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Technical support for the

NIRS/NUTBAL Nutritional Management System

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Preface

This publication is to assist Natural Resource Conservation Service employees, consultants, and livestock producers in making decisions about nutritional needs of livestock when using the decision support software package, Nutritional Balance Analyzer (NUTBAL). This publication has supporting technical information to aid the user in understanding the science within the decision support system.

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In this publication . . .

BWT	Body weight
CP	Crude protein
DIP	Degradable intake protein
DM	Dry matter
DOM	Digestible organic matter
DSS	Decision support systems
DUP	Digestible undegraded protein
GAN Lab	Grazingland Animal Nutrition Laboratory
IDM	Indigestible dry matter
ME	Metabolizable energy
NEg	Net energy for gain
NEm	Net energy for maintenance
NIRS	Near infrared reflectance spectroscopy
NRC	National Research Council
NUTBAL	Nutritional Balance Analyzer
OM	Organic matter
TDN	Total digestible nutrients
TNZ	Thermal neutral zone

Technical support for the
NIRS/NUTBAL Nutritional Management System

Introduction

Livestock producers have had limited ability to assess the nutritional status of free-ranging herbivores in a manner sufficiently quantitative for precise nutritional management. Affordable analytical tools were not available to interpret the nutritional status of the animal in terms of diet quality, available forage, physiological status, terrain, weather, feedstuffs, and use of metabolic modifiers. Now, affordable high-speed microcomputers, the emergence of decision support systems (DSS), and the analytical power of near infrared reflectance spectroscopy (NIRS) provide a mechanism to deliver practical nutritional advisory systems for free-ranging herbivores.

This publication focuses on a decision support systems for nutritional management that were developed in the United States of America and in Australia, respectively. The authors emphasize

- the developmental aspect of these systems,
- discusses technologies needed to support the use of the decision support systems,
- explores the functional aspects of the systems, and
- shows how computer technology in the form of DSS can allow us to integrate diverse information and predict the nutritional balance of the animal and likely performance.

Overview of NUTBAL

The Nutritional Balance Analyzer (NUTBAL) software estimates the percent of crude protein (CP) and net energy for maintenance (NEm)/ gain (NEg) balance of cattle, CP and NEm balance of sheep and goats, and the CP and digestible energy balance of horses. When coupled with estimates of dietary CP and digestible organic matter (DOM) of the diet of free-ranging animals via NIRS fecal scans from cattle, sheep, horses, and goats, the user of the NIRS/NUTBAL system can provide nutritional management advice to livestock producers.

NUTBAL uses a combination of modeling systems including the National Research Council (NRC) basic nutrient requirement formulas, adjustments to the NRC 1984 equations, rumen degradable protein thresholds, and DOM/CP ratio concepts as well as the concept of rate of intake change and modification of metabolizable energy caused by associative effects in growing animals. Where NUTBAL deviates from other nutritional intake models is in the application of a modified, metabolic-fill system to predict dry matter intake of the animal from dry fecal output. Use of this approach allows modeling of fecal output processes, considering more than just the digestion process.

Impacts of forage availability, appetite drive, and associative effects can be characterized in both the fecal output as a proportion of fat-corrected body weight and the metabolizability of ingested forage. Many of the baseline values of fecal output expressed as a percentage of fat-corrected body weight are derived from literature review, expert opinion, and unpublished data extrapolated from earlier studies. Basal fecal output factors of mature animals in NUTBAL are relatively less complex than those of growing animals that reflect differences in the sexes, impact of DOM/CP ratio, threshold rumen protein degradability and associative effects. Perhaps the greatest weakness of NUTBAL is the inability to account for requirements of degradable intake protein (DIP) and digestible undegraded protein (DUP). Recent research in the prediction of these variables via NIRS fecal scans will make it possible to monitor them and eventually include them in future versions of NUTBAL.

Linking NIRS fecal scans technology with the NUTBAL Decision Support System

A major limitation to supporting nutritional management decisions is the inability of managers and advisors to determine diet quality under field conditions where animals graze freely across diverse landscapes or complex pasture mixes. However, recent advances in NIRS have made it possible to detect fecal by-products of digestion and relate these constituents to dietary CP and DOM. Prediction equations are developed from fecal samples of intact animals and extrusa of esophageal fistulated animals by sharing the same landscape over a wide array of forage conditions or by creating a variety of diets in a controlled stall-feeding experiment.

In 1992 an equation was developed that predicted dietary CP and DOM at similar levels of accuracy as standard wet chemistry laboratory analyses for cattle. To date, dietary prediction equations for cattle appear to be reliable across a broad spectrum of forage types including

- subtropical shrublands,
- temperate and tropical pastureland,
- temperate and subtropical grasslands,
- desert shrublands,
- desert grasslands,
- Mediterranean annual grasslands,
- hardwood forests,
- coniferous forest,
- marshland, and
- mountain meadows.

Critical advisory issues

When a person has received the estimated diet quality results from the laboratory, nutritional balance analyses can be conducted with NUTBAL. There are several critical concepts to be considered when using the system.

Characterizing the animal

Weight, body condition, and frame score

NUTBAL calculates the requirement of an animal by first determining the standard reference weight of the animal adjusted to a body condition score 5 (BCS=5), given its sex, age and frame score. Requirements are based on a normal age-weight-fatness relationship with fatness assumed to be 25 percent of body weight at BCS=5. The Animal Attribute data base in NUTBAL will allow assignment of a frame score (hip-height class for cattle). The COWSCORE utility in NUTBAL allows the user to explore sex, age, weight, body condition, and frame relationships to help assign the most appropriate frame score for the animals in question. The ability to accurately score body condition is critical to the usability of the NUTBAL DSS.

