Impact and Management of Variability in Feed and Diet Composition

William P. Weiss[1] and Normand R. St-Pierre
Department of Animal Sciences
Ohio Agricultural Research and Development Center
The Ohio State University

Summary

The nutrient composition of feeds and diets has always been, and will continue to be, variable, but methods are available to reduce that variation. Reducing variation in nutrient composition of diets can lower feed costs, improve animal health, and/or increase milk production. To manage variation in the total diet, you must have some idea of the size or scope of the variation in nutrient composition for each ingredient in the TMR. An accurate standard deviation **(SD)** can be calculated when feedstuffs are sampled enough times and the sampling is done correctly. With simple nutrients (e.g., fiber or crude protein), the contribution of an ingredient to total diet variance changes with the square of its inclusion rate. If an ingredient has a large SD for a simple nutrient, reducing its inclusion rate will make the total diet more consistent for that nutrient. Complex nutrients such as energy (net energy for lactation**;** **NE_L)** or metabolizable protein **(MP)** are a function of the composition of the total diet; therefore, variation in those nutrients must be derived from multiple sampling of the TMR or by using mathematical and simulation techniques. Variation in nutrient composition of TMR can be reduced by:

1. Choosing feedstuffs that have low variability.
2. Increasing the number of ingredients and limiting their inclusion rates.
3. Buying commodities from a single source from suppliers that have good quality control systems in place.
4. Maintaining separate inventory for feeds with different nutritional characteristics.
5. Purchasing blended feeds (rather than several different feedstuffs) from a manufacturer with an effective quality control program.
6. Proper training of feeders.

With more consistent nutrient composition, diets can be formulated to more closely match cow requirements (i.e., smaller safety factors), which should result in reduced feed costs or greater milk yields. This paper will discuss measurement of variation, sources of variation, and methods that can be used to reduce variation in nutrient composition of diets.

Introduction

A fundamental rule regarding diet formulation is that one never knows the true value of anything. Although we have reasonably accurate estimates of the ***average*** requirements for most nutrients, we have less certainty regarding nutrient requirements of a specific herd or animal under specific circumstances. We have equations that accurately estimate the ***average*** dry matter intake **(DMI)** for groups of cows, but estimating intake accurately of a specific cow is more difficult. We have developed several good analytical procedures to measure the concentrations of many nutrients, and tables are available that contain the ***average*** nutrient composition of all feeds commonly fed to dairy cows. However, biological and manufacturing

[1]Contact at: 1680 Madison Ave., Wooster, OH 44691, (330) 263-3622, FAX: (330) 263-3949, Email: weiss.1@osu.edu

variation, variation caused by sampling, and variation in analytical measurements can be substantial, meaning that the concentrations of nutrients within a specific feedstuff may be quite different from the average. Does all this uncertainty mean that we should give up on ration formulation and feed analysis? The answer to that question is obviously, no. However, the uncertainty associated with feed analysis and ration formulation must be understood and addressed. With proper sampling techniques, adequate number of samples, and appropriate data handling, one can reduce the uncertainty associated with feed analysis data. The objective of this paper is to discuss expected variation in feed composition, factors affecting variation, and methods one can use to reduce the variability in nutrient composition of total mixed diets.

Elementary Statistics

We need to start thinking about feed composition data in terms of probabilities rather than actual, absolute concentrations. In other words, how confident should you be that the analytical value received from a laboratory actually represents the true concentration of a nutrient in a feed? Because we are working with probabilities, a basic understanding of some statistical principles and terminology is needed.

Populations and samples

The ultimate goal of feed analysis is to obtain an analytical value from a sample that reflects the actual value of a 'population'. Populations can be quite different, depending on the application. For example, a population can be a truckload of distillers dried grains, all the distillers dried grains produced by a specific distillery, or perhaps all the distillers dried grains produced in the country. In statistical terms, a population is loosely defined as a large set from which samples can be taken. If distillers grains from a single distillery were sampled extensively, we would have a good estimate of the average nutrient composition of distillers grains produced at that plant. However, since other distilleries were not sampled, we should be very hesitant to extrapolate the data obtained from a single distillery (i.e., a narrow population) to the larger population of all distilleries.

Central tendency and dispersion

A population can be represented by a set of observations or samples. Because of inherent variation among the particles making a feed and because of variation caused by sampling and analytical procedures, we know that all of the sample values will not be the same. Rather than one single value, one can obtain a distribution of values. The two most important pieces of information we need to obtain from a set of samples are a measure of central tendency and a measure of dispersion. For observations that follow a normal statistical distribution, the mean (in this discussion average and mean will be used interchangeably) is the best measure of central tendency. The mean of a normal distribution is not the absolute 'right' answer, but rather it is the value that has the lowest probability of being substantially wrong (i.e., it is the most likely value or the expected value). The concentrations of most nutrients in plant-based feedstuffs fit approximately a normal distribution; therefore, the mean is the best measure of central tendency for those nutrients. With a normal distribution, approximately one-half of the samples have values lower than the mean and one-half have concentrations higher than the mean. The concentrations of trace minerals and fat often have a skewed distribution (a few observations will have very high concentrations). With this type of distribution, the mean still represents the *expectation*, but it overestimates the central tendency. The median (the value at which half the observations are higher and half are lower) is the best measure of central tendency for this type of distribution.

