CG + 5.2 CGF + 13 SBM + 16 DDGS + 17 CSM + 4.5 AHF
     + 3.7 AHM + 3.2 AHE + 4.2 FH + 3.3 OGH + 1.6 CSH + 5.2 O + 16.8 BDG
     >=    0
        8)    75 CS + 89 CG + 87 CGF + 84 SBM + 85 DDGS + 76 CSM + 45 WCS
     + 53 AHF + 58 AHM + 61 AHE + 56 FH + 59 OGH + 46 CSH + 75 M + 74 O
     + 84 BDG + 51 SMF >=    0
        9)    1.65 CS + 2.16 CG + 1.96 CGF + 2.02 SBM + 2.05 DDGS + 1.78 CSM
     + 0.99 WCS + 1.17 AHF + 1.28 AHM + 1.36 AHE + 1.23 FH + 1.3 OGH
     + 1.02 CSH + 1.74 M + 1.72 O + 2.02 BDG + 2.24 SMF >=    0
       10)    1.67 CS + 2.05 CG + 1.91 CGF + 1.91 SBM + 1.94 DDGS + 1.72 CSM
     + 0.97 WCS + 1.17 AHF + 1.28 AHM + 1.34 AHE + 1.23 FH + 1.3 OGH
     + 0.99 CSH + 1.69 M + 1.67 O + 1.91 BDG + 1.1 SMF >=    0
       11)    34 CS + 89 CG + 90 CGF + 89 SBM + 99 U + 92 DDGS + 91 CSM
     + 91 WCS + 89 AHF + 89 AHM + 90 AHE + 89 FH + 86 OGH + 90 CSH + 56 M
     + 89 O + 92 BDG + 98 L + 96 DC + 100 KCL + 98 TMS + 90 SMF >=    0
       12)    CS + 0.35 CG + 1.37 CGF + 2.2 SBM + 0.7 DDGS + 1.4 CSM + 1.2 WCS
     + 1.7 AHF + 1.9 AHM + 2.4 AHE + 1.7 FH + 2.7 OGH + 0.9 CSH + 3.4 M
     + 0.5 O + 0.1 BDG + 0.1 DC + 50.54 KCL + 1.7 SMF >=    0.6
       13)    0.22 CS + 0.13 CG + 0.897 CGF + 0.7 SBM + 0.82 DDGS + 1.15 CSM
     + 0.25 WCS + 0.22 AHF + 0.23 AHM + 0.24 AHE + 0.24 FH + 0.33 OGH
     + 0.09 CSH + 0.1 M + 0.38 O + 0.6 BDG + 0.02 L + 18.56 DC + 0.18 SMF
     >=    0.26
       14)    8 CS + 10 CG + 16.79 CGF + 50.8 SBM + 288 U + 28 DDGS + 46 CSM
     + 10 WCS + 16 AHF + 17 AHM + 18 AHE + 12 FH + 11 OGH + 4 CSH + 5 M
     + 13 O + 28 BDG + 15 SMF >=    11.75
       15)    0.22 CS + 0.13 CG + 0.897 CGF + 0.7 SBM + 0.82 DDGS + 1.15 CSM
     + 0.25 WCS + 0.22 AHF + 0.23 AHM + 0.24 AHE + 0.24 FH + 0.33 OGH
     + 0.09 CSH + 0.1 M + 0.38 O + 0.6 BDG + 0.02 L + 18.65 DC + 0.18 SMF
     <=    0.3
       16)    28 CS + 3 CG + 10 SBM + 18 DDGS + 13 CSM + 51 WCS + 41 AHF
     + 38 AHM + 41 FH + 40 OGH + 71 CSH + 17 O + 24 BDG + 47 SMF >=    0
       17)    U <=    0.012
       18)    0.24 CS + 0.03 CG + 0.013 CGF + 0.33 SBM + 0.3 DDGS + 0.19 CSM
     + 1.7 WCS + 1.3 AHF + 1.4 AHM + 1.41 AHE + 0.4 FH + 0.34 OGH
     + 0.15 CSH + 1.1 M + 0.07 O + 0.33 BDG + 34 L + 22 DC + 0.05 KCL
     + 0.49 SMF <=    0.5
       19)    0.24 CS + 0.03 CG + 0.031 CGF + 0.33 SBM + 0.3 DDGS + 0.19 CSM
     + 1.7 WCS + 1.3 AHF + 1.4 AHM + 1.41 AHE + 0.4 FH + 0.34 OGH
     + 0.15 CSH + 1.1 M + 0.07 O + 0.33 BDG + 34 L + 22 DC + 0.05 KCL
     + 0.49 SMF >=    0.34
```

VITA

Daniel Martin Sevcik was born February 19, 1963. He is the son of Mr. and Mrs. Thomas A. Sevcik. He received his elementary education in Indiana and secondary education in Tennessee and Ohio. In September 1981, he entered the University of Tennessee, Knoxville and was graduated with a Bachelor of Science degree in Animal Science in December 1985.

In the spring of 1986 he accepted a teaching assistantship in the Animal Science Department at the University of Tennessee, Knoxville and began study toward a Master of Science degree in Ruminant Nutrition. This degree was awarded in August 1988.

The author is married to the former Marianne M. Boyles of Panama City, Florida.