In many cases the user will provide only the weight or body condition score of the animals in question and the user must show some judgement as to which one is *most correct*. Developing *threshold* characteristics of body condition scores is most useful to help an individual visualize the condition score of the animal. For instance the presence or absence of noticeable 12th and 13th ribs is a good threshold of body condition scores that are greater than or less than 5 for cattle.

Energy adjustment factor

NUTBAL allows adjustments in net basal metabolism of a breed type based on the relative amount of *Bos indicus* and *Bos taurus* bloodlines, amount of dairy breed influence, and level of dual-purpose bloodlines, such as Simmental.

These differences are due to varying proportions of soft tissue relative to body weight in the various breeds. Higher proportions of soft tissue, especially the liver and digestive tract, increase the net metabolism of the animal. There are several breed examples in the NUTBAL animal-attribute data base, but the range in values used are depicted below. For requirement calculations, NUTBAL assumes that the animal is a beef breed and requires that a breed's net basal metabolism be adjusted relative to that standard.

Breed class	Energy adjustment factor
Beef breeds	+ 0.00
Dual purpose breeds	+ 0.15
Dairy breeds	+ 0.20
Bos indicus breeds	– 0.20

To compute an energy adjustment factor for a crossbred animal, one needs to know the proportions of the four breed classes above. The example below provides a mechanism for assigning an energy adjustment factor to a breed type.

Breed type	Proportion	Factor	Fraction
Hereford	0.50	+ 0.00	+ 0.0000
Brahman	0.25	– 0.20	– 0.0500
Brown Swiss	0.25	+ 0.15	+ 0.0375
Total			– 0.0125

Peak milk yields

Many of the primary breeds have been assigned peak milk yields in the animal attribute data base in NUTBAL based on National Research Council (1996) recommendations. However, because of the breeding programs of a given client, milk yield may change. Generally, this occurs when producers are selecting replacement heifers from their own herd or from special sales based on percent of the dam's weight when weaned, especially when good nutrition programs are in place. There are three utility programs distributed with NUTBAL called PKMILK, NEWPMILK, and CALFWT that can be used to estimate peak milk yield from the average age and weight of a group of calves and known frame score of the dam or vice versa.

Maximum hair length/hide thickness

Genetic differences within breeds allow selection for cold or heat tolerance, NUTBAL allows for the characterization of maximum hair length (extended from the skin to hair tip) measured at the edge of the rear rib cage just off the spine approximately 4 inches down during the peak of the cold season. The user can also select the degree of thickness of the hide as well. A relative hair length value is derived using the current weekly average maximum temperature and the past 30-day average maximum temperature to derive a relative hair length value that is multiplied by a given breed type's maximum.

Fiber yield

Because NUTBAL also calculates requirements for sheep and goats, provision for wool and mohair production is provided in the animal attribute data base in NUTBAL. The yield noted increases the crude protein requirements based on the amount specified, class of animal, and stage of production.

Assessing performance goals of the client

Before assigning desired performance levels in NUTBAL, the user must determine desired body condition and plane of nutrition in terms of desired calf crop percents or target weights of the animals by a certain date. For example, mature cows during peak lactation that have a body condition score 4 must gain 2.2 pounds per day to attain a body condition score of 5+ in 60 days. The major issue is whether it is biologically possible given that the animal is on an increasing demand for nutrients and the level of input may be economically prohibitive. Establishing performance goals is critical to an ongoing process of keeping the actions focused on a target relative to market and financial conditions of the client (producer).

Representing a feedstuff in NUTBAL

If a client has a given feedstuff or considering an array of potential feeds before a feeding season, those feeds must be properly represented on a dry matter basis in the feedstuff dictionary of NUTBAL. Commercial feeds are reported on an AS FED basis and NUTBAL needs inputs on a dry matter basis.

Most commercial tag values provide ash and crude protein values but seldom provide total digestible nutrients (TDN) or energy value. Many companies will provide average quality values on an AS FED or dry matter basis upon request, particularly if the lot number of the feed under consideration is known. In many cases these will include TDN values. However, if the user has major ingredient values but no TDN values and the feed dealer cannot provide the information, the TDNCALC utility in the NUTB subdirectory provides an estimate of TDN value.

The Grazingland Animal Nutrition Laboratory (GAN Lab) maintains a data base of typical feedstuff values reported to them by feed companies and are on the Internet, http://cnrit.tamu.edu/ganlab.

Determining negative associative effects of a feedstuff

The use of high-starch grain, such as corn, introduces another problem that must be dealt with in NUTBAL. When the user enters a given feedstuff, NUTBAL assumes that the animal assimilates the nutrients at the specified concentration with no impact on the desire to eat or on the availability of nutrients from other sources of feed.

High starch diets suppress the appetite because of low rumen pH and elevated volatile fatty acids and reduce the availability of energy and protein in associated feedstuffs, such as roughages. There is a threshold above which these grains cease to be additive and begin to have a negative impact, eventually negating the value of the grain to the animal. If the animal is consuming more than 0.15 percent of its fat-corrected body weight (BCS=5) of a high-starch grain, we recommend that the GRAIN utility be run to determine if the level fed is benefiting the animal.

Typically, the user must adjust the CP and DOM value of the forage/ roughage base of the diet and intake adjustment factor. The GRAIN utility provides the values to use in NUTBAL. Have feed grain tested by a certified laboratory to assess their DM, CP, and ME, content rather than using book values.

Special issues to consider for case information

How detailed should the analysis be?

Usually a fecal sample is sent in for analysis that represents a complex herd of breed types, age classes, physiological stages, and body condition. In some cases the information is represented as an average but the herd structure is diverse. In other cases, the consultant is not familiar with the herd and the producer must fill in the form with either the classes separated and (or) a range in weights, ages, and body condition scores provided on the form. In either case one diet CP and DOM analysis from GAN Lab represents that group of animals.