Although many people are familiar with and often use measures of central tendency (i.e., the mean) in ration formulation, fewer people consider or use measures of dispersion in ration formulation. In simple terms, a measure of dispersion should be used to determine how much confidence one has when using a mean value. When a distribution of values has a large dispersion, the probability of being substantially wrong increases when using the mean. For a normal distribution, the most common measure of dispersion is the SD. In a normal distribution, approximately 38% of all observations are within $\pm$ 0.5 SD units of the mean, 68% of all observations are within $\pm$ 1 SD of the mean, and approximately 95% of the samples are within $\pm$ 2 SD of the mean. If the mean concentration of CP in a population of brewers dried grains is 25% and the SD is 2, we would expect that about 68% of the samples would contain between 23 and 27% CP, and 95 % of the samples would contain between 21 and 29 % CP. This also means that about 5 % of the samples would contain less than 21 or more than 29 % CP. The smaller the SD, relative to the mean, the less likely it is that using the mean value will cause a substantial error in diet formulation.

Sources of Variation

Understanding potential sources of variation in feed composition data helps determine which data to use and how to use it. The nutrient composition of grains and by-products can be influenced by plant genetics (hybrid, variety, etc.) and growing conditions (drought, climate, soil fertility, etc.). In addition, the composition of by-products is affected by manufacturing techniques. The above sources of variation are considered fixed (i.e., they can be described and replicated). In statistical quality control jargon, they are labelled as *assignable causes*. Hybrid X may have been genetically selected to produce corn grain with higher than average concentrations of protein. Distillery Y might dry their distillers grains at very high temperatures, causing high concentrations of acid detergent insoluble protein. A drought may reduce kernel size; thereby, increasing the concentration of fiber in corn grain. Another possible fixed source of variation is the analytical lab. Although great progress has been made in standardizing methods, labs may use different analytical techniques to measure nutrients. If lab A measures neutral detergent fiber **(NDF)** using sulfite, but another lab does not, the NDF concentrations will differ between the labs because of procedure.

Other sources of variation are considered random. We do not know why the values differ, they just do. If you sample a load of brewers grains 10 times and send those 10 samples to a lab, you will probably get back 10 slightly different concentrations of CP. The variation could be caused by variation within the load of brewers grain, or it could be caused by random errors at the lab. The causes of the variation are unknown. They are referred to in quality control jargon as *unassignable causes*.

Ideally, random variation would be considered within population variation and fixed variation would be considered as variation between populations. For example, because of manufacturing differences, distillers grains from distillery X has consistently higher NDF concentrations than distillers grains from distillery Y. If distillers grains from X and Y were considered separate populations, the SD within each population would be lower than the SD when the results from both distilleries are combined. Because of blending grains and multiple sources of feedstock for manufacturing facilities, many fixed sources of variation become blurred (you will not know the variety of soybeans used to make the soybean meal you purchased or whether the gluten feed you purchased was made from drought-stressed corn grain). In these situations, the fixed sources of variation (assignable causes) become random sources (unassignable causes), resulting in an increase in the within population variation. Nonetheless, accounting for as many fixed sources of variation as possible by defining separate populations will reduce the dispersion of the data and reduce the potential of being substantially wrong when using the mean.

Expected Variation in Nutritional Composition of Feeds

A large publicly-available data base of feed composition can be found in the NRC (2001) dairy publication. That database contains means, SD, and the number of samples for measured nutrients in most common feedstuffs used in North America. The data used to calculate those means and SD came from a wide array of sources. Samples came from across the US and over several years. For some feeds and nutrients, the number of samples used to calculate the mean and SD is quite limited, and those values should be used with caution. For other feeds, the sample size is quite large and the mean and SD are probably good estimates for the broad population from which the samples were drawn. However, it is important to remember that the broad population represented in the NRC tables may not be a good estimate for a specific source of a feed. Kertz (1998) also provides data on variation in nutrient composition of a limited number of feeds and some commercial labs also provide statistics on feed composition (e.g., DairyOne (www.dairyone.com/Forage/FeedComp) and Dairyland Labs (www.dairylandlabs.com/pages/interpretations/summaries.php)).

Based on expected variation, feeds can be classified as having low, moderate, or high variability. Feeds with generally low variability include corn grain, sorghum grain, and perhaps barley (Table 1). Feeds with the largest variability in composition are by-products that are usually not a direct co-product of manufacturing. For example, potato waste has extremely high variability because it may include cull potatoes, potato peels, or waste products from the manufacturing of potato products for human consumption, rejected product, etc. Millrun, corn screenings, and cannery waste are other examples of feeds that are not well-defined and would be expected to have high variability, even when they come from the same originating source. Feeds with moderate variability include most feeds that would be considered co-products rather than by-products. Distillers grains, brewers grains, and corn gluten feed **(CGF)** are end products of alcohol, beer, and corn sweetener production. Because production of these products is generally well-controlled, the composition of the resulting co-product can be relatively constant within a production facility. The forages in Table 1 have moderate variability, but note how variation decreases when a more exact definition of the forages is used (alfalfa silage vs. mid-maturity alfalfa silage).

The NE_L and MP are arguably the most important nutrients used in dairy diet formulation, but they present unique problems in terms of variation. Those nutrients are not measured by laboratories but are calculated from numerous variables, some of which are measured while others are estimated. The complexity and nonlinearity of the new models used for diet evaluation and/or balancing (e.g., NRC, 2001) make it impossible to calculate directly the variation in NEL and MP of the diet that is attributable to the variation in the nutritional composition of the feeds making up the diet. However, we can simulate this variation and examine its effect through multiple replications, using modern high speed computers and a method called Monte Carlo simulation. A new software program, called *Ping Pong*™ has been developed at Ohio State to study the effects of nutrient variation in feedstuffs on the variance in NEL and MP of the diet (Beta version available for free at www.sesamesoft.com). An example of variation in NEL of alfalfa hay is shown in Figure 1. If NRC data (Table 2) are used (a broad population), the average NEL is 1.23 Mcal/kg with a SD of 0.15. If samples are from a well-defined population (e.g., hay from a single farm and cutting, Table 2), the average NEL is still 1.23 Mcal/kg, but the SD is now 0.04.