Finally, there are cases where the producer has represented the herd properly and the analysis is reasonably straightforward. The question arises as to how best to represent these different situations in a case analysis? When information is limited, the producer is asked to take pictures of

- the cow herd close enough to see the diversity of individuals,
- typical cows in the herd, and
- forage availability of the species being grazed at time of sample collection.

This allows you to *see* the data written down on the form.

At the end of the NUTBAL analysis, the advisory prepared should consider the managerial capability of the client, their ability to provide quality information and to take action, such as separating animals of significantly different requirements. Generally, if a range in values is presented, a call to the client is warranted to determine if that range is skewed toward one end of the group.

Typically, at least two cases are conducted representing the bulk of the dominant set of conditions and that group in the herd that has the highest requirements. In one case, a client may separate individuals for special treatment, and identify two or more groups for the analysis that would result in significantly different feeding regimes (type and amount) to alleviate the problem. In the second case, these separations may occur for young cows versus older cows in low or high body condition.

The differences represented, communicate valuable information for the client that could lead to greater efficiencies of production if the anticipated benefits are not offset by the costs to separate the animals.

When more time is spent by the consultant to conduct multiple analyses per sample, the action should be considered a *value-added* activity but not more work.

Getting the age correct

Proper representation of the age of a herd of animals that are less than 60 months of age critically affects body condition/weight relationships, milk yield, nutrient requirements, and increases the sensitivity of fecal output to DOM/CP ratio of the diet. This is especially true when the animals are less than 18 months old. When herds are composed of multiple age groups with diverse body condition score classes, the consultation can become complicated if the client wants a detailed analysis. Again, one must go back to the needs, capability, and flexibility of the client to determine the level of analysis used to advise them on nutritional issues.

Representing the activity level properly

NUTBAL allows the user to input a range of terrain conditions that reflect slope, distance from water, depth of snow, and incidence of marshy conditions or any condition that requires the expenditures of energy. These *activity* costs are an integral part of NUTBAL's requirement calculations. Activity level for work animals, such as horses working, breeding, and draft animals, are represented by three levels of intensity—light, moderate, and heavy. These levels of activity allow adjustments of net basal energy of the animal.

Representing physiological state

NUTBAL allows you to represent animals as mature, breeding age, and growing, or growing. Mature animals represent fully grown intact males, castrates and breeding females. Breedable growing females are fertile and classed as those greater than and less than 55 to 65 percent of mature fat-corrected body weight. Therefore, representation of age classes and stage of puberty in females is critical.

Setting environmental conditions

Maximum daily temperature is a relatively important variable for cattle if it is generally greater than 77 °F or less than 59 °F. However, upper and lower critical temperatures are computed for the animal based on environmental conditions (temperature, windspeed, and coat condition), breed characteristics (hair length, hide thickness, surface area), and body condition score. Above the upper value, fecal output (intake) is reduced. Fecal output is increased when the animal is below the lower threshold value or is reduced when the animal is wet (wet snow, muddy, or rain) from hair tip to the skin during temperatures below 59 °F.

Windspeed in NUTBAL only affects the animal if temperature is below lower critical threshold conditions. During hot conditions, fecal output is affected by degree of nighttime cooling or elevated body temperatures at sunrise. Most consultants have difficulty assessing this variable. Generally, the user should invoke nighttime cooling of body temperature because many mechanisms are in place for animals to restabilize their body temperature before sunrise the next day. Access to shade, good water supply, and ample forage supply to allow localized grazing at night all contribute to allowing animals such as the *Bos taurus* breeds to minimize afternoon grazing and shift to substantial nighttime grazing. The *Bos indicus* breeds have the additional advantage of sweating to alleviate the heat buildup as well. If early morning temperatures are not substantially different from temperatures at sunset, and the animals had limited access to shade, invoking the *NO* nighttime cooling option is recommended, especially if humidity is high.

The standing forage issue

Perhaps one of the most frustrating aspects of nutritional management is determining when the forage supply is preventing animals from acquiring adequate intake. The FORAGE utility program was established to account for standing crop, stock density, and growth of the vegetation to allow the user to determine if forage supply is restricting intake. This utility calculates an intake adjustment, which is a computed fecal output value as a percent of potential under current conditions and forage not limiting dry matter intake.

Adjusting intake for metabolic modifiers

Negative associative effects caused by grains and impacts of ionophores (feed additives such as monension and lasalocid) on fecal output are reflected in NUTBAL via a *nonforage* intake adjustment field. Advances in new products and highly variable impact on consumed forages, have resulted in use of this variable as a *tuning* variable impacting fecal output. User training and fact sheets are required when attempting to apply an adjustment factor for a new metabolic modifier in NUTBAL. NUTBAL only adjusts NEm value of the forage when an ionophore is selected. If implants are used, NUTBAL increases intake by 8 percent.

Dealing with rumen degradable protein

Forages that use the cool-season (C_3) photosynthetic pathway may supply excess nitrogen in relation to the available carbohydrates for microbial populations to use. This leads to a high concentration of rumen ammonia, which is largely absorbed into the blood stream and excreted in the form of urea. Elimination of urea in urine adds to energy costs and suppresses appetite. NUTBAL assumes that this phenomenon occurs when rumen degradable protein is greater than 75 percent of the CP value of the forage such as occurs normally in actively growing fertilized stands of cool-season grasses. Fecal output is substantially reduced in NUTBAL for growing animals only if the user invokes the same threshold condition. The DOM/CP ratio further reduces fecal output as it declines below a value of 4. It is assumed that the mechanism for reduced fecal output is a combination of high ammonia levels in the rumen and reduced quantities of metabolizable amino acids reaching the lower gut.

Two solutions exits to the problem of excess rumen degradable protein. One solution, already in NUTBAL, is to supply a readily available source of rapidly fermentable structural carbohydrates (beet pulp, wheat middlings) that provide a carbon source for the excess ammonia nitrogen being released. The other technique, not incorporated in NUTBAL, is to feed protected proteins (by-pass protein) that allow amino acids to escape into the lower gut after hydrolysis in the abomasum (fishmeal, blood meal, feather meal, cottonseed meal, corn gluten). Essentially, the fermentable structural carbohydrates or by-pass proteins shift the fecal output to a more favorable situation and appetite returns and basal energy requirements are reduced. If any warm-season (C_4) source roughage or forage is provided this generally will provide adequate by-pass protein and carbohydrates to avoid rumen degradable protein exceeding the threshold of 75 percent (CP).

Writing an advisory

The principal product of the NUTBAL DSS is the nutritional balance and mediation report and a written advisory for the client. Success of the NIRS/NUTBAL nutritional management system will depend on how these recommendations are communicated to the client. After representing the herds diet quality through a fecal sample, and properly describing the animals and their environment, the final step is running the NUTBAL report and writing a recommendation. The client is presented with some preformatted analyses that require explanations and recommended actions at the bottom of the report. The detail provided depends on the complexity of the situation and degree of the problem presented from the analysis. In many cases, you are analyzing a situation where a feedstuff is specified and amount fed is provided. If the analysis indicates that the current situation is alleviating the problem and animals are meeting the desired performance goals, then a simple statement indicating that current conditions and feeding regime are meeting stated goals will suffice.

Another option is to check on availability and pricing of more appropriate or cost-effective feeds. If you are working as an intermediary between the client and feed company, involve feed representatives as much as possible in the analysis to allow them to learn from the process and represent their product in a proper manner. They may have alternative feeds or can provide feedback to the company on needed formulation changes.

Point out the most limiting nutrient at the beginning of the analysis. If input had to be modified relative to information provided on the form, explain the change and why the modification was needed, such as using a lower weight or different body condition score or choosing a different temperature value. Explain what weight gain means in terms of the future body condition of the animal. For instance, a one-unit change in body condition score may be 77 pounds. If the rate of loss is .05 pound per day this means that over the next 30 days they will lose 15 pounds or about 0.2 units of a condition score, a degree of change seldom visible to the human eye.

Sometimes where a problem exists, the client does not have any feed in mind. A variety of common feeds can be chosen and an analysis will show their relative merit. You can also indicate that they need x.x pounds of protein or TDN per day to meet their need and then let them go shopping for a feed that gives the lowest cost per pounds of limiting nutrient. The best solution is to call this client, explore the options and then conduct the analysis for a suite of feeds that were identified in the discussion. It is good to establish cash limits, feeding constraints, and degree of availability of the feed in question. Also, make sure the necessary nutrient information about the feed is available before beginning the analysis.

The actual recommended amount may need to be adjusted given the sampling interval of the individual. For instance, a person samples every 30 days and there is a problem in terms of protein that requires feeding of 1.5 pounds per day of cottonseed meal. In this situation anticipate how the animal's requirements will change during the sampling interval and how conditions in terms of forage quality and environment will alter the recommendation. If the animal is on an increasing nutrient requirement and forage quality is declining, recommend a level of feeding for a specified number of days followed by a change in level over another number of days.

Warnings about unusual conditions and operational adjustments in feeding levels and kind of feed are good for those regions that have unexpected severe weather events (snow storms, ice storms, heavy extended rains in cold weather, early frost). In some cases, it is advisable to run a series of cases that have the anticipated conditions to see if your recommendations should be altered. Sometimes requirements are declining and forage quality is increasing to the next sampling point. In this instance, a projected loss may be short-lived or insignificant. Still recommended actions and adjustment during the sampling interval are warranted.

Establishing a sampling interval

Planning sampling intervals is a wise practice to recommend when and under what conditions the client should collect the next sample. The interval depends heavily on the client's interest in monitoring and the level of expected interaction between you and your client. If you are in a seasonal transition period, it is good to reduce the sampling interval and specify the conditions that warrant sampling again. For instance, fall to winter transition periods are uncertain as to when first frost occurs. The sample can be taken in 21 days or 10 days after a killing frost, and if rains occur after the killing frost, take the sample in 5 to 7 days. A baseline value maybe setup every time conditions change substantially and then wait 14 to 21 days and take another sample to set a trend line.

When to sample and how frequently is dependent on the financial status of the client, variability of conditions, and the degree of interest the producer has in the monitoring program. A minimum of 30-day sampling frequency with the NIRS fecal profiling system is needed in the first year in the program followed by more intensive sampling in transition conditions and less frequent samples when times are known to be good based on prior sampling programs. Unusual conditions warrant sampling 5 to 7 days from the event's start with a 14-day interval to gain a better perspective on the impact of the event.

Modeling intake in NUTBAL

NUTBAL's principal mechanism for driving intake is to model dynamics of fecal output or indigestible dry matter output, using the NIRS predictions of DOM converted to TDN.

$$\text{Voluntary intake}\left(\frac{\text{kgDM}}{\text{d}}\right)=\frac{\text{Upper limit to fecal output}\left(\frac{\text{kgDM}}{\text{d}}\right)}{\text{Diet indigestible fraction}\left(\frac{\text{kgIDM}}{\text{kgDM}}\right)}$$

where:

$$\text{Diet IDM} = 1 - (\text{TDN\%} \times .01) \text{ and}$$

$$\text{TDN} = 1.05 \times \text{DOM}$$

This voluntary intake equation assumes that, at the upper limit of intake, fecal output is a constant percent of the fat corrected body weight of an animal in stable metabolic and physiological state. The positive relationship between daily voluntary intake and digestibility and the nonsignificant relationships between digestibility and fecal output both suggest that increased intake with increased digestibility is attained by increasing the dry matter load within the gastrointestinal tract.