To increase the accuracy of ration formulation, feeds with moderate and high variability in composition must be sampled and analyzed routinely, and the data generated must be used correctly. An accurate estimate of SD for a specific feedstuff can be extremely useful in ration formulation. The SD should be considered when deciding on ration *safety* factors. The SD in the NRC table is a function of inherent variation in composition of the grain or feedstock, lab-to-lab variation, variation among manufacturing processes, and many other sources of variation. If no other measure of dispersion is available, the SD in the NRC table can be used; however, one must remember that for many feeds, the actual variation could be substantially less than the SD in the NRC table (Table 3).

Several common feeds were sampled and analyzed over a one year period in California (DePeters et al., 2000). All analyses were conducted at a single lab, and for the feeds that will be discussed, all samples within a feed came from the same production facility. A similar type study was conducted in Missouri (Belyea et al., 1989). Dried distillers grains were sampled in both studies. The calculated distributions of CP concentrations are shown in Figure 2 for the two studies and for NRC data. Mean concentration of CP was very similar for the three data sets (29.7, 30.6, and 31.2 % of DM for NRC, MO, and CA, respectively). However, dispersion differed greatly. The SD for NRC, MO, and CA were 3.3, 1.6, and 0.6, respectively. Based on the means and considering typical dietary inclusion rates for distillers grains, essentially the same concentration of dietary CP would be obtained regardless of the source of the data. However, because the SD is substantially lower when all samples were obtained from a single source, one would be much less likely to make a substantial error when the mean value is used if the sample is from a limited, rather than a broad population. Not all feeds or nutrients follow the pattern shown for distillers grains in Figure 2. The mean CP concentration for rice bran from the NRC data set (broad population) is very different from the mean obtained from Belyea et al. (1989; limited population) (Figure 3). If one used the mean concentration of CP from NRC for rice bran obtained from the particular production facility sampled in the Missouri study, the CP concentration would be substantially underestimated, resulting in increased protein supplementation costs. For nutrients that are routinely measured, means obtained from a broad population (e.g., NRC) should be used only when other data specific to a limited population are not available.

Handling Variation in Feed Composition

Variation in feed composition is handled differently depending upon whether a given feed is best conceptualized as the outcome of a batch process versus a continuous process.

Batch-process feedstuffs

Feeds in this category are handled in lots such as trucks and train cars. The manufacturing may be a continuous process, but their use is generally best described as a batch process. Most feed commodities used by commercial feed manufacturers fall into this category. They are characterized by small variation within lots and small to large variation between lots.

Feeds with low expected variability between lots do not have to be analyzed routinely and, in some cases, not at all. Sampling and analytical errors become relatively small when large numbers of samples are analyzed. For these feeds, a mean derived from a large number of samples may actually be better than a single observation or a mean from a small set of samples. For these feeds, book values can be used unless one has good reason to believe that a particular feed is different.

For feeds with moderate or high variability in nutrient composition, routine feed sampling and analysis is essential. Although most people realize this, it is often not done because by the time they get the report back from the lab, the load has been fed. If this is your opinion, you are not using the analytical data correctly. As stated above, we need to think in terms of probabilities, not absolute numbers. You should be sampling and analyzing load samples to obtain estimates of mean composition and SD; the values obtained from a single load sample are not that important. The frequency of sampling depends on the expected variation, how much error one is willing to accept, and the cost of being wrong (e.g., feeding a diet with inadequate CP). A general guideline is that about 10 samples from a given population should produce a reasonably accurate SD. For highly variable feeds, more samples are needed.

The approach followed by many nutritionists is to sample a load of feed, have it analyzed, and then formulate a diet based on that information. When a new analysis is obtained, the previous data are eliminated and a new diet is formulated based on the new composition. The inherent assumption underlying this practice is that the new data better represent the feed than did the old data. This may or may not be true. When new analytical data are obtained, you should ask yourself one simple question: "Is there an identifiable reason why the composition changed?" Possible answers to that question include: the supplier changed, the distillery changed production methods, or probably most commonly, I don't know. If you cannot think of a good reason for the composition change, the change may simply be a random event. The difference could be caused by load-to-load random variation, by within load (i.e., sampling) variation, or both. In this case, the new number may be no better than the old number, but the mean of the two numbers has the lowest probability of being substantially wrong. The mean, rather than the new or old number should be used for ration formulation. You should collate feed composition data using a spreadsheet or some other method and recalculate the mean and SD as new data are collected. If you can come up with a logical reason why composition changed (i.e., a new population), then the new number should replace the old number and you start the process of collating data again. Statistical process control charts, such as the X-bar chart, can be used to identify composition changes resulting from assignable causes.