The indigestible fraction is determined by the reciprocal of the total digestible nutrients in the diet selected by the animal. As digestibility increases, intake increases as long as indigestible dry matter limits are not exceeded. Fecal output changes as capacity of the gastrointestinal tract changes in response to morphological differences between species, breeds and individuals as well as physiological stages of the animal interacting with the environment. Fecal output levels within physiological stages and within species can be used to predict potential forage intake when expressed as a proportion of fat-corrected body weight. Furthermore, these fecal output factors can be used as driving variables in simulation and decision support models.

Under extensive grazing, intake is simultaneously influenced by the amount of forage, the concentration of critical nutrients (energy, crude protein, minerals), ratios of nutrients, and partitioning of components among these nutrients. Fecal output is not only sensitive to animal metabolic and physiological state, but also to the concentration and ratio of diet crude protein fractions and energy, forage availability, environmental conditions, feed supplements/additives, and metabolic modifiers such as growth hormones and ionophores. Concentration and ratio of critical plant nutrients is affected by photosynthetic pathway (cool-season vs warm-season), growth habit (grass, forb, browse), stage of growth, rate of growth at the time of ingestion, and level of leaching from senescent plant tissue.

The following factors affecting ruminant intake are considered in NUTBAL when assessing the level of demand that animals will place on the forage resource and their subsequent nutrient balance.

Species

Smaller ruminants have proportionally smaller forestomachs and faster rates of digesta passage, thereby generally resulting in increased fecal output as a percentage of fat-corrected body weight. Typical baseline fecal output constants (kg dry matter intake per kg of fat-corrected body weight) for dry, open females of cattle, sheep, and goats are 0.01, 0.011, and 0.012, respectively.

Breeds

All nutrient requirements and intake functions assume a medium frame, body condition score 5 for a mature animal. Growing animal requirements are computed from fat-corrected body weight adjusted to a medium frame steer, with other computations as deviations from this standard. Dairy cattle breeds have higher gastrointestinal capacity relative to body volume during lactation. This greater capacity results in proportionally higher intakes for equivalent fat-corrected body weights compared with other *Bos taurus* beef breeds. Intake is approximately 11 percent higher for Holsteins and 4 percent for Holstein crossbred animals. Special attention should be given to many of the dual-purpose breeds to determine the level of deviation from traditional beef breeds relative to fecal output relationships. NUTBAL does not currently adjust for seasonal variation in net basal metabolism.

Body condition

One of the primary assumptions of nutritional requirement systems is that the weight of the animal should be standardized to a given level of fatness. Standard reference weights for cattle, should be based on an observable average fatness index or body condition score 5 on a 1 to 9 system. This corresponds to a body fat content of 25 percent. Too many intake studies have been reported on a percent body weight basis without any correction for fatness, leading to a wide array of *intake relationships* in the literature that cannot be compared or contrasted. The use of a standard reference weight at an average fatness allows intake determinations across a wide range of body fatness. This ensures that these determinations are more a reflection of gastrointestinal tract size and of function than animal weight. Essentially, NUTBAL corrects a given body condition score for specified sex, age, and frame score to a common body weight at body condition score 5 using the formula below.

If body condition score is greater than 5

$$\text{Standard reference weight} = \frac{\text{Body weight}}{\left[.5444 + \left(.0898 \times \text{Body condition score}\right)\right]}$$

If body condition score is less than 5

$$\text{Standard reference weight} = \frac{\text{Body weight}}{\left[.6663 + \left(.0657 \times \text{Body condition score}\right)\right]}$$

Body condition and age relationships in growing animals must also be considered for animals experiencing *compensatory gain*. Failure to correct body weight for fatness would result in underestimates of intake. Gastrointestinal tract capacity in these animals is greater than indicated by body weight alone.

Compensatory gain

Compensatory gain is the result of reduced net basal metabolism, increased efficiency in conversion of net energy of gain for feed consumed, and proportionally greater intake.

Because NUTBAL corrects body condition to a standard score, growing animals at body condition scores less than 5 have adjusted body weights that allow proportionally more intake per unit of body weight. Compensatory gain is most common among young animals subjected to suboptimal nutritional regimes, but can occur only if the animal has not been *stalled* or stunted in the development of its genetic potential to develop its skeletal frame The animal's morphology indicates that sufficient skeletal development has occurred to allow realimentation of the soft tissue, muscle tissue, and fat deposition to levels consistent with the age and size of the animal under normal conditions.

Because maintenance energy costs are greater for soft tissue than for muscle and adipose tissue, animals that have less organ mass than normal have lower net basal metabolism per unit of body weight. The largest mass of organs affecting net basal metabolism includes the stomach and small and large intestines along with the liver and to a lesser degree kidneys, heart, and spleen. The liver mass of lambs exhibiting compensatory gain has been noted to be 45 to 60 percent less, the stomach and small/large intestines 28 to 48 percent less, and the fasting heat of production 20 to 22 percent less when compared to lambs on normal planes of nutrition.

Baseline fecal output factors

Mature cows

The gastrointestinal capacity of animals that are not carrying a fetus or that are in the first two trimesters of pregnancy is similar to that of the baseline fecal output constant for the species. However, at least with cattle, there may be as much as a 10 percent reduction in fecal output during the last trimester. Although this reduction has usually been attributed to reduced rumen capacity in relation to the growing fetus, some evidence indicates that increasing estrogen levels may be at least in part responsible. The following baseline fecal output factors (proportion of fat corrected body weight) for mature cows:

Dry, open, cow	.01
First 1/3 pregnancy, cow	.01
Middle 1/3 pregnancy, cow	.01
Last 1/3 pregnancy, cow	.009
Seven-month pregnancy, cow	.0095
Eight-month pregnancy, cow	.0092
Nine-month pregnancy, cow	.0088

Milk yield at a given point in the lactation curve is a complex sequence of calculations starting with adjustment of the stored value for peak milk yield relative to body condition. Peak milk yield estimates of cows that have body condition scores less than a 5 are adjusted down 7 percent per score unit. The body condition adjusted milk yield is then adjusted for cow age, decreasing from 5 years old down to 2 years.

$$\text{Fecal output factor} = .009938 + \left[0.000372 \times \left(0.454 \times \text{daily lb of milk}\right)\right]$$

If lactation is less than 158 days, a lag factor is applied with the following formula:

$$\text{Lagged fecal output factor} = \begin{bmatrix} \left(.00996 + .006387 \times \text{lactation day}\right) \\ \times \left(\text{non - lag fecal factor - .009}\right) \end{bmatrix} + 0.009$$

Mature bull and ox

Mature oxen are assumed to have similar base fecal output factors as cows, with intact males having somewhat higher values at equivalent physiology and body condition states.

Mature bull	.0102
Mature ox	.01

Growing heifers up to 60 months

Growing animals are sensitive to protein concentration and energy/protein ratios in their diet, changing with age. Intake of indigestible dry matter (IDM) output in growing animals is influenced by DOM/CP ratio and the proportion of rumen degradable CP. Nitrogen is considered inadequate for microbial populations when the DOM/CP ratio is greater than 7, with optimum levels approaching 4. Generally, DOM/CP ratios less than 4 result in a suppression in IDM output if rumen degradable protein is greater than 75 (CP).

If rumen degradable protein is less than 75 percent (CP), as in most rangeland species, then the following formula is applied to compute the baseline IDM factor of growing animals. This formula considers age of the animal and DOM/CP ratio of the diet.

$$\text{Fecal output factor} = \left\{0.02344 - \left[0.00642 \times \log_{10}\left(\text{avg\_age\_mo}\right)\right]\right\} - \left\{\begin{matrix} 0.0156 - \left[0.00711 \times \log_{10}\left(\text{avg\_age\_mo}\right)\right] \\ \times \log_{10}\left(\dfrac{\text{DOM}}{\text{CP ratio}}\right) \end{matrix}\right\}$$

If rumen degradable protein is greater than 75 percent (CP) as in many cool-season annuals, then the following set of baseline IDM factors are used for diets greater than and less than a DOM/CP ratio of 4.

DOM/CP less than or equal to 4

$$\text{IDM factor} = \left\{ \begin{array}{l} 0.03024 - \left[0.01749 \times \log_{10}\left(\text{total\_diet\_DOM\%}\right)\right] \\ + \left[0.01625 \times \log_{10}\left(\dfrac{\text{DOM}}{\text{CP ratio}}\right)\right] \end{array} \right\}$$
$$\times \left\{1.04269 - \left[0.05912 \times \log_{10}\left(\text{avg\_age\_mo}\right)\right]\right\}$$

DOM/CP greater than 4

$$\text{IDM factor} = \left\{ \begin{array}{l} -0.04358 - \left[0.03066 \times \log_{10}\left(\text{Total\_diet\_DOM\%}\right)\right] \\ - \left[0.00453 \times \log_{10}\left(\dfrac{\text{DOM}}{\text{CP ratio}}\right)\right] \end{array} \right\}$$
$$\times \left\{1.04269 - \left[0.05912 \times \log_{10}\left(\text{avg\_age\_mo}\right)\right]\right\}$$

Environmental factors

The thermal neutral zone (TNZ) of livestock is the range in ambient temperature where the ruminant is at relative equilibrium with the environment. NUTBAL uses maximum daily temperature as a measure of temperature stress. Thermal conditions above and below the TNZ have a major affect on forage intake. The TNZ of an animal is defined by its upper and lower critical temperatures. Generally, beef cattle have a TNZ for voluntary intake of 59 to 77 °F. Below the TNZ (cold stress), intake increases in response to heat loss down to –13 °F if fill limitations are not encountered. However, animals exposed to sustained temperatures below –13 °F may restrict grazing activity and intake to minimize energy expenditures for grazing. Animals subjected to muddy conditions or rainy/wet snow conditions, depress intake as temperatures decreases. Occurrence of rain during extended periods has been observed to depress intake, regardless of animal thermal status. Two IDM output adjustments are made for environment. One adjustment in IDM is condition of the animal’s coat. This factor also impacts on energy requirements.

Coat condition	**IDM adjustment factor**
Dry	1.00
Legs/lower body muddy	0.95
Mud up to upper side	0.85
Coat wet, snow, covered with mud	0.70

Intake decreases in response to increasing temperature above the TNZ (heat stress). At night is a period during which daytime heat load is dissipated. If high temperatures and high humidity persist during the night, there is less opportunity for body cooling before the next day’s heat load, resulting in greater intake depression.

If daily high temperatures exceeds 59 °F (upper critical threshold) the following adjustments are made to the IDM adjustment factor. With nighttime cooling of core body temperature (rectal temperature at sunrise normal) occurs:

$$\text{IDM adjustment factor} = 1.4938 - \left(.0198 \times \text{Max temp } ^{\circ}\text{C}\right)$$

If nighttime cooling does not occur then:

$$\text{IDM adjustment factor} = 1.8750 - \left(.035 \times \text{Max temp } ^{\circ}\text{C}\right)$$

In many arid climates, animals walk long distances to water resulting in reduced forage intake, particularly if ruminants require daily access to water. In Merino sheep, generally intake does not change during the first 2 days of deprivation but a 46 percent decrease in intake was observed by the 4 day of deprivation. In Hereford heifers, a 50 percent reduction of each preceding day's intake during 4 days of water deprivation has been observed.