Continuous process feedstuffs

Silages are excellent examples of feeds of this type. Silos are filled and, more importantly, unloaded in a somewhat continuous fashion. The true composition of the silage remains relatively constant until the occurrence of an assignable cause: the hybrid or the variety changed, or the field from which the silage originated changed, etc. Although the true or real composition may be constant (until some event occurs), the measured composition of samples may vary. Many feedstuffs consist of nutritionally heterogeneous particles (corn silage is an excellent example of this), and if samples vary in the relative proportion of different particles, the measured or apparent composition will vary (e.g., a sample of corn silage that has more pieces of corn cob would be expected to have a higher concentration of NDF than a sample from the same silo that happens to have more corn grain pieces). One way to reduce this "sampling error" is to take and analyze duplicate samples and then average the results. With a continuous process, sampling for analysis is not done as much to determine means and SD but to identify the occurrence of a real shift in composition. Statistical process control tools such as X-bar and CUSUM charts are invaluable in this instance. To use these tools, an optimal sampling design (includes the number of samples to be taken at one time and the frequency of sampling) must be determined. A typical 'sampling design' has been to take one sample, once a month, and to automatically reformulate diets with the new data.

We have successfully modelled the process as a renewal reward process with 13 inputs that must be accounted for in the calculation of the total quality cost (St-Pierre and Cobanov, 2007). Inputs that have a major effect of the sampling design include milk price (higher the price, the more frequent the samples), herd size (larger herds should sample more than smaller herds), and the loss in milk production that could occur if the change in forage composition was not detected (greater the potential loss, the more frequent the sampling). Some of the factors that have a minor effect on sampling design include the cost of the analysis and the cost of changing the diet once a change in forage composition has occurred. Example sampling designs for a small (50 cows), medium (200 cows), and large (1000 cows) dairy farm are shown in Table 4. Basically, the traditional sampling design of once monthly samples is close to optimal for small herds but is grossly erroneous for large herds.

Accounting for feed variation during diet formulation

As previously mentioned, the SD is an important statistic. It is an indicator of how wrong you could be. In Table 1, CGF has a mean CP concentration of 23.8 and a SD of 5.7. Assuming a normal distribution and totally random loads of CGF (i.e., not from a single source), approximately 16% of the loads would have a CP concentration less than 18.1% and 16% of the loads would have a CP concentration greater than 29.5%. If a particular load had 18% CP, you used the mean concentration and CGF made up 10% of the diet DM, the actual CP concentration of the diet would be 0.6% units lower than the formulated value. An error of this magnitude or larger would be expected 16 out of every 100 loads. If you are willing to accept this risk, then using the mean is the best option. However, if you think that milk production would drop 2 lb/cow/day (or some other number) if the diet contains 0.6 percentage units less CP than formulated and you are unwilling to accept that risk, you need to adjust for variation. You can reduce the risk of substantially under feeding CP by *adjusting* the mean value. Based on a normal distribution, if you use the mean minus 0.5 SD, you reduce the risk of making the error discussed above from 16 % of the time to 7% of the time. If you use the mean minus 1 SD unit, you reduce the risk of making the above error to just 2% of the time. The mean CP for CGF was 23.8 (SD = 5.7). If you are willing to be substantially wrong 7 out of every 100 loads, then use 23.8 - (0.5 x 5.7) or 21.0% CP for CGF when you balance the diet. If you only wanted to be wrong 2% of the time, you would use 23.8 - 5.7 = 18.1% CP. By using a lower CP concentration, you have decreased the probability of being substantially deficient in CP; however, you will be over supplementing CP most of the time. You need to determine how much risk you are willing to accept and balance that against increased feed and environmental costs.

The problem with this approach is that it only considers variation in a single ingredient, but the nutrient composition of all ingredients in a diet will vary. What really matters is not the variation in a single ingredient, but rather the variation and mean for a diet. Methods of diet optimization when considering multiple nutrients from multiple variable sources are well defined (St-Pierre and Harvey, 1986). These can be optimized using nonlinear programming methods; unfortunately, this means that the convenient and widely available linear programming algorithms for ration formulation can no longer be used.

For measured nutrients such as CP, nutrients across feeds are independent (e.g., the concentration of CP in corn is independent of the CP in soybean meal). In these instances, the variation in the total diet is a function of the square of the inclusion rate of each ingredient – which is where the nonlinearity enters the formulation model. That is, the contribution of a given feed to the total variance of the diet is quadrupled if its inclusion rate is doubled. Two pounds of alfalfa has four times the CP variance of one pound. In Table 5 we present the expected CP and variance of the CP for a total mixed ration **(TMR)** under 3 different scenarios. The significant variance reduction from multiple feeds is one major contribution of the commercial feed industry and has been calculated to be worth an additional 18 US$/ton over and above the mean value of the nutrients.

For calculated nutrients such as NEL and MP, the calculation of the variation of the diet becomes analytically intractable because nutrients are no longer independent across feedstuffs (i.e., the MP of soybean meal is dependent on the nutritional composition of corn). Monte Carlo techniques have been used to estimate the variation of these nutrients. The software program mentioned previously (*Ping Pong* ™) can calculate variation in nutrient composition of diets if the user has information on variation in the individual ingredients. In addition, the program will calculate the implications of variation in nutrient composition on milk production. Currently, the software simulates the nutrient variation of a given diet, but it cannot optimize the diet. The computational problems associated with profit optimization in these circumstances are immense. We have tried non-parametric approaches, such as the genetic algorithm with some success, but much work remains to be done.