If daily high temperatures are less than 15 °C (less than lower critical temperature) IDM adjustments are made for the following conditions:
If coat is dry:

$$\text{IDM adjustment factor} = 1.0441 - \begin{bmatrix} \left(0.0055 \times \text{Max temp } ^{\circ}\text{C}\right) \\ +\left(0.00018 \times \text{Max temp } ^{\circ}\text{C}^{2}\right) \end{bmatrix}$$

If coat is covered with rain or wet snow:

$$\text{IDM adjustment factor} = 0.73 + \left(0.018 \times \text{Max temp } ^{\circ}\text{C}\right)$$

Forage quality

Intake by the animal is not only influenced by gastrointestinal tract capacity but concentration of indigestible dry matter of the diet. Forage quality as it pertains to intake generally implies digestibility, crude protein, secondary compounds, and mineral content. The level of digestion is generally related to the relative proportion of cell contents and composition of fibrous components of the cell wall (structural carbohydrates). These components are influenced by

- their content of specialized tissues of inherently different digestibilities,
- intrinsic composition of structural carbohydrates,
- changes with age in composition of structural carbohydrates, and
- association of potentially digestible entities with indigestible entities.

Digestibility of forages and its impact on intake by the animal must be viewed in terms of the rate and extent of digestion. The extent of digestion within a given segment of the gastrointestinal tract is influenced by the composition and indigestibility of each chemical entity within the forage residue as well as the residence time of the residue within the gastrointestinal tract.

Essential to this process is the activity of the microbial population in each gastrointestinal tract. Microorganisms hydrolyze and ferment forage constituents to obtain nutrients they need for maintenance and growth. Where the rate of nutrient acquisition limits microbial growth as in the case of limited nitrogen (plant crude protein), the rate of digestion slows depending on residence time in the gastrointestinal tract. This reduced microbial activity results in reduced forage intake. The critical forage crude protein concentration below which intake declines is 7 percent. For mature animals IDM adjustment is made for crude protein levels below 7 percent in the following formula:

$$\text{IDM adjustment factor} = \frac{\left[35.92 + \left(9.026 \times \text{crude protein}\right)\right]}{100}$$

The growing animals are adjusted based on level of DOM, DOM/CP ratio, and user determined rumen degradable crude protein.

Forage availability

An underlying assumption of voluntary intake computations is that quantity of forage on offer is not limiting ability to meet dry matter fill constraints. However, animals are often subjected to standing forage (lb/ac) that restricts intake. The FORAGE utility in NUTBAL is used to determine if forage supply is restricting potential dry matter intake. Extensive use of the utility has emerged a general rule that a stock density less than 6 ac/au (au = animal unit consumption of 26 lb DM/d) and standing crops of less than 900 pounds per acre constitute conditions where the program needs to be run to determine potential restrictions in intake of grazing animals.

Grain and negative associative effects

When dietary crude protein is below 7 percent, use of a protein supplement can stimulate dry matter intake. However, at levels above 7 percent CP, the role of protein supplements is to meet protein requirements of the animal relative to desired performance level. Growing animals and to a certain extent early lactating cows are sensitive to balance of DOM and CP. Fecal output is enhanced when the DOM\CP ratio is below 7.

To effectively use protein supplements, there must be a good assessment of nutrient requirements relative to performance goals and projected nutrient intake. Allocation of a protein supplement then becomes a matter of feeding enough supplement in a least-cost manner to meet the imbalance. When animals exhibit both a crude protein and net energy imbalance, then the energy concentration (NEm and NEg) in the feedstuff must be considered along with the crude protein content. Often combinations of a protein supplement and high-energy feedstuff (soluble sugar in molasses or highly fermentable carbohydrate of grains) or high fat content protein supplements, such as whole cottonseed, are used in these situations.

Associative effects can manifest themselves when feeding highly fermentable carbohydrates in two ways:

- increases in protozoa in the rumen which can reduce microbial protein available to the animal, or
- reduction in digestibility of ingested forage caused by lowering of ruminal pH that inhibits bacterial cellulolytic activity.

A general rule of thumb is that grain intake should remain below 0.4 percent of fat-corrected body weight to minimize negative associative effects.

The NUTBAL decision support system provides a utility that uses the *intake change rate* concept to reflect changes in IDM output and forage digestible organic matter caused by associative effects. Forage and supplement values are converted to an organic matter basis. NUTBAL converts the *deviation in ME concentration* to NEm and NEg and corrects the forage NEm and NEg values by subtracting or adding the NEm and NEg deviation values because of associative effects. These values do not affect TDN values used in the divisor of the intake equation. Therefore, in NUTBAL, associative effects on IDM output affect intake while caloric concentration of the diet is affected independent of TDN derivations. The behavior of NUTBAL will require further scrutiny to determine if this logic requires modification as we better understand the mathematics of associative effects.