Reducing the Impact of Variation

The composition of all feeds vary. However, the probability that all feeds in a diet will have a lower than expected concentration of a given nutrient on a given day is low. Some feeds will have higher than expected concentrations; others will have lower than expected concentrations. Therefore, the variation in nutrient composition of feedstuffs is usually greater than variation in nutrient composition of the TMR (assuming good, standardized feeding practices are in place). The impact of variation in the composition of a feedstuff is reduced as more feeds are included in diets (Figure 4). Two diets that are completely identical in average composition were formulated. Both diets contained (DM basis) 28% corn silage, 24% corn grain, 15% alfalfa silage, 5% protein/mineral mix, and 28% "byproduct". In diet A, the byproduct was a single feed. In diet B, the byproduct consisted of 3 feeds, each fed at 9.3% of the diet (all byproducts in the diets had identical nutrient composition and identical variation, but they varied independently of each other). Both diets contained an average of 13.6% MP, but the SD for MP in diet A was 0.73 and for diet B it was 0.48. Using 3 ingredients to replace 1 ingredient reduced the SD for MP by 34%. A farm may not be able to purchase and store several different commodities, but they can have a mill blend several different commodities and use the blend as an ingredient in the TMR rather than purchasing a single commodity.

Relying on a particular feedstuff that is highly variable in a certain nutrient to provide a large proportion of that nutrient in the diet increases the risk of being really wrong. We know that on a theoretical basis, the contribution of a feedstuff to the variance of the total diet grows with the square of its inclusion rate (St-Pierre and Harvey, 1986). If that particular feedstuff provided only 10% of the CP in the diet, a 5 percentage unit change in its CP concentration would cause dietary CP concentration to change by only 0.5 percentage units. De Peters et al. (2000) measured the concentration of CP in different loads of corn gluten feed. The CP concentration ranged from 19.4 to 33.4% (mean = 22.9; SD = 4.3). The load-to-load variation was quite large. However, if the TMR was balanced for 17% CP using the mean value for corn gluten feed and the diet contained 10% corn gluten (DM basis), the variation in the concentration of CP is much smaller and ranged from 16.6 to 18%. In conclusion, using a wide variety of ingredients in a TMR and not relying too heavily on a single ingredient is probably the best way to reduce the costs associated with variation.

References

Belyea, R.L., B.J. Steevens, R.J. Restrepo, and A.P. Clubb. 1989. Variation in composition of by-product feeds. J. Dairy Sci. 72:2339-2345.

DePeters, E.J., J.G. Fadel, and M. Arana. 2000. Variability in the chemical composition of seventeen selected by-product feedstuffs used by the California dairy industry. Prof. Anim. Sci. 16:69-99.

Kertz, A.F. 1998. Variability in delivery of nutrients to lactating dairy cows. J. Dairy Sci. 81:3075-3084.
National Research Council. 2001. Nutrient Requirements of Dairy Cattle. Natl. Acad. Press.Washington, DC.

St-Pierre, N.R., and B. Cobanov. 2007. Optimal sampling schedule of diet components: Model derivation and sensitivity analysis. J. Dairy Sci. 90:5395-5404.

St-Pierre, N.R., and W.R. Harvey. 1986. Incorporation of uncertainty in composition of feeds into least-cost ration models. 2. Joint chance-constrained programming. J. Dairy Sci. 69:3063-3074.

Table 1. Average (Avg) concentration and standard deviation (SD) for CP, NDF, and ether extract (EE) in selected feeds. Data are from NRC (2001) and represent very diverse populations.

	CP		NDF		EE	
	Avg	SD	Avg	SD	Avg	SD
Grains						
Barley	12.4	2.1	20.8	8.6	2.2	0.6
Corn	9.4	1.3	9.5	2.3	4.2	1.0
Sorghum	11.6	1.8	10.9	5.0	3.1	0.8
By-products						
Wet brewers	28.4	4.0	47.1	6.8	5.2	1.6
Corn gluten feed	23.8	5.7	35.5	6.8	3.5	1.1
Dry distillers grains	29.7	3.3	38.8	7.8	10.0	3.4
Potato waste	10.5	8.4	22.1	14.3	10.8	7.8
Rice bran	15.5	2.2	26.1	6.8	15.2	4.2
Soybean hulls	13.9	4.6	60.3	7.4	2.7	1.4
Soybean meal, 48% CP	53.8	2.1	9.8	5.6	1.1	0.4
Wheat midds	18.5	2.1	36.7	7.5	4.5	1.3
Forages						
Corn silage	8.8	1.2	45.0	5.3	3.2	0.5
Alfalfa silage – average	20.6	3.0	45.7	6.5	3.1	0.7
Alfalfa silage – mid maturity	21.9	1.8	43.2	1.5	2.2	0.3

Table 2. Standard deviations of nutrients for two alfalfa hays used in the Monte Carlo simulation. The commodity alfalfa data are from NRC; the lab-tested alfalfa represents a well-defined population.

Nutrients (%)[1]	Commodity Alfalfa	Lab-Tested Alfalfa
DM	1.4	0.5
CP	2.6	0.3
NDF	6.3	0.8
Ether extract	0.5	0.5
Ash	1.2	0.2
Lignin	0.9	0.2
ADICP	0.4	0.4
NDICP	0.9	0.9

[1]DM = dry matter, CP = crude protein, NDF = neutral detergent fibr, ADICP = acid detergent insoluble CP, and NDICP = neutral detergent insoluble CP.

Table 3. Average (Avg) concentrations and standard deviations (SD) for selected nutrients and selected feeds. The California data are from DePeters et al. (2000) and the Missouri data are from Belyea et al. (1989). Within experiment and feed, samples originated from the same production facility (i.e., limited populations). These values should be compared to those in Table 1 (a broad population).

	CP		NDF		Ether Extract	
	Avg	SD	Avg	SD	Avg	SD
California						
Brewers grains, wet	27.0	2.2	37.3	3.4	6.3	0.4
Corn gluten feed, wet	22.9	4.3	38.8	3.8	3.4	0.4
Distillers grains, dried	31.2	0.6	35.6	8.2	13.0	1.3
Missouri						
Corn gluten feed, dry	23.3	1.4	51.9	2.3	6.6	1.9
Distillers grains, dried	30.6	1.4	33.0	1.5	7.4	0.9
Rice bran	19.1	0.4	21.8	1.3	17.3	1.9
Soybean hulls	11.8	0.2	72.5	0.8	0.8	0.3

Table 4. Expected mean CP and variance of a simple TMR without and with forage analyses, and a multi-component (complex) TMR made by a feed manufacturer with an effective quality control.

	TMR (lb DM/day)		CP (lb/day)		Variance (x 10,000)		
Feeds	Simple	Complex	Simple	Complex	Simple No analysis	Simple Forages analyzed	Complex Forages analyzed
Corn silage	11.2	16.1	1.00	1.45	226	25	47
Alfalfa silage	16.8	8.1	3.36	1.61	2,964	282	65
Alfalfa hay	-	2.7	-	0.54			6
Ground corn	12.9	6.5	1.26	0.63	67	67	17
Soybean meal, 48% CP	3.6	2.7	1.95	1.42	25	25	13
Distillers dried grains	6.8	3.0	2.06	0.91	324	324	63
Wheat middlings	-	4.0	-	0.77			19
Ground barley	-	3.2	-	0.39			8
Corn gluten feed	-	3.0	-	0.69			15
Soybean hulls	-	1.0	-	0.12			1
Canola meal	-	1.0	-	0.41			3
Corn gluten meal	-	0.5	-	0.33			1
Minerals-Vitamins	0.9	0.9	-	-			
TOTAL	52.2	52.2	9.63	9.63	3,606	723	257
Standard Deviation					0.60	0.27	0.16

Table 5. Example optimal sampling designs for silage on small, medium, and large dairy farms assuming typical conditions. Multiple factors affect the optimal sampling design and as conditions change so does the design.

	Herd Size, Number of cows		
	50	200	1000
Number of samples/sampling1	1	2	2
Frequency of samples, days	30	7 to 10	3 to 4
Cost savings compared to conventional2, $/day	0	50	250

[1]Number of independent samples taken on a given day.
[2]The assumed conventional sampling design is 1 sample taken once monthly. For a small herd, the conventional design is approximately optimal, but the conventional method has significant cost as herd size increases.

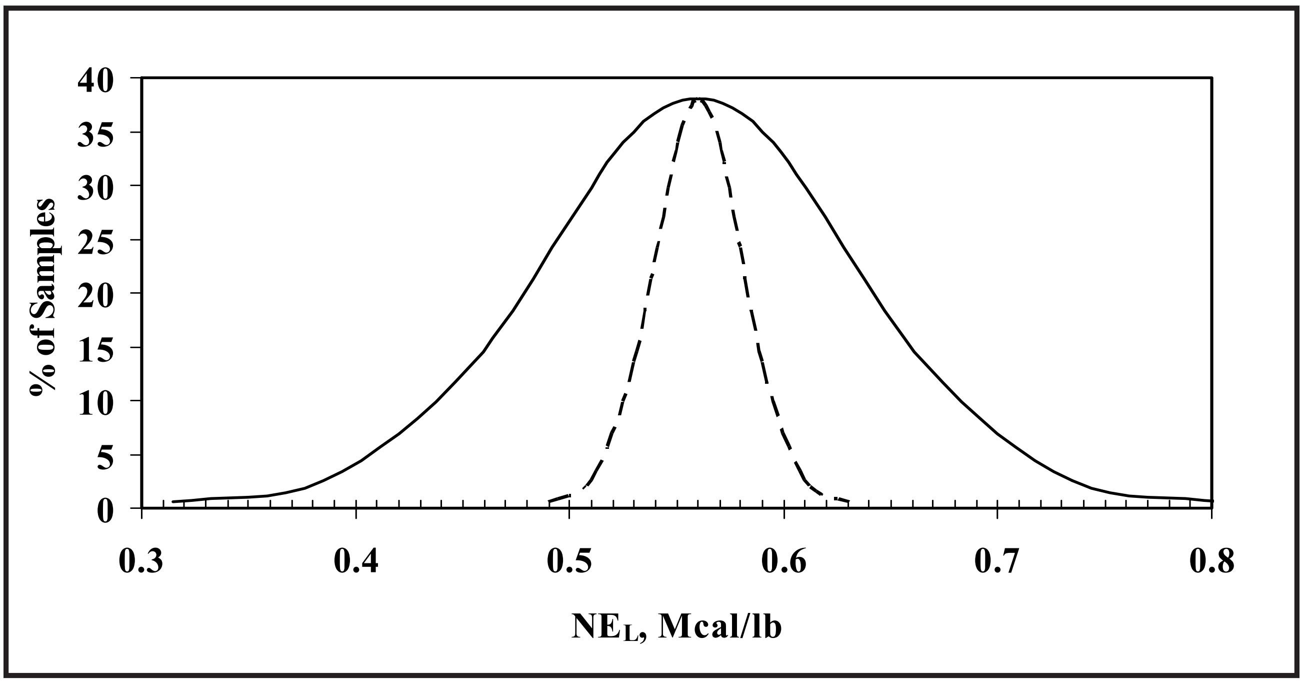

Figure 1. Expected variation in NEL of alfalfa hay as calculated by the software Ping Pong™. The solid line represents a broad population (NRC, 2001). The dashed line represents a very well defined population (see Table 3 for standard deviations used in the simulation).