Fecal output (Forage intake) Change rate (OM, % BWT)

$$\text{IDM adjustment factor} = 0.0827 - \left\{ \begin{array}{l} \left[0.1519 \times \log_{10}\left(\text{OM intake \%BWT}\right)\right] \\ -\left[0.1847 \times \log_{10}\left(\text{Supplement \%CP}\right)\right] \end{array} \right\}$$

$$R^2 = 0.23 \left(\text{related to limited range in data values}\right)$$

Deviation in ME concentration (mcal/ kg OM)

$$\begin{aligned} \text{ME adjustment factor} = -0.03627 &- \left[3.1208 \times \left(\text{Supplement OM intake \%BWT}\right)^2\right] \\ &+ \left[\begin{array}{l} 0.3245 \times \left(\text{Supplement OM intake \%BWT}\right)^2 \\ \times \left(\text{Supplement ME}\right)^2 \end{array} \right] \\ &+ \left[0.000336 \times \left(\text{Forage CP\%}\right)^2\right] \times -1 \end{aligned}$$

$$R^2 = 0.67$$

Metabolic modifiers

Ionophores, such as monensin and lasilocid, are microbial population modifiers used to improve efficiency of conversion of feed to liveweight gain in growing animals. Feeding these additives can affect the dry matter intake of forage, net energy for maintenance value of the forage ingested, digestibility of forage crude protein, and possibly the net basal metabolism of the animal at the tissue level. Organic matter digestibility (OMD) of forages is increased by 4 percent with a quadratic effect on fecal output (percent body weight), and a negative impact on DOM below 45 percent or above 65 percent, and a peak increase in fecal output at 55 percent DOM. Greater turnover and escape of ingested forage can also lead to higher propionate levels and more efficient yield of microbial protein that escapes rumen degradation thereby increasing crude protein digestibility. In its current form, NUTBAL only adjusts NEm given the dynamics of intake associated with ionophores and other metabolic modifiers. The user is directed toward using the intake adjustment factor in NUTBAL to impose IDM output adjustments for ionophores, a surrogate for rate of passage, appetite drive, and chemostatic control.

Implants, which stimulate growth of the animal, increase IDM fecal output (% BWT) 8 percent when applied in NUTBAL. A new family of growth hormones and antibiotics are being approved for use in cattle and will impact this adjustment factor. This is the function of the intake adjustment factor field in NUTBAL.

Validation of the NIRS/NUTBAL system

Most of the validation work for the system has focused on validating the predictions of the NIRS system. Over the years the equations have become more robust if regional samples are included in the equations to allow detection of the nuances of change in forage quality conditions. To address issues of mixed warm-season and cool-season vegetation in the northern Great Plains, validation samples were added from studies conducted in Montana, South Dakota, and Nebraska.

A demonstration study on mature, lactating cows in South Dakota found that the system gave good predictions of performance of the cows when properly parameterized. However, this demonstration helped to identify several human issues in the use of the system. The first of which was getting the animals properly characterized to the correct frame, weight body condition relationship. Another critical piece of information was providing the correct description of the vegetation so that the appropriate NIRS fecal equation could be applied. The original data or sample form indicated native range when in fact the range was dominated by an introduced cool-season perennial grass, requiring use of the cool-season dominant equation set. Maximum temperature characterization was critical for this region as it fluctuates widely during hot periods varying from 65 °F to 95 °F in the same week. Fecal samples were collected on the hottest days and these temperatures were represented as the maximum temperature for NUTBAL collections. However, the animals were subjected to maximum temperatures of only 65 °F to 68 °F the following day, negating the effects of the high temperatures. When thermal neutral temperatures were input into the model, predictions corresponded to observed performance.

The impact of protein deficiency was felt the most in the late summer dormancy period and only a 0.7 unit difference in predicted crude protein (6.1 to 6.8% CP) from the NIRS resulted in a projected weight loss exceeding that observed. NUTBAL has several critical *threshold* values that make characterization under field conditions critical with 7 percent CP and a DOM/CP ratio of 8 being the most sensitive levels in the model.

In the later stages of the demonstration, the animals were transported to another ranch and predictions were higher than observed because the amount to reduce intake and energy requirements for transport stress was not known. However, the system performed well when the data input reflected the reality of the grazing conditions of the animals. This information points out that acquisition of accurate data for the decision support system is as important as the accuracy of the nutrition model's algorithms.

A 9-month NIRS/NUTBAL nutritional management validation trial was also conducted in the subtropical region of southern Texas, and a second, 24-month validation trial was conducted in temperate woodland of east central Texas. F1 Hereford-Brahman cows were used in both validations.

In the subtropical validation site, when external factors influencing forage intake were not considered, model predictions were greater (P=0.0001) than observed gain, with model predictions falling outside a 95 percent confidence interval in 7 of 10 weigh periods. Negative forage intake adjustments for high environmental temperatures accounted for improved predictions for most weigh periods. Because the site was located near the coast of the Gulf of Mexico and receives night breezes, all predictions were made assuming cows had the benefit of night cooling. During January and February, negative forage intake adjustments for low forage availability accounted for observed weight loss. Weight gain following this period was due to availability of free-choice hay.

In the temperate woodland site, no differences (P=0.9226) were observed between model predictions assuming night cooling and observed performance. Model predictions without the night cooling tended to be lower (P=.0001) than observed performance. With the Brahman-Hereford cows used in this study, intake did not appear to be depressed because of the reduced grazing time in response to high night temperatures and high humidity. Differences between model predictions without inclusion of supplemental feeds offered and observed performance approached significance (P=0.1319) with model estimates tending to underestimate observed performance. Model estimates that have supplements were higher than observed gain (P=0.221), possibly because cows were fed on the ground and as a group. Across this 2-year study, there was no difference (P=0.412) between model estimates and observed gain/loss when night cooling and supplemental feed were included in the model. Correlation’s between model estimates and observed performance were lowest (r=0.68) with no night cooling and no supplements included in the model and highest (r=0.85) with night cooling and supplements.

NUTBAL is not a simulation model and is illustrated by model estimates during months during the first 10 to 12 months of the study. During these months, cows were lactating. The model in its current form overestimated weight loss because it does not partition energy between maintenance and lactation. The model treats milk production as a production goal and does not reduce it in response to an energy deficit. In these instances, if the energy deficit were equally partitioned between weight loss and a reduction in milk production while maintaining forage intake, model estimates would approach observed performance.