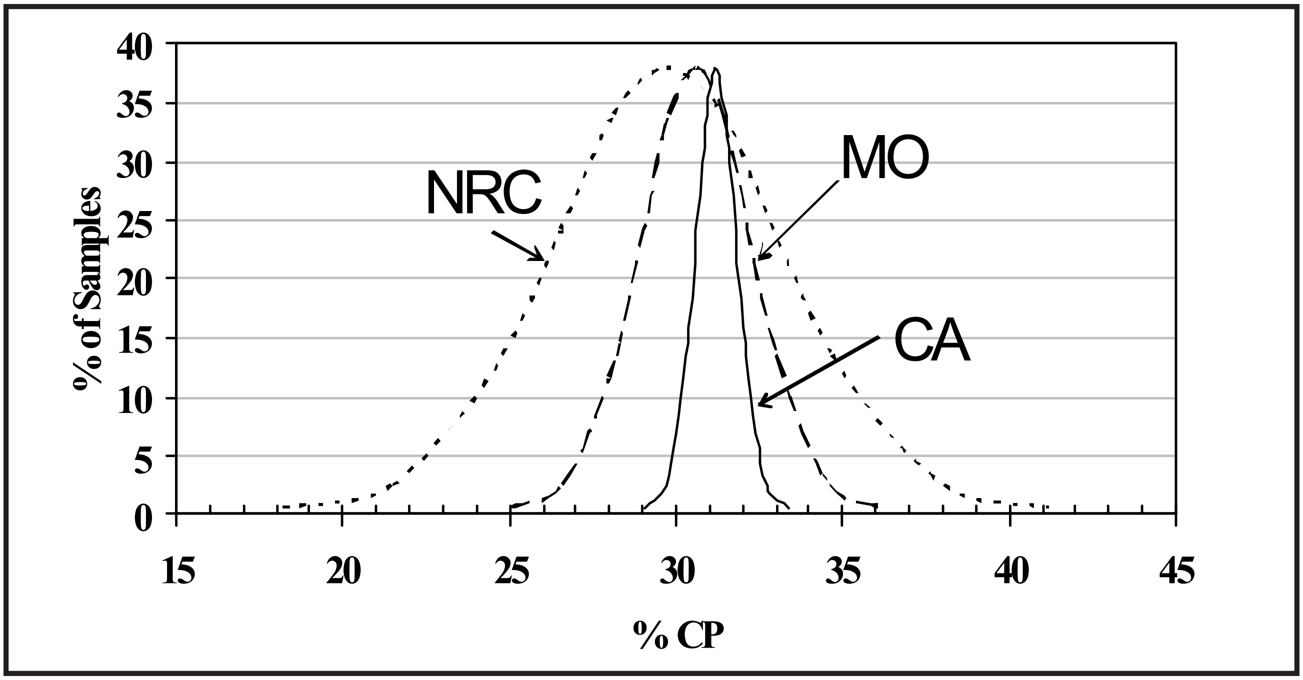

Figure 2. Distributions of crude protein (CP) concentrations in dried distillers grains. The small dashed line represents data from a nationwide population (NRC, 2001); the large dashed line represents samples from a single source in Missouri (Belyea et al., 1989) and the solid line represents samples from a single source in California (DePeters et al., 2000).

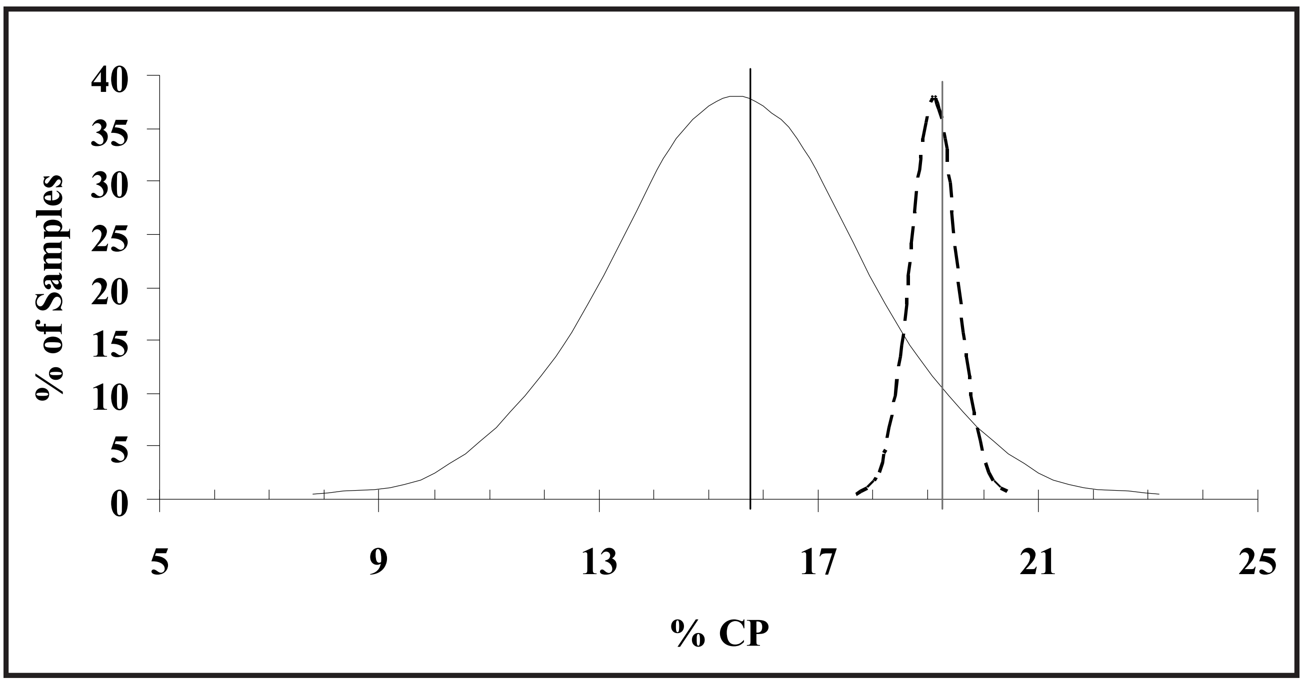

Figure 3. Distributions of crude protein (CP) concentrations in rice bran. The solid line represents data from a nationwide population (NRC, 2001) and the dashed line represents samples from a single source (Belyea et al., 1989). The means of the two populations are substantially different and the dispersion is much greater for the broad population.

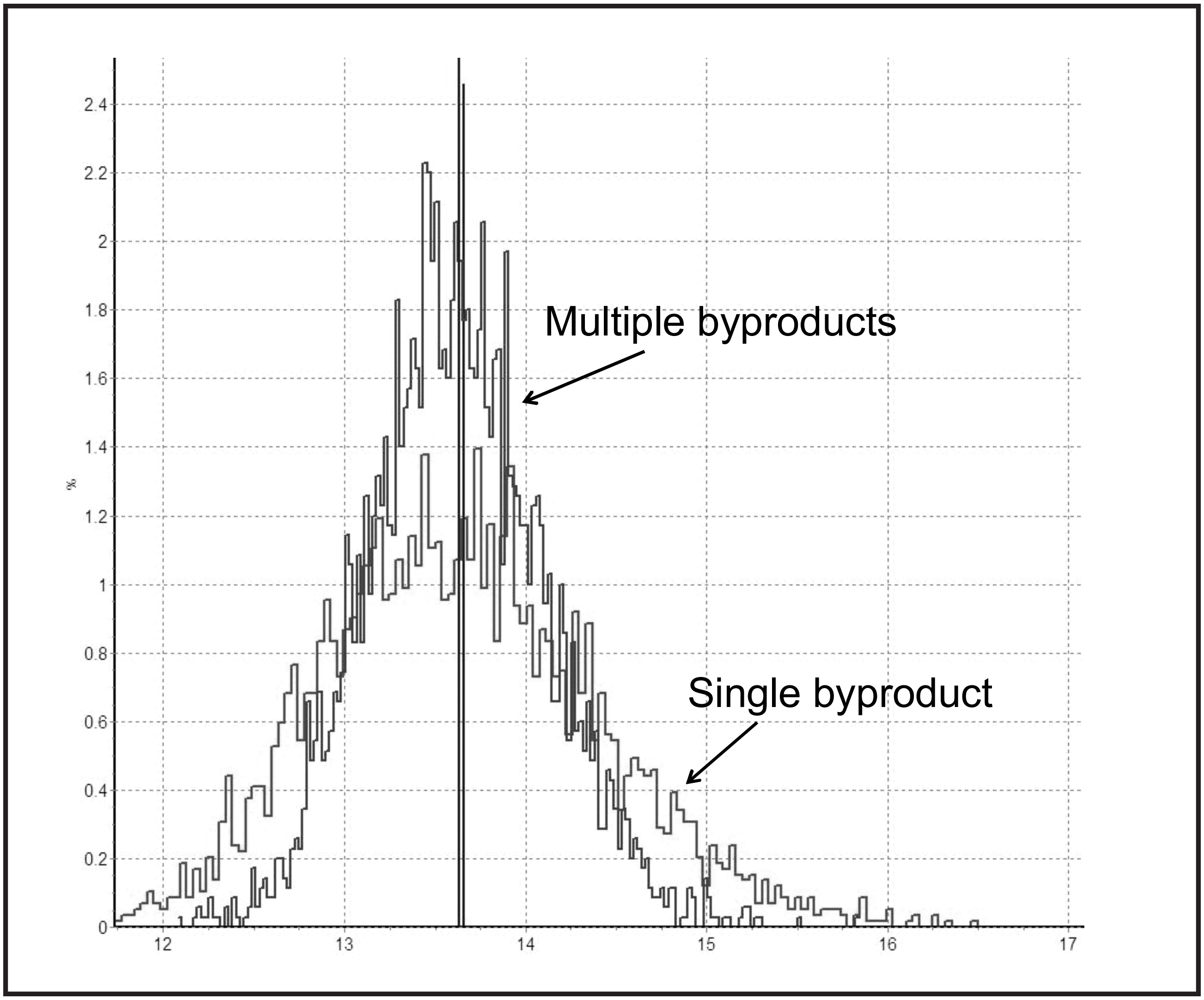

Figure 4. Frequency distribution (variation) in the concentration of metabolizable protein of two diets. Both diets were identical except that one diet (identified as Single Byproduct) contained 28% of the DM as a single byproduct. The other diet (Multiple byproducts) contained 3 identical byproducts (same mean and variation for all nutrients) each included at 9.33% of the diet. Using 3 independent ingredients instead of 1 reduced the standard deviation from 0.73 to 0.48.